



Cities on Volcanoes **6th**

Abstracts Volume

Puerto de la Cruz

Tenerife, Canary Islands, Spain

May 31 - June 4, 2010

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ABSTRACTS VOLUME



Cities on Volcanoes 6 CONFERENCE

Puerto de la Cruz
Tenerife, Canary Islands, Spain
May 31 - June 4, 2010

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Session 1.1
1.1-O-01
Mass Rate Trends From Different Magma Sources During The 2001 Etna Eruption

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Effusion rate greatly influences lava flow emplacement thus it is important to model its variation for hazard reduction. Previous works generally relate observed trends to the emptying of a pressurized enclosed system or to magma overflows from summit craters. Nevertheless it is also influenced by thermal effects which can cause dike closing or widening, depending on the balance between heat supplied by the magma and heat transferred to the surroundings. This work reconstructs the mass rate trends of seven fissures, belonging to two different systems (upper, US, and lower, LS), opened during the 2001 Etna eruption. Mass rate were evaluated instead of effusion rates because the US activity was purely effusive while that of LS was both effusive and explosive, thus the emitted products had different densities. The LS mass rate trend presents the two phases connected to the emptying of a pressurized reservoir: the rapidly rising phase (waxing) followed by an exponential decline (waning). Nevertheless the explosive activity, accelerating the rising and expanding magma, led to a constant effusion and a linear decrease that preceded the waning phase. The US behaves as a semi-open system, indeed it shows two phases of quite constant mass rate similar to overflows from Etna summit craters. Nevertheless it ended with a final phase of decreasing mass rate and a queue that can be related to the hydrostatic pressure of the remaining magma column coupled with dike cooling and closing. This work demonstrates that explosive activity makes mass rate more complex than the waxing-waning trend previously defined. Moreover it individuates a new eruptive behavior, that is the discharge from a semi-open system. The presented data might be used to model the influence on mass rate of the elastic and thermal behavior of the feeding dike and of the reservoir.

1.1-O-02
Giant, Eruption-Triggered Ocean-Island Landslide at Tenerife: Onshore Record and Long-Term Effects on Pyroclastic Dispersal

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We report the discovery of an extensive debris-avalanche deposit on Cañadas volcano, Tenerife. The onshore component of the Abona landslide is superbly exposed across 90 km² and preserves classic jigsaw-fit 'block facies' and 'mixed facies'. It was demonstrably triggered by an explosive eruption, and is dated at 733

± 3 ka by ⁴⁰Ar/³⁹Ar on sanidines. Evidence it occurred during the ignimbrite-forming phase of a Plinian eruption includes: (1) the deposit forms part of a single eruption-unit in which the deposit is enclosed by phonolitic ignimbrites and preserved hummocks are draped by a Plinian layer; (2) it contains prismatic-jointed blocks of pumiceous phonolite that were clearly hot during emplacement, indicated by chilled rims and bread-crusting; and (3) the juvenile blocks in the deposit and in the associated ignimbrite and pumice fall deposit all yield the same ⁴⁰Ar/³⁹Ar date within error. Debris-avalanche hummocks dammed surface water forming ephemeral lakes perched on the volcano flank. Phonolite dome growth destabilised the SE sector of the mid-Pleistocene Cañadas caldera wall and the landslide created a major breach that affected the pyroclastic density current dispersal on Tenerife for 0.5 mys, demonstrating that landsliding at large volcanoes can have enduring geomorphologic consequences for pyroclastic dispersal and hazards.

1.1-O-03
Bimodal Volcanism In Tenerife - An Anatectic Origin For The Teide-Pico Viejo Phonolites

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The Teide-Pico Viejo central complex on Tenerife shows a distinctly bimodal composition of erupted lavas. Eruption volumes indicate that fractional crystallisation may not have been the sole cause for this phenomenon. Whole-rock trace element data divide lavas into three compositional groups on the basis of their trace element fingerprints and allow to demonstrate statistically that each of the three groups originated through a combination of processes distinct from the other groups. Using groundmass Sr-Nd-Pb along with groundmass/feldspar d18O data, we constrain the petrogenesis of the erupted products of Teide-Pico Viejo and its associated rift zones. Sediment, hydrothermally altered components or seawater influences are unfeasible as major contaminants to explain the origin of the recent phonolites. The ²⁰⁶Pb/²⁰⁴Pb of the phonolites is tightly confined, while ²⁰⁷Pb/²⁰⁴Pb shows variability comparable to the primitive lavas. This suggests that instead, the phonolites have largely been derived from partial melting of igneous country rock with varying amounts of subsequent assimilation and fractionation in shallow magma chambers. Progressive melting, from selective to bulk, of intrusive rocks related to older phonolitic successions (e.g. nepheline syenites) allows to produce

the unusually high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (<0.7049) in the most evolved post-collapse phonolites, but is also consistent with the Pb isotope ratios from older phonolitic successions.

We envisage a two stage process in which phonolites are primarily generated by crustal anatexis of evolved country rock and secondly evolve further by assimilation and fractional crystallisation. Intermediate magmas principally form in the same two-stage process, however, isotopic and textural evidence indicate that some are generated by magma mixing of compositionally more extreme endmembers.

1.1-O-04

Explaining the Plinian-phreatoplinian Shift during the 1875 Askja Volcano Eruption by Coupling Geological and Numerical Techniques.

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During the 1874-76 a large volcano-tectonic episode took place on the North Iceland rift zone and the 1875 eruption of Askja is part of it. This is one of the few eruptions showing both phreatoplinian and Plinian styles and the only well documented by eye witnesses. The eruption began the 28th of March with a subplinian event (phase B) and continued on the 29th with a phreatoplinian phase (phase C1, 1 hour). This phase included the emplacement of dilute density currents (phase C2, 2 hours) which became dryer with time. At 7 am the Plinian phase D commenced and lasted for about 5-6 hours. The vent position migrated throughout the eruption. Aside from a small pond, no standing water was present. therefore the source of external water driving the phreatoplinian phase is uncertain. We have undertaken a study to test if groundwater residing in the lava pile that fills the main Askja caldera could have been the provider of the external water involved in the phreatoplinian phase. The key questions are; (a) Does the intra-caldera groundwater reservoir hold enough water and (b) can the water be transported fast enough to the vent site (i.e. upper part of the conduit). A discrete fracture modelling technique is used to compute the corresponding permeability and porosity. A 3D digital model of the Askja caldera that represents the pre-eruptive topography and hydrostratigraphy has been reconstructed. The calculated porosities and permeabilities provide factual data as model input parameters. Results show that the eruption resulted in ultra-fast radial flow of groundwater towards the conduit and provides sufficient water flux to drive the phreatoplinian phase of the 28-29 March Askja eruption. Furthermore, the model also produces rapid draw-down of the intra-caldera groundwater which explains the drying-out of the phreatoplinian phase depicted by the dilute density current deposits.

1.1-O-05

Determination of Conduit Dynamics During the Soufrière Hills 2003 Vulcanian Events

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During July 12-13, 2003, at Soufrière Hills volcano (SHV), Montserrat, British West Indies, the largest volume dome collapse of the current and ongoing eruption occurred. Tephra samples from the third Vulcanian event in a series of five were analyzed using scanning electron microscopy (SEM) and secondary ion mass spectrometry (SIMS) to examine textural and geochemical variations at high spatial resolution. SEM images of all clasts show heterogeneous crystal and vesicle contents, suggesting that groundmass microlite studies for constraining the magma decompression path are not appropriate for this stage of the eruption due to a lack of consistency for individual clasts or for the sample population as a whole. As an alternative, plagioclase phenocrysts were depth profiled using SIMS. Changes in crystal rim anorthite (An) contents range from 2 to 14 mol%, corresponding to calculated decompression magnitudes of 13 to 94 MPa. Independent estimates indicate the magma witnessed a total decompression of at least 50 MPa. Despite the large range in An values, phenocryst rims show consistent lithium (Li) trends which indicate decompression-induced growth averaging $2.7 (\pm 0.7) \mu\text{m}$ for the entire sample set. Corresponding growth rates average $8.3 \times 10^{-8} \text{ mm s}^{-1}$ and are of the same order of magnitude as experimentally constrained microlite growth rates in the same system. These results demonstrate that for short-duration decompression events (< 10 hours), Li contents can provide crystal growth rates even when major element compositions, such as An, fail to record reliable information concerning decompression magnitudes due to disequilibrium ascent conditions. These results also provide evidence that phenocryst growth during magma ascent through the conduit is significant, even when timescales of ascent are short (< 10 hours) or decompression magnitudes would favor microlite nucleation. Therefore, future estimates of evolving magma crystallinity and rheology during decompression must consider phenocryst growth in addition to microlite nucleation.

1.1-O-06

Recognition of a Major Ignimbrite in the Early Evolution of The Santorini Group: The Christiani Ignimbrite

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Rhyolitic pumice deposits on three Aegean islands are

interpreted as belonging to a major ignimbrite event early in the history of the Santorini group, the Christiani Ignimbrite. These white pumice-flow deposits were identified at the base of the volcanic sequence of the ring islands of Santorini itself and on the non-volcanic island of Anafi, 30 km east of Santorini. They are correlated with the "Christiani pumice" (Puchelt et al. 1977) or "Unterer Bims" (Aarburg 1998) on Christiani 25 km southwest of Santorini. The uninhabited Christiana Islands, Christiani, Askania, Eschati are small volcanic islands related to the larger Santorini group by their position on the SW-NE oriented Kameni-Columbos line. Christiana andesitic-dacitic lavas are older than the oldest Akrotiri volcanics of the Santorini volcanic field (645 ± 92 ka, Drutt et al. 1999) and are mantled by several pumice-tuff units of which the most prominent is the "Christiani pumice/Unterer Bims", representing proximal, unwelded pumice-flow deposits including co-ignimbrite breccias with lithic diameters of 1 m (Aarburg and Frechen 1999). Besides the high-silica-rhyolite glass composition of the pumices, distinctive features are the phenocryst content with hypersthene, augite, Fe-Ti-oxides and feldspars, with most prominently zircon and cummingtonitic amphibole as key index minerals for the correlation (Keller 1996). Cummingtonite has not been detected in any other pumice formation of Santorini and is generally rare in volcanic rocks (Evans and Medenbach 1997).

The outcrop on Anafi is 57 km from the assumed proximal area of Christiani. Therefore the pyroclastic flows must have crossed a considerable stretch of the Aegean Sea. With the three distribution points an area of several hundred km² is assumed for the original ignimbrite cover. We relate early fission track ages of 0.94 ± 0.16 and 1.05 ± 0.14 Ma on volcanic zircon in "white tuffs" of Santorini (Seward et al. 1980) to this newly defined Christiani Ignimbrite.

1.1-O-07

The Role of Magma Mixing on Eruption Trigger and Eruptive Dynamics at Tenerife: the Example of 1798 Chahorra Eruption.

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On Tenerife island volcanic activity is represented by monogenetic basaltic volcanism located along rift zones and by the Teide-Pico Viejo stratovolcanoes, located in the centre of the island inside the Cañadas caldera. Magmas emitted along the rift zones have mafic composition, while felsic and intermediate compositions are erupted at the central system. A large range of eruptive dynamics has been produced by the central system and has been correlated with injections of mafic recharges into shallow volatile-poor reservoirs (phonolites) (Marti and Geyer, 2009). Historic volcanism has occurred along the rift zones and only in one case inside the central caldera, on the SW flank of the Pico Viejo edifice (Chahorra eruption, 1798). The 1798

eruptive fracture opened on the eastern side of an older fracture fan (sub-parallel to the NW rift), which has produced pre-historic eruptions younger than 4.100 years BP, often associated with mixing processes. The Chahorra magma has an intermediate composition (Tephri-phonolite; cpx+ol+felsdps±amph) and shows textural and chemical evidences of mingling. At Tenerife, intermediate magmas originate from two main types of mixing/mingling mechanisms: 1) either mixing represents the overturn of a zoned reservoir (Triebold et al., 2006) or 2) mixing is related to a syneruptive intrusion of mafic magma into a shallow reservoir (Araña et al., 1991; Ablay et al., 1998). The study of volatile-bearing phases (amphibole, apatite) and glasses (melt inclusions and matrix) in lavas and tephras of the Chahorra eruption constrains the timing of the mingling and the fluid transfer associated with it. Our data suggest that mingling cannot be considered as the immediate eruption trigger, but that the most explosive phase of 1798 eruption is associated with the eruption of the most mafic magma end-member.

1.1-O-08

Major, Trace Elements and Nd-Sr-Pb Isotopes of the Young Edifice of La Gomera (Canary Islands).

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La Gomera is the only island of the Canaries with no Quaternary volcanic activity. The youngest unit is the so-called Young Edifice. We propose that it was built up in two main stages (Ancochea et al., 2006; Herrera, 2008): the Young Edifice I (5.9-4.9 Ma) and the Young Edifice II (4.7-2.3 Ma). The first stage is represented by basaltic lava flows, called Young Basalts I, flowing essentially south and south-westwards and ranging between basalts and trachyandesites ($\text{SiO}_2=43-59\%$, $\text{MgO}=13.2-1.2\%$). The Young Edifice II is mainly made up by the Young Basalts II (that crop up in the central, NE and SW sectors) but also by the Felsic Domes, the Trachytic Unit and the Late Basalts (Herrera, 2008). The Young Basalts II show all the varieties between picobasalt and trachyandesite ($\text{SiO}_2=44-58\%$, $\text{MgO}=14.4-1.5\%$; most with $\text{SiO}_2=44-49\%$ and $\text{MgO}=12.7-3.2\%$). The rocks of the Trachytic Units are basaltic trachyandesites, trachyandesites and trachytes ($\text{SiO}_2=50-62\%$, $\text{MgO}=3.6-0.6\%$). Both mafic units show similar mineralogical composition, with a limited variation interval (especially the olivines and pyroxenes). The Young Edifice mafic rocks are alkaline OIB basalts coming from a very similar mantle source, that is enriched in incompatible elements at least two or three times the primordial mantle concentration (Ta, Nb) and less in Th, U and LREE. The incompatible elements ratios, the $^{143}\text{Nd}/^{144}\text{Nd}$ (0.512880-0.512923) and the $^{87}\text{Sr}/^{86}\text{Sr}$ (0.702944-0.703095) isotopic ratios, are typical of HIMU mantle reservoir. Whereas, the Pb isotopes ratios ($^{206}\text{Pb}/^{204}\text{Pb}=19.6782-19.9315$, $^{208}\text{Pb}/^{204}\text{Pb}=39.3752-39.8335$) point at FOZO mantle component (Herrera, 2008). Despite the great resemblance between both growth stages, we detect differences in the rate of partial melting and the fractionated crystallization processes; in addition, the clinopyroxene-melt thermobarometry

metry reveal that the last equilibrium crystallization of Young Basalts II occurs at higher temperature and pressure than the Young Basalts I one. References: Ancochea et al., 2006, JVGR; Herrera 2008, UCM.

1.1-O-09

Testing the Hypothesis About the Origin Of Las Cañadas Caldera (Tenerife, Canary Islands).

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Despite the numerous geological and geophysical studies performed in Las Cañadas Caldera (LCC; Tenerife) its origin is still controversial between two different hypothesis: 1) a nested collapse caldera formed by three different vertical collapses; and 2) one or several lateral landslides. We have critically analyzed the implications of the existing hypothesis, looking for evidences which allow discarding any of them. We have gathered in a 3D GIS the existing geological information from water galleries and boreholes drilling LCC and Icod valley together with off- and on-shore geological, volcanological and geophysical data. This allows us to obtain a coherent surface of Icod landslide breccia deposits, although data from LCC are still insufficient to discard any hypothesis base on the breccia geometry. Other data from LCC, such as Montaña Majua borehole, allows making estimations of the geometry of the proposed calderas. For Guajara caldera case (6.5 km diameter) a 1500 meters minimum depth is obtained, resulting in a theoretical volume of around 50 km³. Applying typical density values for magma and pyroclastics, this represent an emitted volume of around 250 km³ of pyroclastics (pumice + ignimbrite). Since the Granadilla eruption, the proposed Guajara caldera forming event, has produced a maximum estimated volume of 25 km³ of pumice (including offshore estimations), the emitted ignimbrites should have a total volume of more than 200 km³, which seems highly improbable due to the estimated 5 km³ volume of onshore ignimbrites. Therefore, our results cast further important doubts about an origin related to vertical magmatic collapses for LCC, the most widely cited hypothesis at present. In our opinion existing data do not allow discarding the lateral avalanche origin for LCC but show some questions still open about the geometry of the Icod landslide and therefore additional geological and geophysical data of the area are necessary.

1.1-O-10

Magma reservoir of AD472 eruption of Mt. Vesuvius

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Mt. Vesuvius has experienced several Plinian and Subplinian eruptions. Compositionally variable magmas, from evolved to less-evolved magmas, have been issued within a single eruption, and this compositionally variable nature has been considered to be derived from a zoned magma reservoir which may contain double convective layers. In order to find out the detail struc-

ture of those reservoirs, juvenile fragments from the fall out tephra of the AD472 Pollena eruption were examined. SiO₂ decreases and CaO increases with stratigraphic height as similarly shown in the other major eruptions such as AD79 Pompei eruption. The composition of the groundmass was estimated by averaging several hundreds EPMA analyses by defocused beam. It was confirmed the composition obtained by this method coincides with the XRF analysis of the mechanically separated groundmass by handpicking. The groundmass composition also varies with stratigraphic height from evolved to less-evolved. Some compositional gap exists between the least evolved and the less evolved ones, indicating existence of thermal boundary layer in a zoned magma reservoir or dual magma reservoirs. Pressure and temperature condition where the liquid of each groundmass composition can coexist with phenocrystic minerals, leucite and clinopyroxene, was estimated applying Melts program (Ghiorso et al., 1983). The results prefer the existence of dual magma reservoirs at different depth; one at a depth of 4 km and the other at 6km, rather than a single zoned magma reservoir with double convective layers.

1.1-O-11

A total volatile inventory for Masaya volcano, Nicaragua

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The state of emissions from Masaya Volcano, Nicaragua was assessed in March 2009. A range of techniques were used to offer the most comprehensive characterisation of Masaya's emissions to date. Results from open-path Fourier transform infrared spectroscopy (OP-FTIR) and filter packs demonstrate that the gas composition in terms of H₂O, SO₂, HCl and HF is virtually unchanged from the 1998-2000 period, indicating stability of the shallow magma system. This continuity also extends to less abundant constituents, including the heavy halogens (i.e., HBr and HI) and aerosol species (i.e., SO₄²⁻, Na⁺, K⁺, Ca²⁺ and Mg²⁺). There is some preliminary indication of deeper changes within the system on the basis of elevated CO₂/SO₂ since 2000 although further measurements are needed to confirm this trend. In general, SO₂ fluxes (measured using differential optical absorption spectroscopy, DOAS) were low suggesting that Masaya is presently at the trough of its degassing cycle. By combining our compositional results with the SO₂ flux, we estimate a total volatile flux from Masaya of 10000 Mg d⁻¹. These results extend the exceptional time series of measurements at Masaya and will allow for a better understanding of degassing processes in basaltic systems.

1.1-O-12

High-temperature hydration and explosive fragmentation of glassy rhyolite at Katsuma-Yama volcano, Okushiri Island, Hokkaido, Japan

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Katsuma-Yama volcano is a small composite volcano including Horonai-Gawa caldera and Katsuma-Yama crater located on the northeastern caldera rim. Explosively erupted rhyolite fragments from Katsuma-Yama crater 0.7 km across constitute eruption-fed turbidites in the Horonai-Gawa caldera-lake 1.5–2 km across. Effused from the same crater, Katsuma-Yama rhyolite lava continues to the Horonai-Gawa caldera and is intruded into the caldera infillings with a thickness of 100 m. All the juvenile fragments and the lava from the Katsuma-Yama crater are glassy and hydrated up to 4 wt.% H₂O in close association with contraction cracks of mm-to-cm scale. The water contained in these materials increases with decreasing dD from -77 to -108 ‰, suggesting hydrogen isotopic fractionation between OH in silicate glass and external water vapor at high temperatures. The coefficient of water diffusion in a rhyolite glass/melt is 0.001–10 μm²s⁻¹ at 0.1 MPa and 400–800 °C, and requires a time scale of 10⁸–10¹⁰ years to complete hydration of the 100-m-thick Katsuma-Yama lava. Upon direct contact with lake water, the lava was quenched and cracked by heating the water to steam, and then the steam permeated into the interior through cracks, resulting in further cooling, cracking and thus, rapid hydration of glass. The magma staying in an underground watery environment is also likely to be quenched, cracked, and hydrated in direct contact with groundwater, but explosively fragmented as the water confined and superheated in the quenched intrusive body is vaporized very fast upon failure of seals induced, for example, by succeeding magma ascent and/or earthquakes. Curvilinear surfaces of glassy rhyolite fragments cut across the internal perlitic cracks, showing that the quenching, cracking and hydration predated the explosion. Explosion plausibly occurred at a minimum time interval of 10⁻²⁻⁴ seconds that allowed hydration to a depth of 10–100 μm.

1.1-O-13

Cyclic Ground Tilt Associated with the 2004-2008 Eruption of Mount St. Helens, Washington

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Cyclic activity of different types and periods has been observed during the eruption of a number of silicic volcanoes, and has been used to infer properties of magma ascent and extrusion. While the long-term behavior of the 2004-2008 eruption of Mount St. Helens was characterized by a gradual decline in the rates of seis-

micity, dome growth, and broad-scale ground deformation, near-periodic earthquake activity over timescales of minutes indicated episodic short-term behavior. In this work we process and analyze data from a network of tiltmeters at Mount St. Helens which recorded thousands of cyclic tilt events over periods of minutes to hours. These events – detected only in the crater – were characterized by a recoverable, asymmetric pattern of rapid tilt away from the vent followed by a more gradual reversal, were strongly correlated between different tiltmeters, displayed temporal correlation with local volcanic seismicity, and ceased at the end of the eruption. Tilt orientations converged on a point near the south edge of the pre-existing 1980s lava dome, and inversions – although highly non-unique – suggest a shallow source (< 1 km). Modeling suggests that stick-slip behavior on the interface between the ascending plug and the 1980s lava dome could produce episodic tilts similar to those observed. These results highlight the unique ability of tiltmeters to record the often small, transient signals associated with cyclic behavior at erupting volcanoes, despite the difficulties associated with interpreting tiltmeter data.

1.1-O-14

An Example of Highly Explosive Mafic Activity at Villarrica Volcano, Southern Andes: The Chaimilla Deposit (~3.1 ka)

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Villarrica (Chile) is one of the most active volcanoes in South America having erupted about 60 times in the last 460 years. The volcano is a very popular tourist destination for both skiing and hiking activities. The population of its closest city, Pucón has doubled in the last 10 years due to the growing economy. Although its historical eruptive activity has been mainly effusive and only weakly explosive, it had highly explosive behaviour in postglacial times. The widely-dispersed Chaimilla deposit is a clear evidence of this highly-explosive behaviour. The Chaimilla deposit was formed during a single short-lived eruption, which dispersed tephra over an area exceeding 250 km². The eruption evolved from i) an opening phase, dispersing ash, lapilli clasts, accretionary lapilli, blocks and bombs, to a ii) pulsatory phase originating a series of magmatic explosions, to an iii) intermediate phase, which emplaced a series of diluted pyroclastic density currents and finally to iv) a sustained phase forming a convective plume which eventually collapsed generating pyroclastic density currents. The fall-out units have a total volume of 0.5 km³, with the main sustained phase being associated with a VEI 4 eruption. Pyroclastic flows had minimum runouts of about 4 km. The eruption was driven by the fast rise of a volatile rich magma batch from depth which triggered the eruption and controlled explosivity. The involvement of deep magma batches suggests that this type of eruption is not significantly affected by the state of the uppermost

part of the feeding system and could also occur during open conduit state. The occurrence of a similar eruption at Villarrica volcano at present times would be largely disruptive, representing a significant hazard for the population living in the surroundings and significantly affecting all tourist activities, which are crucial to the economic system of the area.

1.1-O-15

Magma Extrusion Mechanism and the Transition Between Eruptive Styles at Volcán de Colima, Mexico

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Volcanic eruptions typically switch between different styles over different time scales, varying from hours to years, and can be cyclic. Attempts have been made to model these transitions but there is lack of data from real events. The current eruption of Volcán de Colima commenced in 1998 and during the previous 12 year has undergone various transitions in style, between extrusion and explosive or between different regimes of explosivity defined by certain characteristics of magma degassing.

The most recent episode comprises of exceptionally slow extrusion (mean rate $0.02 \text{ m}^3\text{s}^{-1}$) with duration of more than three years, unusual for a silicic volcano. Thermal imagery has been used to characterize the mechanism of dome growth. Whilst the dome was of small volume, the growth was characterized by the formation of lobes. With an increased volume this changed to more endogenous growth until in early 2010, an increase effusion rate initiated the emplacement of a new lobe on the NW side.

Seismicity associated with magma ascent has been dominated by long-period events, modelled as resulting from brittle deformation with the conduit or fracture zone. During the current eruption, the most active period occurred in 2005 with >30 Vulcanian explosions producing pyroclastic flows with a runout of up to 5.4 km. Swarms of long-period events were associated with each event and analysis has produced a remarkable insight into the ascent process and the transition between regimes. Cross correlation produced some 12 families of events, which not only reoccurred between different swarms, but also were present months earlier during magma ascent prior to the 2004 effusive eruption. This implies a consistent source over this period. The amplitude of the long-period events was observed to increase for various swarms after the explosion occurred. This has been modelled to be a result of the post-explosion unloading that occurs within the magma column.

1.1-O-16

Periodically Erupting Degassed Magma: The Evolution Of Karymsky, Bezymianny, and Shiveluch Volcanic Systems In The Past Decade

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Gas overpressure in magmas is a plausible mechanism for initiating explosive eruptions. We use the uranium-series decay chain of ^{226}Ra - ^{222}Rn - ^{210}Pb to quantify gas motion. The intermediate nuclide ^{222}Rn strongly partitions into volcanic gas, potentially fingerprinting gas flux by U-series disequilibria. We present data from 15 eruptions of Karymsky, Bezymianny, and Shiveluch volcanoes over the past 50 years. Equilibrium (^{210}Pb)/(^{226}Ra) values of 0.92-1.02 characterize a continued eruption at Karymsky starting in 1996. However, we measure deficits following short quiescent periods. Karymsky activity decreased in November 2008 while steaming continued. The eruption cycle began again in March and April of 2008. A ^{210}Pb deficit of 0.3 (70%) in an April 2008 lava bomb suggests the bomb was strongly degassed prior to explosion. Activity decreased during June, and an explosive phase initiated on July 25, 2008. Again, we measure a ^{210}Pb deficit of 0.83 (17%) in a lava bomb from this eruption. We interpret this geochemical signal as evidence that at Karymsky, constant gas jetting between eruptions degasses magma in the shallow system until a degassed plug forms which allows the system to build pressure and initiate eruption. Bezymianny and Shiveluch volcanoes in northern Kamchatka are similar to Karymsky in that passive degassing occurs at the surface prior to periodic explosive eruptions. We find a trend towards ^{210}Pb deficits in the past decade at all three volcanoes with Bezymianny recording deficits of 15% in 2007, and Shiveluch as much as 8% in 2007. We propose that in these systems, periodic explosive eruptions are not caused by an increase in overpressure by sudden gas addition to the systems but rather by the loss of gas and formation of a shallow degassed plug of magma sealing a system with continued deep degassing.

1.1-O-17

Plagioclase Zoning As An Indicator Of Magma Processes At Bezymianny Volcano, Kamchatka

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Bezymianny volcano is located in Central Kamchatka Depression and is a part of Kluchevskaya group of volcanoes. It is one of the most active andesitic volcanoes in the world. More than 17 large explosive events occurred since 1956 catastrophic eruption. Last decade is characterized by frequent (1-2 times per year) significant explosive events accompanied by continuous extrusive dome growth. Frequent eruptions let us study dynamic changes in magmatic system recorded in eruptive products.

The erupted magmas are homogenous two-pyroxene andesites, which last equilibrated at ~915°C temperature, 77 - 87 MPa pressure, and a water content of ~1.4 wt.%. Textural and compositional zoning of individual plagioclase phenocrysts typically includes a repeated core-to-rim sequence of oscillatory zoning (An_{50-60}) truncated by a dissolution surface followed by an abrupt increase in An content (up to An_{85}), which then gradually decreases rimward. This zoning pattern is interpreted to be the result of a magma heating event caused by an individual mafic recharge, which caused a temperature increase of $\leq 100^\circ\text{C}$ and the corresponding dissolution of $\leq 30-40\%$ of plagioclase. The outermost 70-150- μm -wide zoning patterns of plagioclase phenocrysts are composed of dissolution surface with a subsequent increase in An content, which suggests that every eruption was preceded by a replenishment event. Replenishments seem to trigger the eruptions and cause reheating and remobilization of the resident magma.

1.1-0-18

Recent Volcanism at Los Humeros Caldera and Surroundings, Central Mexico

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A north-south migration of volcanism has been proposed in several areas of the Mexican Volcanic Belt (MVB), including the eastern sector, indicating that the oldest volcanoes are preferentially located to the north. Present volcanic activity is restricted to the dormant Citlaltépetl (Pico de Orizaba) stratovolcano, which today shows passive fumarolic activity. However, one of the most important geothermal fields in Central Mexico lies within the Los Humeros caldera located north of Citlaltépetl in the Serdán-Oriental basin. In addition, recent (late Pleistocene to Holocene) activity on the northern side of the belt has been discovered in several volcanoes as a result of new detailed stratigraphic studies, such as El Volcancillo, Cerro Pizarro, and Cofre de Perote. Although the latter can be regarded as an extinct volcano, multiple edifice collapse events have occurred since Late Pleistocene-Holocene time, with the consequent hazard implications. El Volcancillo is a paired scoria cone that erupted as recently as ~900 yr BP and it is located at the end of a ENE cone alignment that is parallel to a regional structural and seismically active system. Cerro Pizarro is a rhyolitic dome that most recently erupted at ~65 ka. In contrast to most rhyolitic domes that usually have short-lived (10's-100's years) eruptions, Cerro Pizarro behaved as a polygenetic volcano with a complex evolution, involving long-term repose periods (~ 50-80 ky) between eruptions. This indicates that reawakening of apparently extinct rhyolite domes cannot be ruled out. Los Humeros is a Pleistocene caldera with an active geothermal system. Although its evolution involved very large explosive eruptions (115 km³, DRE), its most recent activity (younger than 20 ky) is dominated by ring-fracture basaltic lava flows. All these examples indicate the potential for volcanic activity and associated hazards in the northern zone of the eastern MVB.

1.1-0-19

The Deep Magma Plumbing System of The Phlegraean Volcanic District (Southern Italy) Through The Melt Inclusion Studies

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Melt inclusions (MIs) represent pristine melt droplets trapped in early forming phenocrysts, which record the variable physico-chemical conditions of their hosting system. Compared to whole rock studies, the MIs approach shows advantages especially because it provides information on melt composition, volatile content, pressure and temperature at well-defined pre-eruptive stage. A large amount of geochemical data is available for the magmas generated in the Phlegraean Volcanic District (PVD), which is one of the most densely populated and high-risk volcanic areas of the world, but the knowledge provided by those data on their plumbing system, ascent, degassing and extrusion is limited. We investigated the glass/melt inclusions in olivines from the Solchiaro 1 volcanics, erupted on Procida Island, which is located along main tectonic alignment of the PVD. These products represent the least evolved magma of the PVD and could testify for the presence of the "basic" and deepest reservoir from which the Phlegraean magmas upraised and differentiated through various steps. Often invoked in literature, this "primitive" reservoir is basically unconstrained. We performed microprobe and microscopy measures to determine textural and compositional features of the MIs and host-minerals. The measures by Fourier Transform InfraRed spectroscopy provided the content of dissolved H₂O and CO₂, hence the volatile budget of magmas and entrapment pressures (i.e. depths of crystal growth). Recalculated crystallization depths for the Solchiaro 1 olivines result to be very deep (~350 MPa) and isobars obtained for the MIs describe a degassing trend with high CO₂ content, of deep origin. Taking into account the geophysical data and the MIs studies on other Phlegraean products recently published, our dataset depicts a new framework for the evolution of the PVD plumbing system up to the present time that improves both the comprehension of magma evolution and migration through various reservoirs and the volcanic hazards assessment.

1.1-0-20

The Hazardous Initial Phreatomagmatic Phase of Scoria Cones: Jorullo Volcano (Mexico) (1759-1774): Basal Tephra Deposits and Historic Accounts

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Phreatomagmatic activity dominated the initial phase of the historic Jorullo (Mexico) eruption (1759-74?). A widespread basal tephra up to 50 cm thick and rich in basement lithoclasts, was regionally gullied shown by up to 30 cm steep erosional rills spaced several cm apart, reflecting the cohesive nature of the tephra due to a critical water content. The gullies are filled by a gray fine-grained tephra up to 50 cm thick. A pinkish fine-grained 2-10 cm muddy tephra covers the 2 basal units regionally. The poorly sorted massive-appearing basal tephras consist practically entirely of relatively well-sorted accretionary lapilli (ca. 2 – 3 cm in diameter). Abundant water erupted prior to the eruption (beginning October) and subsequent deposition of mud plastered onto houses, globular eruption clouds and other indicators of magma-water interaction were reported by the hacienda administrator (in Gadow, 1935). The erosional rills suggest massive precipitation possibly by a major hurricane on November 7, 1759 - a time of extremely explosive eruptions and powerful thunderstorms, perhaps triggered by the eruption. Subsequent violent strombolian activity was interrupted at several stages by phreatic and phreatomagmatic activity, major unconformities possibly being related to downpours during rainy seasons. The wide areal distribution at least ca. 120 km² of basal tephra and the major unconformity indicate powerful explosions, very large eruption columns and massive downpour at Jorullo. The initial phase of scoria cone evolution worldwide is commonly governed by magma-water interaction, very hazardous and was powerful during historic (La Palma, 1949) and Holocene eruptions in the Canary Islands. Literature: Gadow, 1935, Cambridge Univ press; Sumita & Schmincke, 2009, 250th anniversary of Volcán Jorullo's birth in Mexico, conference abstract; Schmincke & Sumita, 2009 250th anniversary of Volcán Jorullo's birth in Mexico, conference abstract.

1.1-O-21

Ash Recycling and Volcano Monitoring: The Stromboli Case

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Glassy ash clasts can provide useful information on the ongoing magmatic and volcanic processes. Textures and compositions of ash can be used as a proxy of the state of the magmatic system, possibly highlighting transitions between eruptive styles. In particular, at Stromboli, paroxysms are related to the fast uprise of volatile rich, crystal poor (LP) basaltic magmas, contrasting with the crystal rich, degassed magma that produces the common mild Strombolian explosions. However, during persistent explosive activity, primary magmatic information can be hidden by the recycling that occur within the crater or in the upper part of the conduit. To verify how the primary magmatic "signal" can be discriminated by these "noisy" not-magmatic processes, we collected and studied ash erupted at Stromboli from 18 distinct, mild Strombolian explosions during a period of activity of 5 days. SEM investigations were performed

in order to characterize the external morphology, texture and composition of the different clast types. Preliminary results indicate that glassy fragments represent the majority (>50 vol%) of the juvenile material, together with dense clasts (<30 vol%), in all the analysed samples, while crystals and lithic clasts are less than 20 vol%. A minor but significant amount of highly vesicular fragments (< 3 vol%) shows glass composition typical of deep-seated, volatile-rich, LP magma. Two alternative explanations for the presence of these fragments can be invoked: this juvenile fraction is related to the intracratere recycling of LP clasts erupted 18 months before (last paroxysm), or they reflect the arrival at surface of small blobs of LP magma. To unravel the cause of this unusual occurrence we performed high temperature experiments at atmospheric pressure on natural LP samples in order to investigate the effects of reheating on morphology, texture and composition of ash. Textural and compositional modifications obtained in laboratory are compared with similar features observed in natural samples.

1.1-O-22

Do ²²⁶Ra-²³⁰Th Isochrons Provide Realistic Crystallization Ages?

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In this contribution we investigate the timescales of melt evolution and crystal growth in the Mt Erebus magmatic system using measurements of ²³⁸U-²³⁰Th-²²⁶Ra-²¹⁰Pb-²¹⁰Po and ²³²Th-²²⁸Ra-²²⁸Th. Our sample suite consists of 22 historic bombs, ranging from 1972-2005; and 5 anorthoclase megacrysts separated from historic bombs for the years 1984, 1989, 1993, 2004, 2005. These samples ²³⁸U-²³⁰Th and ²³⁰Th-²²⁶Ra are significant and uniform over the 36 year historical record. The anorthoclase megacrysts and phonolite glass show complimentary ²²⁶Ra/²³⁰Th disequilibria. In all samples, ²¹⁰Pb/²²⁶Ra are in secular equilibrium for both phases. For the phonolite glass ²²⁸Ra/²³²Th is in equilibrium, whereas in the anorthoclase megacrysts ²²⁸Ra/²³²Th is significantly greater than unity. For the 2005 bomb, whose eruption date is known explicitly, ²¹⁰Po was not completely degassed. In-situ ion probe measurements of Ba and Th in the anorthoclase and phonolite glass show that our anorthoclase and phonolite glass separates are pure with regard to ²²⁶Ra/²³⁰Th systematics.

Instantaneous crystal fractionation, with long magma residence time (> 100 years, < 3 kyrs, depending on D_{Ba}/D_{Th}), can account for the ²³⁸U-²³⁰Th-²²⁶Ra-²¹⁰Pb systematics. However, the significant ²²⁸Ra/²³²Th disequilibria

in the anorthoclase megacrysts preclude this simple interpretation. To account for this apparent discrepancy we have developed a continuous crystallization model, which incorporates both nuclide in-growth and decay during crystallization. Our model can successfully reproduce all of the measured ^{238}U - and ^{232}Th - decay series disequilibria. More importantly, this model shows that when the timescale of crystallization is comparable to the half-life of ^{226}Ra , the simple ^{230}Th - ^{226}Ra isochron techniques typically used in most U-series studies likely provide erroneous ages.

1.1-O-23

Residual Isostatic Anomalies of the Canary Islands

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Isostatic analysis allows us to better understand the structure of the crust and upper mantle of an area, and to increase our knowledge of the geological evolution of topographic features. To assume that all the islands of the archipelago and the seafloor surround them are been compensated by the same isostatic mechanisms could be extremely simplistic. To discuss which isostatic mechanisms are working in each area, we have calculated isostatic residual anomalies using several types of compensation models: local, regional with a surface load and regional with a hidden load. Isostatic residual anomaly maps were obtained by subtraction from the Free Air anomaly (offshore) and the Bouguer anomaly (on the islands and African continent), the gravity effect of: 1) the water layer, 2) the sediments, 3) the compacted sediments, 4) the density contrast at the base of the crust, with a different root depending on the isostatic mechanism consider. The isostatic stability of the Canary Islands in the last few millions of years implies that they may have reach isostatic balance or they are very near to it, therefore we can assume that the anomalies seen in the isostatic residual anomaly maps are mainly reflecting differences in geometries and/or densities of the crust and the upper mantle from the ones considered in the models used. We discuss here which isostatic mechanisms better explain each island, the seamounts and the surround seafloor. We also discuss the presence of several gravity highs in the islands that appear independently of the isostatic anomaly model used. Those highs are also seen in the regular Bouguer Anomaly map, the short-wavelength Bouguer Anomaly map and the Mantle Bouguer anomaly map. We interpret that these anomalies do not reflect lack of isostatic balance, but instead local changes in crust and/or mantle densities.

1.1-O-24

Global CO₂ Emission From Volcanic Lakes

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During the last two decades, scientists have paid attention to CO₂ volcanic emissions and its contribution to the global C budget. Excluding MORB, the global CO₂ discharge from subaerial volcanism has been estimated about 300 Mt y⁻¹ and this rate accounts for both visible and non-visible volcanic gas emanations (Mörner & Etíope, 2002). However, CO₂ emissions from volcanic lakes have not been considered to estimate the global CO₂ discharge from subaerial volcanoes. To improve this global CO₂ emission rate and estimate the global CO₂ emission from volcanic lakes, an extensive research on CO₂ emission of volcanic lakes from different countries has been carried out by means of lake surface CO₂ efflux measurements following a modified floating device of the accumulation chamber method. To quantify the total CO₂ emission from each volcanic lake, CO₂ efflux maps were constructed using sequential Gaussian simulations. CO₂ emission rates were normalized by the lake area (km²), and volcanic lakes were grouped following classification in acid, alkaline and neutral lakes. The observed average normalized CO₂ emission rate values increase from alkaline (5.5 t km⁻² d⁻¹), neutral (210.0 t km⁻² d⁻¹), to acid (676.8 t t km⁻² d⁻¹) volcanic lakes. Taking into account (i) these normalized CO₂ emission rates from 31 volcanic lakes, (ii) the number of volcanic lakes in the world (~ 800), (iii) the fraction of the investigated alkaline (45%), neutral (39%), and acid (16%) volcanic lakes, and (iv) the average areas of the investigated alkaline (36,8 km²), neutral (3,7 km²), and acid (0,5 km²) volcanic lakes; the global CO₂ emission from volcanic lakes is about ~ 136 Mt year⁻¹. This estimated value is about ~ 45% of the actual estimated global CO₂ discharge from subaerial volcanism. This study highlights the importance of a deeper revision of the actual global CO₂ discharge from subaerial volcanism.

1.1-O-25 - Keynote lecture

Evolution of the Canary Islands with Emphasis on Volcanic Hazards

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The Canary islands are one of the two large ocean island groups of the Magmatic Belt off Western Africa – Cape Verde islands to the south being the other, with Madeira to the north and two major large seamount – formerly island – groups (Sahara and Sierra Leone) to the south represent the ca. 3000 km long intraplate volcanic province. The Canarian archipelago comprises 7 major and 3 minor islands, forming a roughly east-west oriented chain from ca. 100 to ca. 450 km west of the African continent: Fuerteventura, Lanzarote, Gran Canaria, Tenerife, La Gomera, La Palma and Hierro. The eastern islands Fuerteventura, connected Lanzarote and Conception bank together make up an elongate group roughly parallel to the African coast. A pronounced decrease in age from the highly eroded eastern (shield

ages ca 20-15 Ma) to the youthful westernmost islands of La Palma and El Hierro (1.5 and 1.1 Ma) reflects migration of the dominant basaltic shield stage volcanism at a rate of ca. 1.5-1.1 mm/a.

All Canary Islands are built on ocean crust ranging from 180 Ma in the east – one of the oldest ocean crust known – to 150 Ma in the west. A small sliver of MORB Jurassic ocean crust and ca. 500 m of overlying Mesozoic sediments have been uplifted probably by intrusions forming the central core of western Fuerteventura. A thick section of uplifted intrusives, pillow lavas and basaltic volcanoclastics reflecting decreasing water depth represent the submarine stage of La Palma while uplifted basement of La Gomera is equivocal.

Holocene volcanic activity has occurred on all islands except La Gomera with historic activity having been most common on Tenerife (latest eruption in 1909) and particularly La Palma (latest eruptions 1949 and 1971) while one of the largest historic basaltic eruptions took place 1730-36 on Lanzarote. The 600 m high seamount Hijo de Tenerife between Gran Canaria and Tenerife is in an active stage judging from dredged bombs but needs to grow a lot from 1100 m bsl to the surface of the ocean before becoming an island proper.

The magmatic, temporal, and volcanic evolution of the Canary Islands differs in several fundamental ways from the classic Hawaiian model. Basic similarities include: dominating basaltic shield edifices migrating roughly linearly with time over major melting anomalies, post-erosional magmatic stages and general strongly decreasing melting rates and increasing alkalinity with time. Fundamental differences include: duration of magmatic activity on single islands lasting for at least 20 million years; several phases of post-erosional volcanic activity being interrupted by hiatus lasting up to 10 million years; composition of shield basalt magmas being more alkalic – with clinopyroxene as the most common phenocrysts phase – than those in Hawaii, tholeiites being rare; huge volumes of highly differentiated alkalic and silicic magmas, especially on Gran Canaria (many hundred km³ of trachytes, rhyolites and phonolites) and smaller volume of phonolite on Tenerife; the large magma reservoirs that developed especially on Gran Canaria for some 5 million years imply long term decreasing rates of magma and heat transfer at critical rates sufficient to keep the system alive in the upper crust, probably reflecting waning dynamics of the melting domain; decreasing magma production rates with time being more irregular with some high post-erosional magma production rates on some islands (e.g. Roque Nublo on Gran Canaria). The thickness of the old and thus cold and thick lithosphere beneath the Canary Islands having grown close to a continent is clearly the reason for other major contrasts with the Hawaiian evolution in the middle of the Pacific Ocean. At least some of the islands such as Gran Canaria have been remarkably stable with respect to sea level throughout their evolution, as clearly shown by the elevation of major erosional canyons formed during the Miocene shield stage and whose height asl is practically identical to present-day elevations. The nearly horizontal major seismic reflectors such as those between Gran Canaria and Tenerife is equally impressive and also constitute major evidence against an often proposed major fault between the islands. Island growth on thick old lithosphere is likely the reason for the stability.

Alkalinity of Canarian magmas increases regionally from east to west, alkalinity being correlated roughly with increasing pyroclastic activity, e.g. higher abundance of scoria cones in the Tenerife compared to the Gran Canaria shield basalts. Less alkaline shield magmas in the east are differentiated to trachyte and syenite while the western islands have evolved exclusively to highly alkaline phonolite; Canarian magmas are generally Fe and Ti-rich, increasingly so in the western islands, possibly due to higher melting pressures.

Theories on the origin of melting anomalies – a term we prefer – that produced the magmas forming the islands have necessarily been speculative and will remain so. We have argued for many decades that the striking string of island and seamount provinces in a belt parallel to Africa is unlikely to be fortuitous and suggested that fertile – asthenospheric – mantle may have risen along the critical boundary between thick old continental and thin young oceanic lithosphere. Speculations on a fixed mantle plume beneath a moving oceanic lithosphere have also been discussed for many years. Both models have their pros and cons. A consensus has not yet been reached and a combination of both models is likely.

The volcanic aprons around the Canaries, penetrated in 4 holes drilled during ODP Leg 157 by more than 1000 m north of Gran Canaria consist of roughly 50 vol.% of nanoforam ooze. Particles from the islands are not dominantly due to erosion during long nonvolcanic intervals but mainly due to mass transfer resulting from explosive eruptions on the islands, especially ignimbrites and sector collapses. The dominant trade wind directions around the Canaries (northeast to southwest) have been constant for over 15 million years and have led to the north flanks of the islands being highly eroded and thus wet and vegetated. This asymmetric deep erosion may also have influenced sector collapses to occur preferentially on the northern flanks of some islands.

Eruptive mechanisms, sector collapses and associated hazards

A newcomer to the Canary Islands landing on Gran Canaria or Tenerife and having previously visited Hawaii will be struck by the multitude of scoria cones dotting most of the islands. This illustrates that the alkalic basaltic magmas are also more volatile-rich and therefore more commonly generate explosive eruptions than those in Hawaii. Prediction of likely scenarios of hazards and risks is primarily based on Holocene and historic eruptions. Volcanic hazards on the Canary Islands are overwhelmingly those of basaltic eruptions with the main hazard and risk posed by long lava flows. Lava flows can destroy settlements and infrastructures on a grand scale as on Lanzarote (1730-36) where several villages were overrun, and the town of Garachico on Tenerife having being largely destroyed by a lava flow in 1706 or settled land on La Palma (1949, 1971). Fallout from such eruptions can be a major nuisance and hazard in densely populated areas such as around Las Palmas, Santa Cruz de Tenerife or Puerto de la Cruz.

Phreatomagmatic eruptions due to magma-water interaction are especially explosive and hazardous because of common horizontal transport by base surges. Examples are the 1949 eruption on the crest of La Palma and several Holocene eruptions on Gran Canaria (La Calderilla, Marteles, Bandama and others) and other islands. Highly evolved eruptions such as M Blanca in the caldera of Tenerife (2000 years go) can cover large

areas by fallout aprons.

Sector/flank collapse of volcano edifices and resulting debris avalanches and, when these impact the sea, destructive tsunamis are extreme hazards. Such collapses have been especially frequent on the Canaries in the past, characterized as the islands are by steep flanks, high level intrusions in many, interlayering of lavas and pyroclastics, soil horizons and resulting pronounced slope instabilities. Fortunately, the occurrence rates of sector collapses are low, on the order of a few hundreds of thousands of years, but, nevertheless, can be much shorter. La Palma is the most likely candidate for future flank collapses but there are presently no signs for imminent collapse. Huge steam-rich blasts may follow a major flank collapse as on Tenerife ca 0.2 million years ago, the deposits covering most of the island probably generating tsunamis. This mega-event was dwarfed by the giant Roque Nublo debris avalanche on Gran Canaria ca 3.5 (?) million years ago that devastated much of the island, impacted the sea now forming the most widespread clear seismic marker bed peripheral to the island.

For more detailed summaries see Schmincke (1976, 1982, 2004) and Carracedo et al., (2002); references in *Geology of Gran Canaria and field trip guide* (Schmincke & Sumita), this conference.

1.1-O-26

Geo-Petrological Study of The Roque Nublo Cycle (Gran Canaria, Spain)

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Roque Nublo (RN) volcanic complex represent the second magmatic cycle of Gran Canaria subaerial volcanic activity and it's one of the most distinctive of the island for folds appearance and encompassing a large degree of evolution. However, it was so far somewhat neglected. Geochemical and magmatological features of rocks from RN have been analysed using different methods and investigated basing on both major and trace elements. The Roque Nublo products mainly consist of alkaline rocks with a concentration of SiO₂ that ranges from 42.60 wt% to 56.10 wt%. These rocks can be semi-modally classified as tephri-phonolites while TAS diagrams inconsistently classify the samples in a wider range that goes from alkali-basalts to phonolites. Mg# values vs major oxides -diagrams show two different trends, while Cr+Ni distribution is consistent with magmatic differentiation by crystal settling. Further details on magma evolution are given by multielement diagrams using HFSE and LILE. The diagrams show an enrichment in LILE, a characteristics concentration in Zr and negative peaks for U and Rb. LREE/HREE ratios suggest a low degree of partial-melting of the magmatic source and parallel REE pattern highlight the co-magmatic relationship between the rocks of the RN association. On this base is also possible to determine evolutionary sequence of the RN suite. Comparing this sequence with the depositional model from literature and field survey it's apparent that the sequence shows an inverse order that can be justified assuming the existence of a zoned magma chamber or multiple chambers in a different state of evolution. Explosivity asso-

ciated with mafic alkaline magmas requires additional juvenile propellant such as CO₂ whose virtual presence needs a re-examination of emplacement mechanism and magma-coolant interaction.

1.1-O-27

Fumarole and Plume H₂S Emission from Active Volcanoes

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It is widely recognized that volcanic sulfur dioxide (SO₂) and hydrogen sulfide (H₂S) emissions are significant sources of sulfur release to the atmosphere. Quantifying and monitoring H₂S flux from volcanoes is tremendously useful not only for volcano surveillance but also to estimate the total sulfur input into the atmosphere. H₂S is the most important sulfur specie in low-temperature fumaroles and solfataras, where discharges arise from deep hydrothermal systems. If the lifetime of volcanic H₂S in volcanic plumes and fumaroles is longer than frequently assumed as was observed by Aiuppa et al. (2005), then the total sulfur emissions of many volcanoes could be significantly underrepresented. For the last thirty years SO₂ fluxes measured using the Correlation Spectrometer (COSPEC) has been the only volcanic sulfur emission that has been taken into account. H₂S emission rate can be estimated multiplying the observed SO₂ emission rate times the observed H₂S/SO₂ mass ratio measure on the fumaroles and plume gases. In this work we present new measurements of H₂S emissions rates from Etna, Poás, Masaya, Pacaya and Sierra Negra volcanoes. The measured H₂S emission rates from the visible gas emissions of these volcanoes ranged between 2.4 t/d emitted by Sierra Negra in 2006 and 133 t/d emitted by Etna in 2008. The emissions of SO₂ exceeded the H₂S emission in all the studied volcanoes. The percentage of the sulfur emitted as H₂S depends on the level of the volcanic activity, and ranged between a minimum of 6% measured in Pacaya volcano during an eruption episode and 29% measured in Sierra Negra, a quiescent volcano. These numbers will improve the knowledge of the total sulfur emission at these volcanoes.

References: Aiuppa et al. (2005): *Geochimica et Cosmochimica Acta*, Vol. 69, No. 7, pp. 1861–1871.

1.1-O-28 - Keynote lecture

Historical Volcanism of Canary Islands

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The historical volcanic activity in the Canary Islands has been characterized by its low eruptive frequency. There are possible mentions to the occurrence of eruptive events in the Canary during the Roman Empire period. However, there are not precise documents about volcanic eruptions until the immediately previous and later moments to the conquest of the islands, carried out between 1402 and 1496. The catalog of the historic

volcanic eruptions started in that period. From those dates, only fifteen volcanic eruptions occurred in the Canary islands (1430/1470, 1492, s. XVI, 1585, 1646, 1677-1678, 1704-1705, 1706, 1730-1736, 1792, 1798, 1824, 1909, 1949 and 1971 eruptions) at La Palma, Tenerife and Lanzarote islands. Through a rigorous analysis of the documental sources, valuable data and important information can be obtained about the eruptive behavior and associate phenomena (seismic crisis or anomalous volcanic degassing processes). The combined data analysis coming directly from the historical documents together with those referred to its geomorphological features allow to obtain a more precise picture of the processes. Through the historical documents, it has been also possible to find out the main social, political and economic events associated to the eruptions, as well as, the administration of the volcanic crises carried out by the civil and military authorities.

1.1-P-01

A Study of the Influence of Particle Shape on Tephra Dispersal

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Tephra sedimentation processes are mainly governed by the settling velocity and wind advection of volcanic particles. Studies on volcanic clasts showed the importance of particle shape on their settling velocities. In the present study, we investigated the variation of particle shape with grain size and with distance from the vent and we used particle shape parameters to quantify the changes in the settling velocity and to compare the measured diameter of volcanic particles with the equivalent diameter of spheres falling at the same settling velocity. Particle morphological parameters were measured with the ParmaVision830 optical device and settling velocities were calculated using different models. The trend of shape parameters as a function of grain size is fairly constant for all the samples analyzed. Therefore the assumption made in tephra dispersal models that particle shape parameters do not vary away from the vent is supported by our data. Comparison between the measured diameter of volcanic particles and the calculated diameter of the equivalent spheres falling at the same settling velocity shows that the measured diameters are larger than the diameters of the equivalent spheres. These results suggest that the settling velocity of ash particles is greatly reduced for particles departing from a spherical shape and that the larger the particle, the greater the influence of particle shape on its settling velocity. However, particle shape parameters for a given particle size do not sort out with distance from the vent, while they do vary as a function of grain size. Therefore, other physical processes happening in the volcanic plume (atmospheric motion, particle entrainment or ice formation) are likely to have a stronger influence on the transport of volcanic particles than their shape. A better characterization of such physical processes may improve volcanic-cloud and tephra dispersal models and therefore related hazard forecasts.

1.1-P-02

From Fissure to Point Source: Lava Fountain Evolution at Mauna Ulu 1969, Kīlauea, Hawaii

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The Mauna Ulu eruption in Hawaii was the second largest 20th century eruption of Kīlauea. It provides an opportunity to analyze fissure conduit geometry via 900 m of preserved initial dike path, which extends tens of meters into the subsurface. Such exposure provides constraints on the mechanics influencing how fissure eruptions taper down to one (or several) point source(s). Activity lasted 18 hours, producing spatter ramparts, tree molds, and lava flows. Geometric analysis of the spatter ramparts indicates the opening fissure localized into several point source fountains. Slopes of the inner and outer rampart walls show variable fountain intensity through time and as the number of point sources became fewer, the intensity of the fountain increased. Several rampart segments became over steepened and unstable, collapsing during fountaining and spatter accumulation. Ejecta on the southern side of the fissure typically rafted away on lava flows, reflecting high (downwind) accumulation rates and a downhill slope. Tree molds formed as lava flows passed, creating lava islands that preserved flow directions between May 24th and 28th, 1969. Lava erupted during the last few hours of fountaining on the western 900 meters of the opening fissure drained back into the fissure. While a two meter difference between the high stand of the lava and the current subsided crust is present, another 3 - 5 meters of lava is overlying the pre-eruptive ground surface. Analysis of vent spacing and geometry indicates that fissure segments which produced the more vigorous point source fountains were fed by a fissure conduit underneath circular flared vent apertures, and were consistently located adjacent to the tallest ramparts.

Changes in focus and intensity often pose the greatest threat during generally benign Hawaiian fountaining; understanding factors that modulate such change will enhance risk assessment in future Kīlauea eruptions.

1.1-P-03

Calcite-Bearing Foiditic Lavas of Colli Albani Volcanic District (Central Italy): New Petrographic and Geochemical Data.

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The Colli Albani volcanic district, near the city of Rome, represents one of the most peculiar volcanic districts on the Earth because of its liquid line of descent characterized by differentiated K-foiditic magmas. Field, geochemical and experimental studies have demonstrated that such a differentiation trend is mainly due

to magma-carbonate interaction. One impressive evidence of this process is the occurrence of magmatic calcite in the lava flows groundmass. Despite many studies have investigated petrological and geochemical features of the Colli Albani magmas, several questions remain unanswered. One of these concerns the $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratio trends observed in products representative of the whole Colli Albani eruptive history. Another open question concerns the role of fluorine in the magmatic system and its effects on phase relationships. Starting from these questions we have started a petrographic and geochemical study on lava flows emplaced during the whole Colli Albani activity with the aim to better understand the processes of genesis and evolution of magmas. Here we present preliminary petrographic and geochemical data on those lava flows. In particular, the oldest lava flow studied (≥ 560 ka) is a lithic fragment in the Trigorina Tor de' Cenci pyroclastic flow that has the highest $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (0.711196) among all those studied. Young lava flows present low $^{87}\text{Sr}/^{86}\text{Sr}$ (0.709879) and high $^{143}\text{Nd}/^{144}\text{Nd}$ ratios and some of these are characterized by the occurrence of strontian fluoro-magnesiostastingsite in the groundmass and lack of calcite, probably linked to changes in fluorine and CO_2 activity. We interpret the variations in fluorine activity and isotope values as due to changes in the metasomatic component (i.e. phlogopite) of the mantle source.

1.1-P-04

Seismic Study of 2005 Vulcanian Explosions at Colima Volcano

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Between 1991 and 2004 four episodes of dome growth took place at Colima volcano, the fourth episode began in September 2004. This dome was destroyed by more than 20 vulcanian explosions that occurred throughout 2005, most of these explosions were detected by the seismic stations of RESJAL. These signals were recorded not only by stations located on the volcanic edifice, but also by stations as far as the northern coast of Jalisco and on Ceboruco Volcano at 184, 182 and 200 km distance, respectively. A study of these seismic signals is presented using the waveforms, spectra, and other features. By means of seismic record sections it was determined that the sound velocities of the shock and pressure waves vary by as much as 10 per cent around the volcano; an analysis of the pressure waves (Lamb pulses) recorded at regional stations shows an apparent subsonic velocity. Different methodologies were used to measure the size of the explosions recorded at local and regional stations. A clear relation between the magnitude of the seismic signals and the amplitude of the sonic and subsonic waves was not observed. This study suggest that the source processes are non-stationary, implying that for the case of this period, a general model of the source process of the Colima volcano explosions cannot be formulated.

1.1-P-05

Insights Of Dyke Emplacement Mechanics From Detailed 3-D Dyke Thickness Datasets

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Dyke thickness datasets offer new insights into the detailed three-dimensional geometry of kimberlite dyke swarms and an exceptional opportunity to evaluate existing theoretical dyke emplacement models. Dykes feed volcanic eruptions and so understanding their emplacement mechanics using field measurements is vital for the improvement of numerical models and for volcanic risk assessment. In total 1532 dyke thickness measurements were taken at Helam Mine to 750 m below the surface over 250 m depth. The minimum total strike length is 7 km and a dolerite, impure quartzite, shale and andesitic lava stratigraphy was intruded. The Star Mine dataset comprises 3354 dyke thickness measurements taken from the surface to 520 m depth. The kimberlites cut flat-lying shales and sandstones, intersect a large dolerite sill at depth and extend to 15 km in length. Both dyke swarms comprise a series of anastomosing en echelon segments, each of which are several hundred metres long. The measurements reveal a complex geometry that varies both along the length and breadth of the dyke segments. At Helam the dyke thickness ranges from 0.05-1.95 m, with a mean of 0.64 m. The Star kimberlite dyke segments are thinner than the Swartruggens dykes, with thicknesses ranging from <0.01 m up to 1.6 m and a mean of 0.40 m. These thicknesses are of similar magnitude to those estimated for basaltic dykes, suggesting there may be similarities between their ascent dynamics. There is a lot of scatter in the dyke thickness data, and elastic models poorly describe the dyke thickness variation along the breadth of the dyke segments. At Helam the dyke segments thicken towards their terminations points, which are regions where stresses are focused. Towards the surface, rock deformation is increasingly difficult to recover as inelastic processes such as host-rock brecciation, stoping, and magma solidification become increasingly important.

1.1-P-06

Morphological and Morphometrical Analysis of Cinder Cones, Tenerife Volcanic Island, Canary, Spain

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Basaltic monogenetic volcanoes constitute the most common eruptive forms produced by subaerial eruptions (Wood, 1980). The cinder cones are formed by accumulation of the volcanoclastic deposits, xenoliths and intercalated lava flows (Martin and Németh, 2006; Valentine et al., 2007). 297 scoria cones are still well preserved on Tenerife, and represent the most common eruptive activity occurred on the island during the last 1 Ma (Dóniz et al., 2008). The high number of these elements has led us to establish a systematic methodology to describe and classify the cinder cones and to

establish their general characteristics. The main aim of this work is to study scoria cones through a morphometric analysis to eventually obtain simple morphological models. A methodology based on the analysis of morphological and morphometric data has been used to define the morphology. Morphometric parameters of cinder cones were obtained from 1:10.000 topographic map, aerial photographs and field research. The morphometric parameters used in this study include cone height, cone major diameter, cone width ratio, cone volume, cone area, number of craters, crater depth, crater major diameter and crater minor diameter, crater width, separation index between cones, cone slope and cone elongation and crater elongation (Dóniz-Páez, 2004). The application of morphometric parameters to scoria cones allows for the distinction of four morphological types: ring type cones, horseshoe volcanoes, multiple scoria cones and mountains of lapilli. The first and second type of cinder cones are divided to obtain a total of seven geomorphological types. The percentage of volcanoes is different for each scoria cones type: the horseshoe cinder cones are the 69.03%, the ring type cones are 13.14%, the mountains of lapilli are 11.45% and multiple scoria cones are 6.38%. This is a simple morphological classification to also apply to other volcanic regions and volcanic fields. References: Wood, 1980, JVGR; Martin and Németh, 2006; JVGR; Valentine et al., 2007, JVGR; Dóniz et al., 2008, JVGR; Dóniz-Páez, 2004 Ph.D Thesis.

1.1-P-07

Degradation of Quaternary Scoria Cones in Tenerife island, Canary, Spain.

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The aim of this paper is observe the erosion of 43 dated volcanoes of Tenerife (range in age from 791ka up to 1909) over time and verify whether or not age is a critical factor in the degradation level of volcanoes. These volcanoes divide in two age groups: Pleistocene volcanoes (PV=13) and Holocene volcanoes (HV=30). These cones are under different climatic types and located in different catchment basins. The methodology based on the morphometric: H_{co} =cone height, W_{co} =cone width ratio, W_{cr} =crater width and D_{cr} =crater depth) and Wood's correlations. The morphometric study of these volcanoes by age intervals reveals that in Tenerife the H_{co}/W_{co} and D_{cr}/W_{cr} correlations don't evolve according to Wood's postulates, but instead they evolve inversely. In this sense, degradation of the cinder cones analyzed in Tenerife doesn't depend on the amount of time that has passed since their creation. Therefore, other factors also influence in the erosion of the volcanoes, e.g. catchment basins, different climatic conditions, etc. If we study the gully formation on 43 volcanoes, it's observed more 84% of the PV have gullies, compared to only 20% of the HV. PV have been most incised and they have a large number of gullies (5-12), these cones are always emplaced on water divides between large catchment basins (>4th) and under humid conditions, but oth-

ers PV have a few gullies and these cones emplaced within lower-hierarchy basins (<2th) and under humid conditions. In addition, there are HV that have the same number of gullies as PV in similar conditions. All of this illustrates the fundamental role that the emplacement of a volcano and climatic conditions plays in its torrential remodeling. Therefore, although the age of a volcano is an essential factor in the degree of torrential erosion, but there are others factors that intervene as well.

1.1-P-08

Eocene-Quaternary Volcanism in Abdar-Dehaj (Iran)

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The studied area is located southeast of Iran at the geographic coordinates of 55° to 54° 30' East Longitude, and 31° to 30° 30' North Latitude. The general characteristics of this area are the very same ones pertaining to southern Orumiyeh-Dokhtar magmatic arc (Kerman magmatic sub-zone). The only rocks outcropping in this area include volcanic and sub-volcanic rocks and small to medium intrusive bodies with age of Eocene to Quaternary. Based on petrographic studies, the rocks in studied area can be divided into the following groups: A- Basalt, andesite, and quartz-andesite; B- Sub-volcanic dacite and rhyo-dacite; C- Small basic intrusive bodies like dikes and stocks; D-Acid to Moderate shallow porphyry intrusive bodies. Four volcanic and sub-volcanic phases occurred in this area during Eocene-Quaternary: Eocene volcanic phase that started with basaltic-andesitic activities and ended with formation of acid volcanic rocks, a diorite-to-tonalite intrusive phase with age of Middle Miocene, a sub-volcanic with age of Mio-Pliocene, which was the most significant phase in the area and shaped the morphology of this area and formed dacitic-rhyolitic peaks, and finally a volcanic and sub-volcanic phase with age of Plio-Quaternary, which formed two volcanoes of Upper Aj and Lower Aj. These two volcanoes are prominently seen on a plain displaying doming into the open air. Based on geochemical studies and magmatic series determining charts, all rocks in the area fall in to calc-alkaline category. In tectonic setting determining charts, these rocks are placed within active continental margin area. Geochemical evidences indicate the magma sources of the rocks in this area had close relationships and similarities with each other, and they all formed in a subduction zone. This subject generally matches and follows Orumiyeh-Dokhtar magmatic belt, which trends in northwest-southeast direction and locates in north of Arabian plate and south-southwest of Central Iran.

1.1-P-09

Tertiary-Quaternary Volcanism in Alborz (Iran)

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Alborz is a mountain range in north of Iran with approximate length of 1000 km and width ranging from 50 to 100 km. It covers an area of about 5200 km². This mountain range sits like an arc south of Caspian Sea. Its southern flank was volcanically active and under the water throughout Paleogene, but that was not the case for northern flank. Severe volcanic activities took place on southern flank of Alborz in Tertiary and during young Apline phases in form of several stages: First stage: it mainly produced acid tuff and tuffit with some intercalations of mudstones. This complex mostly formed in Middle Eocene with thickness of about 3000 meters and longitudinal stretch of 500 km. Second stage: composition of lavas changed in this stage and their spread shrank as well. They mostly include basic and foid-bearing lavas. The largest outcrop of these rocks is seen in northwest of Tehran and their thickness reaches up to 2500 meters. They have been attributed to Eocene-Oligocene. Third stage: it most likely occurred in Early Oligocene, and the rocks mainly include intrusive igneous rocks, dikes and sills, which are seen in southeast and west of Tehran. Volcanic activities in Quaternary were less in Alborz as compared to those in Eocene and Oligocene. However, there were some scattered incidents in some areas, and among them Damavand Volcano is the most important case located east of Tehran. There were other volcanic activities in Alborz during Quaternary that took place in Taleghan and valleys in Alamout area with intermediate composition (trachyandesite) and alkaline nature. Geochemical evidences of Middle Eocene volcanic activities (which mainly formed acid tuffs) point to partial melting of crust underneath Alborz, whereas volcanic rocks of Eo-Oligocene and Plio-Quaternary are mostly basic originated from the mantle, and feature alkaline nature.

1.1-P-10

Physical, Structural and Socio-economic Vulnerability of San Pedro Benito Juárez, Estado de México, Mexico, due to eruptions of the Popocatepetl, volcano

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Popocatepetl volcano (Popo) is a Quaternary andesitic stratovolcano. With a volcanic edifice of 5450 m high, Popo is one of the highest active volcanoes in North America. It is located 65 km SW of México City and 45 km W of Puebla City. After nearly 70 years of quiescence, Popo began a new episode of activity in December 1994. The present investigation was motivated by the necessity of analyzing the physical, structural and socio-economic vulnerability conditions of the population living in the surroundings of Popo. With this purpose, we selected the community of San Pedro Benito Juárez (SPBJ) as case of study. SPBJ is located in the state of Puebla, México, at about 11.2 km from Popo's crater. For our study, we used the methodology proposed by the National Oceanic Atmospheric Adminis-

tration (NOAA) of the United States of America, which allowed us to quantify the different degrees of vulnerability. Our results indicate that the volcanic hazard to which the population of SPBJ is greater exposed is ash fall of volcanic materials. The second in importance are mud flows that would affect 58% of the houses in case of the occurrence of a secondary lahar. Due to its low level of occurrence, piroclásticos flows as well as lava flows, large landslides and ballistic missiles were classified as hazards with third and fourth level of importance to which the community of SPBJ is exposed, respectively. In the case of the occurrence of a volcanic eruption of the Popocatepetl, the estimated global vulnerability is moderate for 48% of the population, for 41% is high and 5% has low vulnerability. Our results represent a contribution for the development of preparation and mitigation plans for disaster reduction in the case of volcanic emergencies at Popo.

1.1-P-11

Tephrostratigraphy of the last 2 ka activity of Etna volcano

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Stratigraphic and facies analysis, conducted in the 90's, on the pyroclastic successions blanking the Etna volcano flanks permitted the reconstruction of the last 100 ka tephrostratigraphic record of the volcano explosive activity. During the Holocene, several strong explosive events occurred, including a basaltic plinian eruption in 122 BC. However, the historical period lacks of detailed investigation on the Etna pyroclastic succession, therefore, we focused our research on this period.

We started with an accurate field work aimed to the description of the pyroclastic deposits cropping out prevalently on the NE flank of the volcano. This tephra succession is characterized by alternations of ash layers, scoriaceous lapilli rich horizons and varicoloured tuffs attributed to a phreatomagmatic activity. Several yellowish volcanoclastic horizons, sometimes rich in charcoal, separate the tephra layers, indicating non-eruptive periods between the eruptions.

We compiled 7 tephrostratigraphic sections having as common base the marker bed "FG" of the 122 BC plinian eruption and we collected 62 tephra samples and 7 charcoals for laboratories analysis. In particular, grain-size, component, chemical and petrographic analysis were carried out on tephra samples, whereas the charcoals were sent to Beta Analytics, Miami, for 14C radiometric analysis. The whole data set permitted us to correlate the tephra layers and to recognised 16 tephrostratigraphic units.

The integration of the radiometric data with historical chronicles regarding the past activity of Etna, allow us to attribute some tephrostratigraphic units to 7 Etna historic eruptions whose distal deposit had never been found before. These eruptions could be considered as belonging to class B of Branca and Del Carlo (2005), characterised by prevalent intense explosive activity producing copious tephra fallouts, as happened during the 2001 and 2002-2003 eruptive events.

1.1-P-12
The 1891 Submarine Vent: New Data of the Latest Eruption at Pantelleria (Sicily Channel - Italy)

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Marine surveys in 2006 and 2008 used high resolution bathymetry and sampling to locate and characterize the 1891 submarine eruption that occurred offshore Pantelleria Island, Italy. During this eruption, the observed activity lasted for 9-days with the presence of steam plumes and floating lava bombs, rising buoyantly to the surface 5 km W-NW from Pantelleria village (Ricco, 1892). Similar activity has been reported in only a few other cases [i.e., Mauna Loa in 1877 (Moore et al., 1985); Socorro Island in 1993 (Siebe et al., 1995); Terceira Island in 1998-01 (Gaspar et al., 2003)]. The formation of such floating lava bombs is still not fully understood. Volcanic sands and scoriaceous blocks were collected in the survey area. The latter displayed porphyritic and holocrystalline texture in the inner portion and a glassy outermost layer. Major and trace element, EMP, and SEM analyses were performed to characterize the highly vesicular scoriaceous blocks and reticulite found in the glass sands. These products were inferred to be debris of the 1891 eruption based on their fresh appearance, structure, and their composition, which agreed with the analysis of a block from the eruption presented by Washington (1909). Combining the historical reports, the detailed bathymetric map, and the location and composition of eruption products from the seafloor, the vent structure for the 1891 eruption was thus identified for the first time. The most likely eruptive site is a cone which rises ~90 m from -350 m and has a volume of ~600,000 m³. These marine surveys also discovered a large cluster of pointed volcanic cones and fissures NW of Pantelleria with heights up to 380 m. The 1891 cone is part of this volcanic field, and represents the most recent eruption that formed the cluster of cones, although when the field began to form remains unknown.

1.1-P-13
White Pumice vs. Black-Grey Scoria in the Tufo Giallo della Via Tiberina (Sabatini Volcanic District, Roman Province): Evidence of Temperature- and H₂O-Zoning in Phonolitic Magma Chambers.

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Changes in colour and texture of the juvenile component

are often observed in the deposits of explosive eruptions. The transition from white aphyric juvenile clasts (white pumice) towards highly crystalline ones (black-grey scoria) is usually explained by means of compositional layering of the magma chamber or by syn-eruptive magma mixing. However, these textural variations may even occur without accompanying compositional changes, as is the case of the Tufo Giallo della Via Tiberina (Roman Province, central Italy). This pyroclastic succession comprises two eruptive units, emplaced at ca. 561 and 548 ka, during the early explosive activity of the Sabatini Volcanic District. White pumice and black-grey scoria, occurring respectively in the lower and intermediate-upper portions of each eruptive unit, are characterized by remarkably different textures, in spite of common phonolitic bulk compositions: white pumice is subaphyric (P.I.<10%), vitrophyric and highly vesicular, while black-grey scoria is highly crystallized (P.I.>60%, with dominant leucite phenocrysts) and poorly vesicular. Phase relationships (MELTS simulations) and cpx-liquid geothermometry yield temperature estimates at 890-920°C and 920-940°C, respectively for white pumice and black-grey scoria feeder-magmas, and P=150-200 MPa. The diffuse occurrence of leucite phenocrysts in black-grey scoria records crystallization at initially H₂O-undersaturated conditions, while the vitrophyric texture of white pumice indicates H₂O-saturated conditions. In our model, the pre-eruptive H₂O over-saturation was achieved by water diffusion from the cooler and highly crystallized, peripheral portions (black-grey scoria) toward the inner, subaphyric, portions (white pumice) of the magma chambers, as a consequence of radial H₂O concentration gradients. The withdrawal of the white pumice feeder-magma in the early eruptive stages caused decompression and extensive crystallization in the peripheral magma portions, triggering fragmentation and eruption of the black-grey scoria magma in the late eruptive stages.

1.1-P-14
Quaternary Hydromagmatic Eruptions and Paleoseismicity at Campo de Calatrava Volcanic Region, Ciudad Real, (Spain)

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Campo de Calatrava is a natural unity located in the central Spain, where some eruptive cycles of different intensity, spatial location and temporality along more than 8.000.000 years took place. Eruptions of this volcanic system derive from the rise of alkaline magmas rich in CO₂. This has caused some eruptive events of low explosivity (Hawaiians and Strombolian eruptions). The interaction magma/water has allowed the development of events of high explosivity (hydromagmatics) with formation of wide depressions (maars and tuff ring) and the development of pyroclastic flows. In Campo de Calatrava, the lands forms derived from the hydro-volcanic activity are conditioned by the water location which interacts with the magma and the strength of the materials over the explosion is developed (González,

2002). The phreatic and phreatomagmatic crisis are accompanied of the emission of explosive breccias, pyroclastic flows, lahars and mud flows. The last eruptions that took place, in the middle Holocene (Gonzalez et al. (2007 to 2007 b) do of this one a potentially active area, and have a hydromagmatic character. Deposits of these events cover hundreds of square kilometers centered under urban areas they most dynamic and fastest growing population (150.000 peoples)

Recently have been found (Rodriguez & Barrera, 2002) the existence of significant seismic events (7'5 degrees of Richter graduation) affecting these deposits. The traces of this paleoseismicity (Alfaro et al. 1995), -Pleistocene-Holocene- have been located in many areas of the volcanic region, with appreciable effect of liquefaction. If there were an seismic event, volcanic or volcanic-seismic as those carried out in the recent Quaternary, in the same areas, the effects would be very dangerous in the biggest cities, (Ciudad Real-38°58'52"N/3°59'50"W and Puertollano-38°41'24"N/4°06'41"W) and have an impact on communications infrastructures: highways, high speed rail (AVE), airport and on industrial areas of danger, like the petrochemical complex in Puertollano.

1.1-P-15

Geomorphology of a Degassing Vent: La Sima. Campo de Calatrava Volcanic Region (Central Spain).

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The Campo de Calatrava Volcanic Region (CCVR) presents a lot of volcanic forms result of different eruptive vents: effusive and explosive (strombolians and hydromagmatics) expanded in the time. Recent works point at eruptions around 6500y. BP (Gonzalez et al. 2007 and 2008), for this reason CCVR has been considered as an active volcanic region. Actually, the degassing vents are very important with CO₂ emissions principally, presents in hot springs (*herveridos*) and "leaks" of gas like La Sima in the SE zone of this volcanic region. The aim of this work is to describe morphologically the degassing vent of La Sima, which origin is attributed to a phreatic type eruption, favoured by the existence of a fracture of 500 m and WNW-ESE direction, located in the SW flank of the Palaeozoic mountain of Valenzuela. This degassing vent is constituted by two craters that are surrounded by a great quantity of quartzite crushed materials result of the eruption, occupying a total surface of 280 m². The main crater presents a mean diameter of 8 m, a maximum depth of 4 m and an area of 55 m². The second crater, of minor morphologic relevancy, has a mean diameter of 6 m, 1 m of depth and 30 m² of surface. The gases emitted by this degassing vent are CO₂ (concentrations higher than 50%), H₂S (around 1 ppm), CH₄ and Radon (>75000 Bq/m³); very dangerous gasses for the alive beings of the environment because numerous wild animals die every year (birds, small mammals and reptiles) and even cattle (sheeps). Up to the date, no similar manifestations have been reported, linked to volcanic areas in the Iberian Peninsula, neither morphologically nor as for the dangerousness associ-

ated with the same ones. References: González et al. (2007); González et al. (2008).

1.1-P-16

Morphology of Lava Fountain Deposits in the Cinder Cone of La Cornudilla Volcano. Campo de Calatrava Volcanic Region (Central Spain).

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There are many volcanic forms described in Campo de Calatrava Volcanic Region (CCVR). Stand out especially landforms resultant of effusive events in which, lava fountains and spatter deposits played an important role in the moment of constructing the different volcanic forms. In this work, we study one of the best examples of volcanic constructions proved of these dynamics and these deposits at CCVR: La Cornudilla volcano. This volcano is located in the centre of Valenzuela-Granátula de Calatrava highland alignment in the suroriental sector of CCVR (Gonzalez, 1997). The aim of this paper is to characterize La Cornudilla volcano morphologically and to describe the deposits constructed, depending on two types of eruptions: Hawaiian and strombolian. The strombolian phases constructed a cinder cone with not agglutinated pyroclasts composed by lapilli, scorias of different sizes, and bombs with presence of interstratified lavas (result of low explosivity pulses). The culminating part of the volcanic edifice – crater rim – is constituted by consolidated and welded deposits associated with hawaiian type phases with presence of lava fountains. Agglutinated lapilli and scorias, bomb plasts and shreds, as well as clastogenetic lavas, typical of lava fountains (Sumner et al., 2000), compose these welded deposits (spatter). In addition, the latter effusive phases of lava fountains developed powerful lava flows, emphasizing the SW lava flow fed by a small lava lake that was formed inside the crater. The erosive processes have favoured the dismantlement of the not consolidated deposits in the cinder cone. The most consolidated and agglutinated deposits (spatter) in the crater rim, have turned out to be more resistant to the erosive agents. This resistance to the erosion can observe also in the SW lava flow that still preserves the original superficial morphology (pahoe-hoe). References: González, 1997; Sumner et al., 2000.

1.1-P-17

The Early Stages of Flank Collapse in Stratovolcanoes as Seen With Analogue Models

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The main structures developed in a stratovolcano during the early stages of flank collapse have been studied using analogue models. The experimental set-up represents a conic stratovolcano, where one flank slides on a viscous layer placed at the base of the edifice. This configuration reproduces the conditions governing the

collapses occurred at Socompa, Parinacota (Chile) and north Mombacho (Nicaragua), which involved a significant part of the volcano substrata. The scaled analogue models were studied using sequential photographs as well as longitudinal and transversal sections to constrain respectively the development of superficial and deep structures in the sliding flank.

The first structure developed in the models is a graben, which forms the amphitheatre limits, and the axis of which divides the sliding flank into a « *toreva domain* » (higher flank) and an « *avalanche domain* » (lower flank). Mainly extensional structures develop in the *toreva* domain, while extension, transtension and even transpression are observed in the *avalanche* domain. Listric faults form *toreva* blocks which stay mainly inside the amphitheatre. Conjugate-normal and transtensional faults form hummocks and ridges in the *avalanche* domain. During collapse, the lateral parts of the frontal *avalanche* domain overthrust the amphitheatre border before spreading laterally. At the end of collapse, the original stratigraphy of the volcano is preserved, though deformed, in the *avalanche* deposit. Most of the viscous basal layer is expelled from under the volcano and forms the base of the *avalanche* deposit. Measurements clearly show that all along the collapse, the *avalanche* domain holds a higher speed than the *toreva* domain. These models provide a new kinematic framework as well as a record of the structures and deformation field that would be expected for flank collapse at stratovolcanoes.

1.1-P-18

Clinker Formation in Basaltic and Trachybasaltic Lava Flows

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Clinker is a term used to describe massive or scoriaeous fragments commonly associated with 'a' flows. Clinker is generally considered to form by fragmentation of an upper vesiculated crust, due to an increase of apparent viscosity and/or to an increase in shear strain rate. Surface clinker is considered to be transported to the flow front and incorporated at the base by caterpillar motion. Clinker that we have observed on a variety of lava flows has very variable textures, which suggests several different mechanisms of formation. In order to study Clinker formation, we examined several lava flows from the Chaîne des Puys Central France, where good sections, surface morphology and surface textures are abundant. We observed basal and surface 'a' clinker that has fragmentation textures similar to those observed in ash formed under dry conditions. In two p hoehoe flows we have observed basal clinker that formed in-situ. Two other flows display clinker features identical to those commonly observed in phreatomagmatic ash, such as adhering particles, blocky shapes, spherical glass and attached microphenocrysts. Another p hoehoe flow has a flakey, angular basal breccia, with microfaulted and abraded clasts. These were probably formed at a cooled lava base by large amounts of simple shear and consequent intra-lava brittle faulting. Us-

ing these observations we propose three different ways of fragmentation. (1) clinker can form at the surface and eventually produce roll-over basal breccia. (2) Water/lava interactions can form basal clinker by phreatomagmatic fragmentation. Water/lava ratio variations may produce different clinker structures, in a manner similar to observed textural changes in phreatomagmatic eruptions. (3) Clinker can be formed by brittle brecciation during basal simple shear. The different clinker can provide information about the mechanisms and environmental conditions during lava flow emplacement.

1.1-P-19

Wet Peperite Formation at the Base of Lava Flows: Insights from the French Massif Central

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Peperite can be formed at the base of lava flows but is rarely described in the literature. Its occurrence can be used as evidence for lava – wet substrate interaction during flow emplacement. They are important to study as they provide important information on lava flow rheology, environmental conditions at the time of emplacement and insight to rootless cone development. Such peperite may also alter the hydrology of aquifers in lava flows.

We studied three peperite occurrences at the base of basanitic lava flows of the Limagne Province (French Massif Central), which were emplaced on wet marly sediments. The juvenile clasts in the peperite display globular shapes typical of the fluidal peperite type. A SEM study of peperites has revealed phreatomagmatism (i.e. interaction between lava and water) by the occurrence of drying fractures in marls, impact structures of lavic clast in marls and lavic spherical glass associated with onion-skin structures.

A model was proposed so to explain wet peperite formation at the base of lava flow: the lava flow will encounter water-logged sediments and will vaporized water as its base so to form a continued vapour film that will be subject to oscillations. By vibrating, this film will incorporate marls and globular lavic clast so to form a continued fluidized peperite layer at the flow base. Then, according a reverse density gradient with the occurrence of discontinuities at the flow base, this fluidized peperitic layer will "drill" the lava core as diapirs in the flow interior. If this drilling process allow peperite to reach the flow surface generation of rootless can be invoked but in a different way than propose in the literature.

1.1-P-20

Volcanoes of the World: a Four-Decades Perspective on Earth's Quaternary Volcanoes by the Smithsonian's Global Volcanism Program

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Four decades' perspective on Earth's volcanoes and their eruptions will be published this year in the 3rd edition of the Smithsonian Institution's *Volcanoes of the World*. From its 1968 roots acquiring information on current volcanic events on 3 x 5 postal cards and subsequent expansion using the IAVCEI regional volcano catalogs, the Global Volcanism Program's (GVP) Volcano Reference File (VRF) has become an internationally utilized resource. This 3rd edition contains data on nearly 1550 volcanoes of known or possible Holocene age, including chronologies, characteristics, and magnitudes for >10,400 Holocene eruptions. It is supplemented by summaries of dominant lithologies at each volcano, along with data on population living within 5, 10, 30, and 100 km radii of each volcano or volcanic field. Population data indicate that the most populated regions also contain the most frequently active volcanoes. Eruption data document lava and tephra volumes and Volcanic Explosivity Index (VEI) assignments for >7800 eruptions. Interpretation of VRF data has led to documentation of global eruption rates and the power law relationship between magnitude and frequency of volcanic eruptions. Data with volcanic hazards implications include those on fatalities and evacuations and the rate at which eruptions reach their climax. In recognition of the hazards implications of potential resumption of activity at pre-Holocene volcanoes, the 3rd edition includes preliminary lists of Pleistocene volcanoes and large-volume Pleistocene eruptions, the latter in collaboration with the VOGRIIPA project of Steve Sparks and colleagues. The GVP volcano and eruption data derive both from the retrospective perspective of the volcanological and other literature and documentation of contemporary eruptions and volcanic unrest in its monthly bulletin and Weekly Volcanic Activity Reports compiled since 2000 in collaboration with the USGS. Much of these data are available on the GVP website. (www.volcano.si.edu<<http://www.volcano.si.edu>>) and on a volcano layer on Google Earth.

1.1-P-21

Highlights on the Dynamics, Structures and Volcanic History of Ischia Island (Italy) for a Conceptual Model of Shallow Magma Feeding System

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A comprehensive conceptual model of shallow magmatic system which fed volcanic activity of Ischia island in the last 55 Ka is proposed, taking into account the available geological and geophysical data. In this model a shallow magma intrusion (laccolith), emplaced after a large ignimbritic eruption (Mt. Epomeo Green Tuff, 55 ka BP), has produced 800 meters of uplift of the island central part (the block of Mt. Epomeo), volcanic and seismic activity and gravitational instability of the uplifted block. The dimensions and volume of laccolith as well as the strain rate exerted on the uplifted overburden are in well agreement with the main tectonic

and volcanological features of the island. Starting from the assumption of the shallow magma feeding model, we also analyse the geological and geophysical data, in order to obtain a comprehensive picture of the possible processes controlling volcanic eruptions and seismicity occurrence in the island.

1.1-P-22

Eruptive vs. Non-Eruptive Behaviour of Large Calderas: The Example of Campi Flegrei Caldera (Southern Italy)

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Caldera eruptions represent one of the most hazardous natural phenomena. Many calderas in the world are still active and characterized by recurrent uplift and subsidence periods due to their magma reservoirs dynamic. These unrest periods are, in some cases, accompanied by eruptions. At Campi Flegrei caldera (CFc), an area characterised by very high volcanic risk, the recurrence of this behaviour has stimulated the study of the rocks rheology around the magma chamber in order to estimate the likelihood of an eruption. This paper considers different scenarios of the shallow crust behaviour, taking into account earlier models of CFc ground deformations, caldera eruptions and recent geophysical investigation of the area. A semi-quantitative evaluation of different factors producing magma storage or its eruption (such as magma chamber size, wall rocks viscosity, temperature, and regional tectonic strain rate) is reported for elastic and viscoelastic condition. Considering the large magmatic sources of CFc ignimbrites eruptions (400km³-2000km³), and a wall rocks viscosity between 10¹⁸-10²⁰ Pa sec, the conditions for eruptive failure are difficult to be attained. Smaller source dimension (few cubic kilometres) promotes the condition for fracture (eruption) rather than flow of wall rocks. We also analyse the influence of the regional extensional stress regime on the magma storage or eruption and the thermal stress as possible source of the caldera uplift. The present paper also emphasizes the difficulty to discern the possibility for eruption or non-eruption at CFc, since an unambiguous model which takes into account of rocks rheology, magma source dimension and location and regional stress field influence, is still lacking.

1.1-P-23

Methodical Approach to Define Morphometric Parameters of Scoria Cones Using Digital Elevation Models

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The morphometrical parameterization is widely used to

quantitatively characterize the most common landforms, such as scoria cones, on the Earth. The original purpose of the morphological examinations is to perform relative dating. On the one hand, relative dating method is cheap and fast way to estimate the age of the volcanic edifices on the basis of their morphometrical state of the cone. On the other hand, this method does not give numerical age and precision will be worse on older cones. Traditional parameterization of the scoria cone was primarily measured manually from topographic maps. This approach is quite subjective and may contain errors. Here we give an overview of the possibilities of parameter estimation in fully digitalized environment. The morphometric parameters were derived from contour line interpolated Digital Elevation Model (DEM). The generated DEM can be subdivided into two main parts: (1) outer and (2) crater slopes. We carried out statistical calculations on outer slopes DEM including maximum/minimum and average cone height and maximum and mean slope angle. The inner slopes, we measured only the depth of the crater. The volcanic edifice elongation, both of the cone base and the crater, were obtained by ArcGIS. We generated the outline points of the crater and the cone, likewise the crater and the cone centre point. Therefore, we could calculate the cone and crater width on the basis of correlation between the geometrical centre point of the edifice and the outline points. Furthermore, other important morphometric parameters are the area and volume of the cone, which also calculated from the DEM. The newly developed digital parameterization method was tested on study areas including eroded cone (Agár-tető, Bakony–Balaton Highland VF, Hungary), fresh (Volcan de Güímar Pedro Gil VF, Tenerife, Spain) and multiple scoria cone (Montaña Chío, Teide-Pico Viejo, VF, Tenerife, Spain).

1.1-P-24

Breaching of Degradated Scoria Cone of Western Hungary: Syn- or Post-Eruptive Origin?

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The studied scoria cones are older (from 3.8 to 2.5 Ma), variously eroded and mainly located at the Bakony–Balaton Highland Volcanic Field, and few at the Little Plain Volcanic Field. Both volcanic fields are small in volcano numbers (<50) as well as in area (3500 km²). Both volcanic fields are inferred to be time-predicted, tectonically controlled, alkali basaltic with low-magma output rates. The numbers of scoria cones are about 15. Half of them are deeply to moderately degraded, but breaching is still identifiable. Here, we focus on the possible origin of the existing scoria cone breachings (syn- or post-eruptive). Generally, the regional stress field and fault systems at the volcanic field are commonly identified and localized on the basis of breaching azimuths and cone spacing/alignment. However, in the case of older scoria cone remnants breaching azimuths may be changed due to erosional processes (e.g. land

slides). In conclusion, we recognized that based on field evidences and morphometry of the studied cones, it is inferred that syn-eruptive breaching can be interpreted as the result of (1) deflection of ash by wind drift and/or tectonic influence on the shape of scoria cones (N and NW; ~325–10°), (2) truncation caused by the lateral migration of explosion loci during the emplacement of the volcanic cone (S; ~180°), (3) slope failure triggered by lava intrusion into the weakest side of the cone (NE; ~40–60°), (4) post-eruptive breaching event can be recognized only 1 cone (Kopácsi-hegy). As a consequence of this, the syn-eruptive conditions, such as eruption style, tectonics, are commonly influenced the shape of older cones as well. In the case of group 1 cones the nature of the breaching is doubtful because direction of local fault system and the estimated paleo-wind direction is the same (mainly NW–SE).

1.1-P-25

Morphometrical Differences of Scoria Cones Between Two Intracontinental, Platform-Type Volcanic Fields (Bakony–Balaton Highland Volcanic Field, Hungary and San Francisco Volcanic Field, Arizona)

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The morphometric studies of the volcanic edifices are enabled by the availability of various, high and medium resolution DTMs and DEMs. In our approach we focus on the evaluation of classic morphometric parameters, like cone width (W_{co}), height (H_{co}) and average slope angle (S_{ave}) with the aim of comparing the scoria cones of Bakony–Balaton Highland volcanic field (Pannonian Basin, Hungary – BBHVF) and San Francisco volcanic field (Arizona, USA – SFVF). BBHVF is a small-size, typical continental, basaltic volcanic field with around 50 individual erosional remnant of maar/tuff ring volcanoes, scoria cones and lava flows. Only 14 scoria cones have been recognized during the last few decades. The scoria cone-building eruption mostly took place during the late Pliocene and early Pleistocene (from 3.8 up to 2.5 Ma). The present erosional landforms are built up mostly from resistant, partly to densely welded scoriaeous breccias.

SFVF is larger than BBHVF in size and the number of erosion remnants of scoria cones (around few hundreds). It is a traditional study area for morphometric studies. The activity of SFVF began at 6 Ma ago, and climatic conditions also differ considerable from that of the BBHVF. The aim of this study is to understand regional differences in scoria cone morphometry between these of BBHVF and SFVF. We measured cone parameters from contour maps and aerial photos as well as various digital models. The two datasets gained have shown relatively large discrepancy between W_{co} (SFVF= 1350 m and BBHVF= 870 m) and H_{co} parameters (SFVF= 87 m and BBHVF= 40 m). In the case of S_{ave} , both of

the examined intracontinental type volcanic fields are shown almost the same value around 8°. We concluded that the morphometrical differences among scoria cones with similar age may be derived from mechanism of cone forming eruptions and/or erosional settings.

1.1-P-26

Flank Eruptions in the Periphery of Etna Volcano: Mt Barca and Mt Moio Scoria Cones

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Stratigraphic investigations at Etna volcano have revealed that the explosive activity related to flank eruptions can be complex and variable, forming medial-distal tephra deposits similar to those of the 2001 and 2002-03 eruptions. To this aim we focused on the study of two flank eruptions that formed the large Mt Barca and Mt Moio scoria cones located in peripheral and populated areas of the volcano at 15 km (west flank) and 18 km (north flank) far from the summit, respectively.

Recent geological surveys, tephrostratigraphic study and 40Ar/39Ar age determinations have allowed to characterize these eruptions and constrain their occurrence during the Ellittico volcano activity about 29 ka ago and not during the Mongibello volcano activity (last 15 ka) as previously inferred.

Mt Barca eruption was characterized by a strong explosive activity that produced pyroclastic deposits dispersed eastward and minor effusive activity with the emission of a 1.1 km-long lava flow. Explosive activity was characterized by a phreatomagmatic phase followed by a magmatic one. Similarly, Mt Moio produced vigorous explosive activity that formed pyroclastic fall deposits and minor effusive activity. In both cases, the wide dispersal area of tephra fallout suggests more energetic and sustained eruptions column than those generally expected by a Strombolian-type eruption of a small-volume cone, formed mainly by ballistic emplacement of clasts.

The eruptive fissure trend of Mt Barca and Mt Moio flank eruptions corresponds to that of the extensional neotectonic lineaments of the Apenninic-Maghrebian Chain evidencing a control by the structural setting of the basement on volatile-rich magma ascent from the deeper part of the plumbing system during the Ellittico volcano activity.

The possible occurrence of highly explosive flank eruption at low elevation in densely inhabited areas, increases the volcanic risk in the Etnean region and widens the already known hazard scenario.

1.1-P-27

Magmatic vs. Hydromagmatic Fragmentation and its Bearing on the Origin of Widely Dispersed Ash Deposits.

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Hydromagmatism is often invoked uncritically to explain the origin of widely dispersed, ash-rich deposits, when alternative fragmentation mechanisms are unknown: for example, “wet” phreatoplinian vs. “dry” plinian eruptive scenarios are inferred essentially from deposit characteristics (dispersal-grain size relationships, abundance of accretionary lapilli, etc.), although efficient explosive interaction of high-flux, highly viscous, silicic magmas with external water is uncertain and poorly supported by theoretical and experimental work. Moreover, well established criteria to assess the hydromagmatic vs. magmatic signature of pyroclastic deposits mostly apply to mafic eruptions. Here we report two examples from the Quaternary Vulsini Volcanic District (Roman Province), in which the fine-grained nature of deposits even in near-vent settings indicates negligible sorting by transport, implying the eruption of highly fragmented magmas. The Sovana example records contrasting degrees of fragmentation of a phonolitic magma: i.e., unusually high degree of fragmentation leading to the emplacement of widespread ash from a dilute, turbulent pyroclastic current at the eruption onset, followed abruptly by “conventional”, coarse pumice- and lithic-rich pyroclastic flows. The Grotte di Castro example includes early strombolian and subplinian phases, respectively fed by shoshonitic and phonolitic magma batches, followed by widespread ash-rich, accretionary-lapilli-bearing surges, pointing out remarkably increasing fragmentation and explosivity of the shoshonitic magma. In both cases, in spite of ambiguous field appearance, the lithic-poor nature of deposits and SEM-microtextural characteristics of juvenile ash (vesicularity patterns, particle morphoscopy) rule out magma-aquifer explosive interaction. We discuss alternative interpretations to explain changing degrees of fragmentation and explosivity within dominantly magmatic eruptive scenarios, including: high amount/rate of decompression with possible volcano-tectonic trigger; mixing of compositionally different magmas; explosive interaction with surficial water of a gas-pyroclast mixture erupted through an intra-caldera lake. In this regard, we show preliminary quantitative analysis of bubble parameters (BSD, BND) as trail marker of decompression history in the feeder system.

1.1-P-28

An Integrated Geophysical Approach for a Better Understanding of Strombolian Activity at Yasur Volcano, Vanuatu

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In late 2008 we carried out a two-week multi-parameter measurement on Yasur volcano, Vanuatu to gain new

insights into the mechanism of Strombolian eruptions by simultaneously recording a wide range of different data types. The measurement was mainly designed to map conduit and explosion processes, such as the development and rise of gas slugs up to their final explosion. We employed four seismic arrays around the volcano each consisting of one broadband and three short-period sensors in order to monitor the possible occurrence of LP signals occurring before an explosion, as well as to record high frequency transients related to the explosion sequence itself. To get a measure of the general surface activity, and to analyse the explosion sequence in greater detail we installed two Doppler radars and one infrared camera at the crater rim. In order to investigate the exit conditions, we recorded atmospheric pressure signals associated with the explosions by deploying four infrasonic arrays and one broadband infrasound sensor on and around the volcano. At the time of our experiment the activity of the volcano was at relatively high level with sometimes several events per minute, and the recorded radar data reveal that one of both craters was clearly more active. The surface observations of this crater expose a change in activity regime from almost ash free explosions dominated by ballistic clasts to explosions showing a very large ash load or even only consisting in ash emissions. On our poster we present some first data examples recorded during these two different activity regimes, and a preliminary combined analysis of two selected data sets consisting each of radar, infrared, infrasound and seismic data.

1.1-P-29

Explaining the Plinian-phreatoplinian Shift during the 1875 Askja Volcano Eruption by Coupling Geological and Numerical Techniques.

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During the 1874-76 a large volcano-tectonic episode took place on the North Iceland rift zone and the 1875 eruption of Askja is part of it. This is one of the few eruptions showing both phreatoplinian and Plinian styles and the only well documented by eye witnesses. The eruption began the 28th of March with a subplinian event (phase B) and continued on the 29th with a phreatoplinian phase (phase C1, 1 hour). This phase included the emplacement of dilute density currents (phase C2, 2 hours) which became dryer with time. At 7 am the Plinian phase D commenced and lasted for about 5-6 hours. The vent position migrated throughout the eruption. Aside from a small pond, no standing water was present. therefore the source of external water driving the phreatoplinian phase is uncertain. We have undertaken a study to test if groundwater residing in the lava pile that fills the main Askja caldera could have been the provider of the external water involved in the phreatop-

linian phase. The key questions are; (a) Does the intra-caldera groundwater reservoir hold enough water and (b) can the water be transported fast enough to the vent site (i.e. upper part of the conduit). A discrete fracture modelling technique is used to compute the corresponding permeability and porosity. A 3D digital model of the Askja caldera that represents the pre-eruptive topography and hydrostratigraphy has been reconstructed. The calculated porosities and permeabilities provide factual data as model input parameters. Results show that the eruption resulted in ultra-fast radial flow of groundwater towards the conduit and provides sufficient water flux to drive the phreatoplinian phase of the 28-29 March Askja eruption. Furthermore, the model also produces rapid draw-down of the intra-caldera groundwater which explains the drying-out of the phreatoplinian phase depicted by the dilute density current deposits.

1.1-P-30

Melilite-Group Minerals at Oldoinyo Lengai, Tanzania.

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Detailed fieldwork at the active carbonatite-nephelinite-phonolite volcano Oldoinyo Lengai and the volcanic centres around shows melilite as a widespread mineral in silicate lavas of the province. Extraordinary Na-Al-rich melilite (> 6 wt.% Na₂O; > 9 wt.% Al₂O₃) from recent explosive eruptions range among the most Na-rich ever reported. Their unusual mineral chemistry leads to optical properties with vivid birefringence colours of 2nd order. The continuous variation in mineral chemistry from common åkermanite to Na-Al-melilite (*alumoåkermanite*) is documented in detail in this paper and reflects the whole peralkaline trend of Oldoinyo Lengai. The data presented allow the volcano's evolution from primitive olivine melilitites to highly evolved and peralkaline combeite-wollastonite nephelinites to be traced. Melilite compositions of Oldoinyo Lengai extend the magmatic field in the Ca₂Fe(Si₂O₇) - Ca₂Mg(Si₂O₇) - (CaNa)Al(Si₂O₇) endmember triangle. In this context, for Al-rich melilite compositions the new mineral named *alumoåkermanite* was approved by the Commission on New Minerals and Mineral Names of the International Mineralogical Association. The average chemical formula of the mineral derived from electron microprobe analyses is (Ca_{1.48}Na_{0.50}Sr_{0.02}K_{0.01})_{S2.01}(Al_{0.44}Mg_{0.30}Fe²⁺_{0.17}Fe³⁺_{0.07}Mn_{0.01})_{S0.99}(Si_{1.99}Al_{0.01}O₇). The name reflects the chemical composition of the mineral.

1.1-P-31

Keeping an Eye beneath the Sea: Knowledge of Volcanic Islands through Case Studies from Italian Seas

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The exposed portions of volcanic islands represent the emergent tip of the overall volcano structure, which largely lies below sea level. Over the last decade, marine investigations through swath bathymetry, long-range-side scan sonar, seismic, and seafloor sampling were carried out on several Italian volcanic islands (i.e. Stromboli, Ischia, Pantelleria, and Pontine Archipelago). They revealed several previously unknown constructive and destructive features, which constitute key insights for volcano-tectonic studies and geo-hazard assessment.

For instance, offshore Pantelleria edifice, the morphological differences between the well-preserved eruptive cones identified on the NW sector (including the latest 1891 eruption) compared to the more degraded morphologies of the SE sector corroborate the north-westward migration of the activity over time. At Western Pontine Archipelago, marine data allowed for significant renewal of the general volcanological setting in terms of areal distribution, ages, and compositional relationships among the different magmatic events which occurred during Pleistocene and Pliocene time.

Regarding destructive features, a large spectrum of mass-wasting, across different scales and frequencies, has been recognized all along the volcanic edifices. Medium scale landslide and gravity flows are more common (in time and space) than sector collapses that produced debris avalanche deposits recognized only at Stromboli and Ischia edifices. Despite their relatively smaller size with respect to their oceanic counterparts, the debris avalanches can be very hazardous for coastal communities and facilities, also because of their tsunamigenic potential. Small to medium-scale submarine slides (e.g., Stromboli 2002 landslide) can be more hazardous, as they are widespread, occur at much higher frequency than sector collapses, and often evolve upslope affecting coastal infrastructures and can generate tsunamis as well.

The achieved results represent an important step towards the complete understanding of volcano-tectonic history of insular volcanoes as well as the refinement of interpretative models for submarine volcanic activity.

1.1-P-32

A Study on Litho-geochemistry of Volcanic Rocks and the Hosted Melt Inclusions in Wudalianchi Heilongjiang, China

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The Wudalianchi volcanic clusters are famous Quaternary volcanoes with fairly good volcanic landscape in the northeast of China. The volcanic rocks are phonotephrite, tephri-phonolite, trachyandesite and basaltic trachyandesite with SiO₂ contents of 47.3 ~ 54.2 wt.%. The characteristic of high K₂O content in Wudalianchi volcanic rocks suggests that they probably share a common potassic magma source. The magma evolutions of Wudalianchi volcanic rocks are similar, while the new eruption products of Laohei and Huoshao volcanoes are slightly more evolved than the old eruption materials, i.e. the magma of the new eruptions in 1719 ~ 1721 from the above two volcanoes is the evolved magma in underground chamber. The main phenocrysts of Wudalianchi volcanic rocks are olivines, clinopyroxenes and some characteristic K-rich leucites. The various shaped melt inclusions are found in olivine phenocrysts from new eruption products of Laohei and Huoshao volcanoes. By electron microprobe analyzing, the contents of SiO₂ and total alkali show a wide range, suggesting the pre-eruptive magma was probably more complicated or the melt inclusions were rather unhomogeneous. On the basis of EMP results, it is believed that the sulfur degassing rate from this new eruption was far more than that of the millennium eruption of Tianchi volcano, while the chlorine degassing rate was a magnitude lower than that of Tianchi volcano.

1.1-P-33

Effects of Vertical and Lateral Gas Escapes on Volatile Compositions, Magma Porosity and Pressure in Volcanic Conduits during Dome-forming Eruptions

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We systematically investigated the effects of vertical and lateral gas escapes on the distributions of volatile compositions, magma porosity and pressure inside the conduit during dome-forming eruptions on the basis of a 1-D steady conduit flow model. The relative importance of the two gas escapes is expressed by a non-dimensional number E_w that is defined as the ratio of the effects of the lateral gas escape to the vertical gas escape. This parameter controls the partitioning of volatile components between gas and melt, and hence, the compositional variation of gas phase and volatile component during magma ascent; the type of the compositional variation gradually changes from the batch fractionation to Rayleigh fractionation as E_w increases from 0 to 1. The distributions of E_w (i.e., the volatile compositions), the magma porosity and the pressure inside the conduit depend on the permeability of vertical gas escape (k_v) and that of lateral gas escape (k_w). Our results show that the characteristics of the distributions and their dependencies on k_v and k_w critically change depending on the dynamics of conduit flow: namely, on the non-dimensional parameter that represents the ratio of the effects of gravitational load to liquid-gas interaction force, B . When the effect of gravitational load exceeds that of liquid-gas interaction force (i.e., $B > 1$), the porosity is kept low and the pressure distribution

is close to lithostatic throughout the conduit regardless of k_w . In this regime, E_w is proportional to k_w and is inversely proportional to k_v . On the other hand, when $B < 1$, the porosity increases from 0 to 0.8 and the pressure becomes larger than the lithostatic pressure with decreasing k_w , which leads to a high-overpressure region at a shallow level in the conduit. In this regime, E_w is approximately proportional to k_w , whereas it is independent of k_v .

1.1-P-34

The Mineralogical And Petrological Characteristics Of Garnet Bearing Rhyolitic Lavas, South Of Ýzmir, Western Anatolia-Turkey And Their Comparison With Chios Island (Greece) Rhyolites

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The volcanic rocks of Görece-Ýzmir are identified as rhyolitic lavas due to their mineralogical and textural characteristics and geochemical data. They contain phenocrysts of quartz, sanidine, albite, biotite and opaque minerals which reach up to 2 mm in sizes. The matrix of lavas are composed of microliths, spherulites, lithophysae and volcanic glasses. Vitreous, trapezoidal garnets occur up to 1.5 cm diameters in some lithophysae as euhedral to subhedral crystals and are brown at cores and black at rims. In addition to vesicular textures and lithophysae assemblages observed by naked eye, axiolic structures, spherical and fan shaped spherulites, lithophysae with fibric and concentric hollows and microcrystalline lithophysae with half moon type lateral voids are determined during microscopic studies. According to Raman Confocal spectroscopic and EPMA analyses carried out at laboratories in Turkey, Switzerland, the USA and Canada, garnets are homogeneous in Fe and Mn concentrations from core to rim exhibiting spessartine-almandine compositions (51.0 and 46.6 mol percent, respectively). Quartz, cristobalite and hematite inclusions are found in garnets. The above mentioned characteristics and field observations of garnets can point out that they should form during cooling of lava, escaping vapour produced lithophysae lined with garnet. According to geochemical data, the rhyolites have high K calcalkaline character and they show extreme depletion in Sr and Ba and enrichments in Nb, Rb, Zr, Y, La, Ce and Nd. Some trace elements such as Cs, Be and Sn are slightly higher in rhyolites. Due to petrological data, it can be postulated that the Görece rhyolites should have been derived from mantle-crust interaction and contaminated by middle or upper crust. The rhyolites of Profitis Ilias, SE of Chios Island (Greece) contain primary almandine and spessartine rich garnets and zinnwaldite phenocrysts. The Görece rhyolites display some similarities when compared with mineralogical and petrological features of Chios rhyolites.

1.1-P-35

The Quaternary Volcanism and Tectonic History in the Suwa-Yatsugatake Volcanic Province, Central Japan

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Beneath Central Japan where three arcs meet, the Pacific plate and Philippine Sea plate are both subducting, resulting in a complex tectonic history. We conducted a chronological study of the Suwa-Yatsugatake Volcanic Province (SYVP) with the aim of elucidating temporal and spatial changes in the tectonic and volcanic activity in Central Japan. The SYVP consists of five volcano groups (Circum-Lake Suwa volcanoes, Utsukushigahara volcanoes, Kirigamine volcanoes, Yabashira volcanoes and Yatsugatake volcanoes). It is characterized by an enormous amount of volcanic activity, with lava flows and volcanoclastic rocks spread over a vast area of more than 1,200 km³ and total eruption volume exceeding 400 km³. We determined K-Ar ages of 41 samples and examined the results together with radiogenic ages previously reported. As a result, we concluded that the volcanic activity has been occurring intermittently since ca. 2.2 Ma.

The volcanic activity in the SYVP was classified into three phases, based on clear dormant periods. Especially, the greatest eruption volume and level of activity was

1.1-P-36

New evidences on mercury emissions from Earth volcanism

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In recent years, there has been increasing environmental concern on the potential impact of volcanogenic mercury, owing to the high toxicity and long residence times of this element in the Earth's ecosystems. In order to extend the currently limited dataset on volcanogenic mercury emissions to the atmosphere, we summarize the work done on deriving of mercury emissions from a set of active open-conduit volcanoes (Stromboli, Asama, Myakejima, Montserrat, Ambrym, Yasur, and Nyiragongo). Our data suggest that volcanic emissions represent an important component of the global atmospheric Hg budget, even if all data refer to quiescent phases of the volcanic activity. Anyway, our original results allow some inferences to be made on the "quality" of previous es-

timates of global volcanic Hg inventories. The acquired data from 7 volcanoes allowed us to derive a global volcanic Hg flux from “persistent degassing” of $\sim 95 \text{ t}\cdot\text{yr}^{-1}$ (still in the $6\text{--}900 \text{ t}\cdot\text{yr}^{-1}$ range of Pyle and Mather’s 2003 estimate). Besides, their cumulative emissions would represent about 55% of mercury being yearly contributed by passively degassing volcanoes at global scale ($75 \text{ t}\cdot\text{yr}^{-1}$), suggesting that published inventories are potentially underestimating global Hg budgets from volcanic degassing. Our range of the bulk plume GEM/SO₂ mass ratios is in fair agreement with previous estimates of passive emissions from all non-erupting volcanoes ($3.7\cdot 10^{-6}$), and falls within the best estimated range (10^{-4} to 10^{-6}) previously proposed for non-explosive volcanic plumes. It is likely that the volcanic contribution of Hg to the stratosphere will be even more important during *large eruptive* events, suggesting that the long-term time-averaged Hg emission rate from these volcanoes may become even higher would the eruptive contribution be taken into account.

1.1-P-37

Holocene Explosive Eruptions in the Rungwe Volcanic Province, Tanzania

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The fundamental principle of volcanic hazard assessment on any volcano is the detailed documentation of its eruptive history. Although the presence of extensive superficial pumice deposits has long been known in the Rungwe Volcanic Province (RVP, SW Tanzania, East African Rift), the recent eruptive history had never been studied in detail before. The two main RVP volcanoes, Rungwe and Ngozi, display deposits of several explosive eruptions in their recent history. Field observations of tephra deposits were combined with whole-rock major (ICP-OES) and trace (ICP-MS) element analyses to correlate deposits. ¹⁴C ages on palaeosols constrain all recognized deposits to <10 ka. Trace element data, e.g. Zr/Y ratios, allow discriminating between Ngozi and Rungwe volcanoes as source of the deposits. All studied samples are trachyte to phonolitic trachyte.

We show evidence of two large-scale Ngozi eruptions and five Rungwe pumice fallout deposits, and also identify several more intercalated poorly preserved pumice and ash deposits. The Ngozi eruptions (1 plinian fallout at ca. 10 ka and 1 ignimbrite-forming eruption less than 1 ka ago) possibly played a role in shaping the present-day caldera. The Rungwe record includes a ca. 2.5 km³ deposit of a Plinian-style eruption dated at ca. 4 ka (Rungwe Pumice), a sub-Plinian one at ca. 2 ka and at least three additional smaller-scale fallout deposits.

The stratigraphic record shows that both Ngozi and Rungwe volcanoes experienced several moderate to large explosive eruptions, including eruptions generating pyroclastic flows, in their recent past. The late Holocene record is characterized by 1 Rungwe eruption

every 500 – 1000 years. A plinian eruption similar to the Rungwe Pumice one would cover the poorly constructed houses of ca. 185,000 people with more than 25 cm of tephra. This study highlights the need for monitoring the RVP volcanoes.

1.1-P-38

Magnetic Petrology of Clastogenic Lava of Izu-Oshima Volcano, Japan

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Izu-Oshima Volcano is one of the most active volcanoes in Japan. During the last fatal eruption in 1986, basaltic-andesite and andesite lavas were erupted from the fissures opened at and around the summit crater and various types of lava flows were formed from fire fountain. Large amount of clastogenic lava (B Lava) was produced at the peak of the eruption, while continuous coherent lavas were overspilled from the crater, resulting usual aa lava (C Lava). In order to clarify the eruption processes and physical conditions of the 1986 activity and to characterize each type of lavas, we have carried out magnetic petrologic analyses on the lava samples. As a result, we found each lava showed distinct magnetic petrologic characteristics. Rock magnetic results of C Lava were simply explained by different grain size distributions due to different cooling rate of each sample. Difference in grain size was also observed under microscope. Although most completely coalesced lava samples suffered oxyexsolution, produced titanohematite, the other parts of lava contained titanomagnetite only. It was suggested that all lavas were cooled rapidly from high temperatures above 800 degrees C. B Lava had most unusual demagnetization curves of artificial remanences, indicating the intense bimodality of coercivity. Microscopic observation revealed that samples which showed bimodal coercivity distributions contained small dendritic titanomagnetite. Its skeletal shape may cause high coercivity, resulting intense bimodality of coercivity. Dendrite was preserved in lava samples with high cooling rate. Titanomagnetite in the samples with low cooling rate had polyhedral or granular shape. This difference was probably produced at the fountain and the spatter cone, depending on difference of cooling rate and the degree of undercooling. Dendritic magnetic minerals and their distinct magnetic characteristics may be helpful to identifying varying volcanic materials produced from fountain-fed eruption.

1.1-P-39

Permeability of Alkaline Magmas: a Study from Campi Flegrei

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Knowledge of permeability is of paramount importance for understanding the evolution of magma degassing during pre-, syn- and post-eruptive volcanic processes. Most permeability estimates existing to date refer to magmas of calc-alkaline compositions. We report here the preliminary results of permeability measurements performed on alkali-trachyte products erupted from the Campanian Ignimbrite (CI) and Monte Nuovo (MTN), two explosive eruptions from Campi Flegrei (CF), an active, hazardous caldera west of Naples, Southern Italy. Darcian permeability spans a wide range between 10^{-11} and 10^{-14} m². We observe that the most permeable samples are the scoria clasts from the upper units of MTN; pumice samples from the Breccia Museo facies of CI are instead the least permeable. Inertial permeability follows the same trend as Darcian permeability. The first implication of this study is that porosity in alkaline as well as calc-alkaline magmas does not exert a first order control on permeability (e.g. the MTN samples are the most permeable but not the most porous). Second, sample geometry exhibits permeability anisotropy (higher permeability in the direction of vesicle elongation), suggesting stronger degassing in the vertical direction in the conduit. In addition, inertial effects are higher across the sample. As inertial effects are potentially generated by tortuosity (or tortuous vesicle paths), tortuosity is likely higher horizontally than vertically in the conduit. Finally, the measured CF permeability values overlap with those of rhyolitic pumice clasts from the Kos Plateau Tuff (Bouvet de Maisonneuve et al. 2008), together with CI one of the major Quaternary explosive eruptions of the Mediterranean region. This indicates that gas flow is strongly controlled by the geometry of the porous media and not by composition and suggests it will depend on the latter only when there is a difference in the vesiculation process or in the rheological properties of the magma.

1.1-P-40

Sub-horizontal Subduction in Western Argentina, between 29°S and 34°S, as viewed from a Local Seismic Network

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A local seismic network, operating in western Argentina from 28°S to 33°S, between August 1995 and January 1999, recorded more than 450 earthquakes. We analysed this seismicity in order to study the seismotectonic characteristics of the flat-slab zone segment of the Nazca plate. To achieve reliable hypocenter locations we select only the events that have an azimuthal gap of less than 180° and at least 9 P-observation. Therefore we applied, to a reduced data set of 128 events, the

concept of minimum 1D model, which incorporates iterative simultaneous inversion of velocity and hypocenter parameters. The minimum 1D model is complemented by station corrections which are influenced by near surface velocity heterogeneity and by the individual station elevations. To verify the robustness of our earthquakes location results stability tests on the selected events were performed. All tests reveal fairly stable hypocentre determination for the selected events. The final relocated seismicity indicates that the subducted Nazca plate is subhorizontal at depths of around 100 km. The seismicity also shows that the seismogenic zone of the downgoing oceanic lithosphere has a thickness of about 30 km.

1.1-P-41

Was the 1991 Eruption of Hudson Volcano, Chile, a Phreatoplinian Event? Evidence for Magma-Water Interaction.

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The 1991 eruption of Hudson volcano in southern Chile was one of the largest explosive eruptions of the twentieth century. Fallout of volcanic ash from this event occurred over an extensive area to the north and east of Hudson and extended across Argentina to the Atlantic Ocean. The deposit from the paroxysmal phase (phase II, August 12-15) is highly stratified with multiple layers of alternating fine ash and coarse pumice lapilli. The coarser grained units are likely related to eruptive pulses associated with well developed plinian columns. The eruption, which occurred through a thick glacier that fills the summit caldera, may be one of the few phreatoplinian events of modern times. A detailed investigation of juvenile particles from a high-resolution section of the deposit has been conducted to assess the possibility of arrested degassing during the event and identify evidence for magma-water interaction.

A detailed SEM analysis of juvenile material has revealed blocky and equant clasts with step features and adhered particles indicative of magma-water interactions. These features, combined with a lack of hydration cracks, suggest a relatively 'dry' interaction, with no excess water present in the conduit. Matrix glass H₂O contents (0.1-1.2 wt%) and the percent of blocky versus highly-vesicular shards appear to co-vary within the fall deposit stratigraphy. This may reflect changes in the amount of glacial melt water involved in the fragmentation process. However, highly vesicular, volatile-rich particles are present throughout the stratigraphy and suggests that both hydromagmatic and primary degassing processes were operating contemporaneously to varying degrees during the course of the eruption.

1.1-P-42

Effects Of Eruptive And Seismic Activities On Mt. Etna Flank Instability

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Here we address the effects of magma dynamics and seismic activity on Mt. Etna flank instability, in the light of results from 2D stress-strain finite-difference-method numerical models. The response of eastward gravitational deformations of the eastern volcano flank to internal (i.e., pre- and syn-eruptive inner pressure variations) and external (i.e., local and far-field earthquakes) triggers is modelled by considering rock-mass heterogeneities in the volcanic edifice, magma properties and ongoing volcano-tectonic deformations. Concerning internal triggers, we illustrate three cases: 1) the role of vertical migration of overpressured magma batches in promoting Mt. Etna volcano edifice deformations, considering the 1991-93 eruptive scenario: i.e. shallow, low-angle dyke propagation that preceded the major effusive phase fed by an eruptive fissure along the SE volcano slope; 2) flank deformations induced by a magma batch uprising buoyantly below the summit craters, documented to be occurred over the last decades of Mt. Etna activity; 3) the effects of conduit pressure variations accompanying steady-state flow of magma-gas mixtures through the eruptive feeder system during 1998 to present lava fountain activity from the South-East Crater. In addition, dynamic inputs of seismic triggers were applied to force the model by taking into account the local attenuation law, considering: 1) local seismic events (i.e., long-period events recorded by the Italian accelerometric network, RAN, and by temporary broadband seismometric stations, owned by INGV); 2) $M > 7$ earthquakes felt in far-field conditions (i.e., Greek earthquakes recorded by the RAN), and 3) the maximum expected earthquake for north-eastern Sicily (derived according to a spectral-equivalent approach). Preliminary results show how the transient migration of overpressured magma batches, as well as local seismic activity, may produce strain fields associated to significant displacements of the Etna eastern flank, in good agreement with those monitored during the 2001-2005 eruptive activity.

1.1-P-43

Volume estimation of tephra deposits using a GIS-based method: an application to the 122 BC Etna eruption

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The 122 BC plinian eruption represents the most powerful event in the historical activity of Etna that produced a thick pyroclastic sequence in the southeastern flank of the volcano. The sequence of the 122 BC eruption comprises pyroclastic scoria fall and minor flow deposits divided in 7 eruptive subunits, named from A to G, whose

depositional characteristics are described in Coltelli et al. (1998). The volume of the plinian fall deposit (only unit C and E) using Pyle's method resulted of $285 \times 10^6 \text{ m}^3$.

In this work we propose a new methodology to calculate the volume of the fall deposit through elaborations performing on GIS (Geographic Information System) environment. For each subunit, the tephra thickness information collected during the field survey was organized in a georeferenced database and was interpolated using a spatial mathematical function to calculate the tephra thickness where unknown. This computation was obtained after a preliminary study about the spatial distribution and geostatistical analysis of field data. The thickness surfaces computed for the 7 subunits allowed not only to estimate the total tephra volume emitted during the 122 BC eruption but also to reconstruct the dispersion map on land of the relative deposit, visualized through a vector and raster representation. The results are compared with the previous studies highlighting the main differences and the significant improvements of this methodology. References: Coltelli et al., 1998. Geology.

1.1-P-44

Evolution and Morphologic Aspects of the 1865 Monti Sartorius Eruption (Etna Volcano, Eastern Sicily)

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Mount Etna is the largest European active volcano, formed by the volcanic products of numerous eruptive centres. It is located in eastern Sicily, between two major structural domains: the Iblean Foreland, consisting mainly of Triassic to Pleistocene carbonate units intercalated by mafic volcanic rocks, and the Apennine-Maghrebian Chain. In this work are described the eruptive phenomenology and the morphologic aspects of the 1865, January 28th – June 15th, Etna lateral eruption, during which the Monti Sartorius have formed. The eruption occurred along the NE flank of the Etna edifice. The position and chronology of prehistorical vents that were active in this area demonstrate a progressive shift of the eruptive fissures toward SE. The evolution of the Monti Sartorius pyroclastic cones is here reconstructed on the basis of written historical reports, analysis of aerial photographs and detailed geologic and geomorphologic surveys. The most typical morphologic feature of Monti Sartorius is a series of five pyroclastic edifices aligned along an ENE-WSW trend to form a row of cones locally called "*bottoniera*" (rows of buttons). A clear asymmetry of their crater rims, highest toward south, reflects the predominant wind direction during the eruption. Along the flanks of these pyroclastic cones, large volcanic bombs with an average size of half a meter are found with the largest of about 2 m in diameter. The 1865 eruption was fed by two systems of eruptive fractures: the main system oriented ENE-WSW and a secondary cluster of fractures trending N-S to NNW-SSE. The morphologic survey highlighted a recent activity of one of the eruptive vents.

1.1-P-45
Analysis of Historical Eruptive Activity at Nyamulagira (North Kivu, D.R.C.): Implications for Hazards.

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Nyamulagira (3058m a.s.l.), located in the Virunga Volcanic Province (VVP), in the western branch of the East African Rift, is a highly active shield volcano, which erupted more than 30 times since 1900. Using a new map of historical lava flows and pyroclastic cones derived from remote sensing analysis, combined with field observations of the 2006 and 2010 eruptions and re-analysis of the available accounts for past eruptions, we present an overview of Nyamulagira eruptive activity in the last century. Estimated lava surfaces and volumes for the last 30 eruptions indicate a marked increase in the average magma output rate since the early 1980's, associated with a higher eruption frequency. The analysis shows that the eruption characteristics change with the location of eruptive vents. The developed GIS database enables to assess the increasing impact of lava flows on the Virunga Volcanic Park (UNESCO World Heritage in danger), with recurrent destruction of significant forest areas. Lava flows from the 1938 to 2010 eruptions occupy ~40 % (more than 430 km²) of the entire Nyamulagira lava field, which demonstrates the rapid re-surfacing of the area by new lavas. Extent of the last century lava flows also illustrates the serious hazard posed by Nyamulagira for the densely inhabited area along the north-western shoreline of Lake Kivu as 3 lava flows have reached the lake in less than 100 years, whereas acid rains and pyroclastic falls regularly affect crops and urban zones in this area during an eruption.

1.1-P-46
The Radial Dyke Swarm of the Lower Old Volcanic Edifice of La Gomera (Canary Islands): Evidence for a Possible Eroded E-W Volcanic Rift.
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The rough topography of La Gomera (Canary Islands) offers an excellent window for the study of the magmatic feeder system of an oceanic volcano. Ancochea et al. (2008) proposed the existence of several radial dyke swarms in the island, due to the migration southwards of three successive subaerial volcanic edifices. We have focused in the dyke swarms of the oldest (10.5 – 8.6 Ma) subaerial volcano of La Gomera, the Lower Old Edifice (LOE), analyzing dykes in 20 outcrops radially distributed at several distances of the proposed volcanic centre. We have measured the location, attitude (strike and dip) and width of a total of 415 dykes. We have separated dykes of the LOE mainly using field crosscutting relationships, and estimated the minimum horizontal stress direction and the strain accommodated by LOE dyke intrusions, following the method proposed by Marinoni (2001). In agreement with previous work of Ancochea et

al. (2008) we find in the LOE two different dyke swarms: one formed by outward shallow dipping sheets, and a later swarm of (quasi)vertical dykes. Our results of the second swarm show a roughly radial stress field but with a clear asymmetrical strain distribution and that the analysis of altitude and distance to the volcano centre of each outcrop is essential to detect this radial asymmetry. In the NE region of the island (Hermigua sector) we find a possible E-W volcanic rift, since the dense network of dykes pointing to the proposed centre of the LOE shows densities of 10 dykes per 100 meter involving a 15% of horizontal extension, similar to volcanic rifts in other islands. This proposed E-W rift, however, is not present in the outcrops located at the NW region, at the west side of the LOE centre. References: Ancochea et al., 2008, JVGR; Marinoni, 2001, JVGR.

1.1-P-47
Hydrogeochemical Constraints for the Nature of The 2004 Seismic Episode in Tenerife (Canary Islands).
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A deep magmatic injection triggering a migration of fluid and gas at depth interacted with Las Cañadas Caldera aquifer is currently the most accepted origin for the seismic episode occurred in Tenerife in 2004. Aquifers in Tenerife are accessible at several locations by hundreds of galleries and wells, and by one of the scarce existing deep boreholes in the world tapping an aquifer close to an active volcano: the Montaña Majua Borehole (MMB), monitored since 1999 by the Tenerife Water Research Council (CIAT). To test the established hypothesis we have used the data set of MMB and galleries-wells provided by CIAT, to search for characteristic signatures of fluid-gas migration into Las Cañadas aquifer at the time of the anomalous seismic activity; i.e., we did not look for a precursory hydrogeochemical pattern of the seismicity, but we have investigated the response that the proposed processes should provoked to the aquifer. Data from MMB do not shown any notable change in water conductivity or temperature coincident with the alleged onset of a tremor in 18 May 2004 proposed by Almendros et al. (2007). Additionally, we did not find any correlation between the seismicity pattern and the recorded changes in water level, conductivity and temperature in MMB during 2004. The temporal irregularity of the hydrogeochemical dataset from water galleries-wells makes difficult its use for testing the magmatic-hydrothermal hypothesis. Besides, after a multivariate statistical study of 459 water analyses from 64 galleries-wells, we have not found in Las Cañadas or neighbour aquifers any relevant change in the hydrogeochemical parameters during 2004. From the results here presented, we propose that the nature of the seismic episode occurred during 2004 in Tenerife must be re-evaluated and other tecto-volcanic hypothesis must be tested using the invaluable data from MMB and water galleries. References: Almendros et al. (2007).

1.1-P-48

Physical Properties of Neapolitan Yellow Tuff from Campi Flegrei Caldera Boreholes: New Perspectives for the Interpretation of the Caldera Dynamics.

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A number of measurements on physical properties of volcanic tuffs from different volcanic Italian districts have been performed in the recent years. Petrophysical investigations carried out at increasing/decreasing effective pressure revealed how revealed that the pressurization and depressurization cycles generate inelastic crack damage/pore collapse and permanent reduction of voids space. When cores from boreholes were investigated, significant variations of physical properties have been found even within the same tuff lithologies, which significantly influence the modelling of the overall physics and mechanics. In this study we analysed the physical properties of Campi Flegrei tuff (12ka) cores from depths up to 100m of depth, which is the most abundant and widely distributed lithology in the caldera. The tuff is a strongly heterogeneous pyroclastic flow material, which include cavities, pumice and crystals of sanidine, pyroxene and biotite. Initial total porosity of 52% was found for cores coming from 30m of depth. Total porosity decreases to 46%, when cores from 100m depth are considered. Bench measurements of P-wave and S-wave velocities carried out in dry conditions are ~ 1.8 and ~1.2 km/s respectively for the 30m depth cores and increase up to 2.1 km/s and 1.35 km/s at depth of 100m. Taken together, the measurements of porosity and P and S wave velocities revealed a significant compaction occurring even at such shallow depths. This observation suggests that pore collapse is a pervasive mechanism affecting such weak lithologies and can be activated even from very modest increase of effective pressure (1-10MPa). The results obtained from laboratory measurements and their comparison with field determinations, provide crucial information for the interpretation of the inner volcanic district structure, and in turn suggest if/how mechanical and thermal stress can significantly change the rheology and permeability tuffs, opening new perspectives for the interpretation of the caldera dynamics.

1.1-P-49

Copper Isotope Ratio (⁶⁵Cu/⁶³Cu) as a Tracer of Volcanological Studies

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The ⁶⁵Cu/⁶³Cu ratios in natural samples were reported to vary from -16.5 to +10.0 permil, using a δ⁶⁵Cu notation as defined below (Mathur et al., 2009).

$$\delta^{65}\text{Cu (permil)} = \left[\left(\frac{R_{\text{sample}}}{R_{\text{standard}}} \right) - 1 \right] \times 1000$$

R = ⁶⁵Cu/⁶³Cu, standard~ NIST-SRM976

A large variation in ⁶⁵Cu/⁶³Cu is observed during ore

formation at low temperature or biochemical reactions. Experimental investigations have shown that the main process that fractionate Cu isotopes in natural system is redox reactions between Cu(I) and Cu(II). While, no systematic variation in ⁶⁵Cu/⁶³Cu is observed among deep terrestrial materials; volcanic rocks from different mantle sources (MORB, OIB) and mantle rocks have almost undistinguishable ⁶⁵Cu/⁶³Cu from -0.2 to +0.2 permil (Ben Othman et al., 2006). Since arc magmas are generated involving slab-derived materials possibly with fractionated ⁶⁵Cu/⁶³Cu, it may be possible to apply ⁶⁵Cu/⁶³Cu for understanding generation and evolution of arc magmas. So, we determined ⁶⁵Cu/⁶³Cu of 12 arc volcanic rocks from Japanese arcs to be 0~+0.5 permil (Ikehata, 2009), which is almost identical to the bulk earth value, although the ratios seem to shift slightly higher from MORB range. Further data for both arc rocks and MORB are needed to discuss the global ⁶⁵Cu/⁶³Cu heterogeneity.

1.1-P-50

Comparing micro topographies of old and new lava flows using difference resolutions of DEM and DSM data -a case study of Tokachi-dake Volcano, Japan-

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Micro topographies of lava flow, like clinkers, are envisaged to be smoothed away by erosions and/or development of soil as time goes on. Tokachi-dake Volcano, one of the most active volcanoes in Japan, has revealed its detail activities (Fujiwara et al., 2007, 2009; Ishizuka et al., 2010 etc.). Various aged lava flows (mainly basaltic andesite or andesite) can be recognized in this area, from 1 Ma to 0.5 ka. We have tried to evaluate the degrees of the smoothing functions using difference resolutions of DEM and DSM data. Used data are obtained from the airborne laser scanner (10 m and 30 m mesh), topographic maps drawn by aerial survey mapping (10 m and 30 m mesh; provided by GSI) and Aster GDEM (30 m mesh; provided by METI/NASA). Comparable lava flow pairs are picked out which contain old (Pleistocene) and new (Holocene) one. We have analyzed the slopes and laplacians of each flow. In regard to slopes, 2 of 3 pairs showed according results with our predictions; i.e. new lava flows showed higher values than old ones about the average, median and standard deviation of slopes. In addition, almost all cases showed according results with our predictions in regard to laplacians; i.e. new lava flows showed higher values of the standard deviation of laplacians than old ones. 10 m mesh data of the airborne laser scanner showed most concordant trend with our predictions in regard both to slopes and laplacians. The results indicate that the airborne laser scanner data can provide most realistic topographies. In this study, standard deviations of laplacian can be most available parameter to estimate the age of lava flows. The part of this study was performed under the sponsorship of Japan Nuclear Energy Safety Organization (JNES) Fundamental Research Project on Nuclear Safety.

1.1-P-51

Characteristics and Origin of Basaltic-Andesitic Pyroclastic Flow Deposits on Tokachidake Volcano, Northern Japan

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A basaltic-andesitic pyroclastic flow deposit associated with 3.3 ka eruption is preserved at the western foot of Tokachidake Volcano, Northern Japan. The deposit can be divided into two units, based on the variation and content of juvenile materials. The lower unit consists of several flow units that are yellowish brown in color and contain a large amount of altered or oxidized lithic fragments and minor amount of juvenile materials composed of pumice, scoria, and cauliflower-shaped bombs. The upper unit consists of several flow units that are dark brown to black in color and mainly contain scoria and cauliflower-shaped bombs as juvenile materials. Although both units are matrix supported and poorly sorted, they lack fine-grained particles (less than 1/16 mm) in the matrix and are more sorted than dacitic and andesitic pyroclastic flow deposits. The lower and upper units are mainly distributed in small valleys and cover areas of 3 km² and 3.6 km², respectively. The ratios of the height and the runout distance are estimated at 0.21-0.32 and 0.15-0.21 for lower and upper units, respectively, which are similar to pyroclastic flow deposits of Unzen volcano (dacite) and Fuji volcano (basalt). The presence and content of juvenile materials of the lower unit suggest that the pyroclastic flow was generated by a collapse of a pyroclastic cone with volcanic edifice. For the upper unit, it could be generated by a collapse of a pyroclastic cone or an eruption column.

1.1-P-52

The Influence of Fine Material in Particle Abrasion During Transport of Debris Flows

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The role of fine sediment inside debris flows is a major item because it determines flow behavior (Scott, 1988; Scott et al., 1995; Vallance & Scott, 1997) and modifies the process of sedimentation (Major & Pierson, 1992; Amy et al., 2006). To analyze its influence, five mixtures of water and sediments, emulating cohesive and non-cohesive debris flows, were introduced to "Los Angeles" machine at 9 intervals of time. The five samples had unimodal distributions, and were identical in sand and gravel fraction varying only the amount of fine sediments. In each period of time, a representative sample of the mixture was taken and sieved at 1phi intervals. Fourier analysis was performed and fractal dimension was measured on 700 particles from 0phi to -6phi fractions, to quantify the change in morphology with time. Results obtained were correlated with the clast interaction during flowage of debris flows, in the presence or absence of fine sediments. Sieving analyses show a general tendency to evolve from unimodal to bimodal distributions with time. These results agree with changes in granulometric histograms observed in natural cohesive and

non-cohesive debris flows, offering a new alternative to explain the evolution from polymodal to bimodal distributions commonly explained by bulking process. Preliminary results of fractal dimension and Fourier analysis show that main modifications in clast morphology and textural irregularities occurred in the first stages of the experiments in spite of the amount of fines. Besides, these changes are clearly related with the amount of fine sediment present at the mixture but also the clast size. This work contributes to analyze how fine content inside debris flows plays a major role in determine the type of clast interaction during flow and therefore gives new insights about dynamic conditions during transport and deposition of debris flows.

1.1-P-53

Gravity Data and Heat Flow Density Using to Determine the Crustal Configuration Associated with Volcanic Activity in Tunisia Pelagian Platform Crossed by the Southern Sicily in Italy

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A description of the crustal and lithospheric structure is coupled with a synthesis of the available geophysical data sets, namely: Bouguer gravity anomalies, heat flow data through Pelagian Platform in Tunisia to southern Sicily in Italy.

The Pelagian Platform, which extends from Tunisia to southern Sicily, has been affected by tectonic activity producing a series of basins and structural highs, from the Miocene onwards to the recent extension of the Pantelleria rift (Reuther, 1987). The most recent basaltic volcanic eruption dates from October, 1981 (Baratta, 1981).

This recent Pantelleria rift is characterized by positive Bouguer anomaly and is thought to be caused by crustal thinning from Pelagian Platform (in Tunisia) towards the Sicily (in Italy).

The heat-flow density (HFD) values on the Pelagian Platform are generally higher than 80 mW. m⁻², reaching 130 mW.m⁻² or more in the younger part of the rift (Pantelleria and Linosa basins). These basins have both been affected, in the Quaternary, by prominent magmatic episodes which led to the formation of volcanic islands.

1.1-P-54

A Synthesis of the eruptive activity at Galeras Volcano, Colombia, 2004 - 2010

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Galeras volcano in the SW of Colombia is considered as one of the most active in this country. Since its re-activation in 1989 the volcano has been monitored us-

ing different Geophysical and Geochemical technologies. The most recent period of activity was detected at the end of June, 2004 and remains in evolution. In this time interval, it has presented different episodes like conduit cleaning revealed by a period of ash emissions from July to August, with a deposited volume of around $4,8 \times 10^5 \text{ m}^3$ and three Vulcanian eruptions on August 11, 12 and November 21, 2004. This process has been associated with changes in seismicity, deformation, temperature variations, etc. Other important process was from August 19 to 22, 2005 with the record of a swarm of around 40 Volcano-Tectonic events, epicentrally located between 3 and 4 Km NW from the active cone and depths between 6 and 8 Km; 9 of them had local magnitudes from 3 to 4.7 (felt in the region) in addition, deformation process were observed. From December 2005 up to May 2006 and then from September 2008 to February 2009, significant increment of Long Period events was detected and it was associated respectively, with the intrusion and emplacement of two lava domes at the bottom of the main crater, last one with a volume estimated on $5 \times 10^6 \text{ m}^3$. Producing changes in SO_2 emissions, thermal anomalies, superficial activity and seismicity (including Tornillo events) the volcano has produced since July 2006 to January 2010, thirteen explosive Vulcanian eruptions, eleven of which occurred from February 2009 up to January 2010. These eruptions produced shock waves, gas and ash emissions (with deposits up to 180 Km), eruptive columns (9 to 12 Km height) and ballistic rocks (with impacts up to 3 Km from the vent). The deposited volume estimated for these eruptions is around $12 \times 10^6 \text{ m}^3$. The volcano still showing fluctuations and evidences of magmatic activity with could reasonable to expect new eruptive episodes in short or medium term.

1.1-P-55

Preliminary detailed stratigraphic reconstruction of debris avalanche deposits at Colima volcano (Mexico).

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Abstract body Colima volcano is a large complex andesitic stratovolcano located in the western part of the Trans-Mexican Volcanic Belt (TMVB) and at the southern end of the N-S trending Colima graben, about 70 km from the Pacific Ocean coast. It is probably Mexico's most active volcano in historic time and one of the most active of North America. Colima volcano yielded numerous partial edifice collapses with emplacement of debris avalanche deposits (DADs) of contrasting volume, morphology, texture and origin. This preliminary labor has the aim to provide an overview of a detailed stratigraphic fieldwork in the south-eastern sector of Colima volcano. The work has been developed in the volcano's radial canyons, the only places where the outcrops show a larger facing. Several debris avalanche deposits was discovered in this sector especially in the deeper and worse practicable canyons and some interesting evidences has been found. In "Montegrande" canyon the finding of pyroclastic deposits (lapilli ash-tuff fall-out/surge deposits), lying on top of a debris avalanche,

suggest a magmatic interaction with the emplacement and/or triggering of the debris avalanche. In "Arena" canyon other DAD is divided into two distinct units by an erosional surface. The meaning of this limit could be the key of the flow's emplacement mechanism and could suggest how the debris avalanche was triggered. In "Muerto" gorge various large epiclastic deposits and debris flows associated to DAD crop out, suggesting the importance of water interaction during or immediately after the emplacement. Moreover soils and organic material found into pyroclastic sequences associated to debris avalanche deposits, have been used for C14 dating to reconstruct the age of the events.

1.1-P-56

Geomorphological analysis of pyroclastic cone using different resolution DEM and DSM data: A case study of Aso Volcano, Japan

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The formation age of a volcano can be estimated by dissection ratio of a volcano edifice (e.g., Suzuki, 1969). In old volcano edifice, dissection advances by rain and weathering (development of gully and slow slope). In this study, we focused on the 4 pyroclastic cones of the central cone group of Aso volcano, southern Japan, because the formation age of the pyroclastic cones is apparent from the recent chronological or geological studies. We tried to quantify the dissection ratio using laplacian (unevenness ratio of the surface) and slope to overview the topographical change of time by different digital elevation model (DEM) and digital surface model (DSM). 10m and 30m mesh data were obtained from the LiDAR (airborne laser scanner), GSI (topographic maps drawn by aerial survey mapping) and 30m mesh data from the AsterGDEM (provided by METI/NASA). In order to distinguish with volcanic fan around pyroclastic cone, we analyzed more than 20 degrees area around pyroclastic cone.

The result of our analysis shows that the average value and the median value of the slopes tend to be small for the pyroclastic cones of old formation age and large for the new pyroclastic cones, respectively. The result of analysis of standard deviation, the laplacian is small for the new pyroclastic cones, and the value tends to be large for the pyroclastic cone of old formation age. These tendencies were obvious in the data made from LiDAR, and in order GSI, Aster.

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1.1-P-57

The Deformation Prediction Possibility for Paroxysmal Directed Eruptions (on the Example of Bezymianny Volcano Eruptions)

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As well-known the deformation processes provoke some strong eruptions (Bezymianny 1956, St. Helens 1980 et al.). Subvertical weakened zones, peculiar to extrusive domes, and subhorizontal heterogeneities, peculiar to stratovolcanoes, are present in transitive extrusive-stratovolcanic forms. The combination of both complexes of the weakened zones in transitive structures conducts to their smaller stability in comparison both with extrusive, and with stratovolcanic formations. It does by more probable occurrence of large volcanic collapses which can provoke development of the powerful directed eruptions. Now Bezymianny is in similar state. Each ordinary eruption with the explosive culmination begins from the deformation process stage. On next stage this process transforms to extrusive dome growth. On following stage the extrusive process transforms to the effusive form of the eruption. Explosive culmination of ordinary eruption corresponds to the culmination of lava effusion. The nonlinear second-order differential equation describes this avalanche-like ordinary eruption development. The stationary (not avalanche-like) development of eruptive process results in prolonged extrusive-effusive eruption without explosive culmination. So the explosive culmination of ordinary eruption is predictable. However sometimes the combination of initial deformation-extrusive process with subsequent lava flow effusion creates preconditions for non ordinary strong eruptions with big destruction of the volcanic structure. Such Bezymianny eruption was in 1985 and similar eruption may be provoked by one of ordinary eruptions in near future. The observations of volcanic structure changes and its correspondence with the beginning deformation-extrusive stages of each ordinary eruption are necessary for prediction such paroxysmal eruptions. The Bezymianny volcano area is not populated absolutely and this region is very difficult of access. Therefore continuous deformation control of Bezymianny structure changes is not executing now. We hope that the ascertained patterns of volcanic development will be useful for using in more populated volcanic areas.

1.1-P-58

Ar-Ar And U-Pb Dating of Young Rhyolites in the Kos-Nisyros Volcanic Complex, Eastern Aegean Arc (Greece): Excess ⁴⁰Ar Galore.

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High-precision dating of Quaternary silicic magmas in the active Kos-Nisyros volcanic center (Aegean Arc, Greece) by both ⁴⁰Ar/³⁹Ar on biotite and U/Pb on zircon reveals a complex geochronological story. U/Pb ID-TIMS multi- and single-grain zircon analyses from 3

different units (Agios Mammias and Zini domes, Kefalos Serie pyroclasts) range in ages from 0.3-0.5 to 10-20 Ma. The youngest dates provide the maximum eruption age, while the oldest zircons indicate inheritance from local continental crust (Miocene and older). Step-heating ⁴⁰Ar/³⁹Ar experiments on 1-3 crystals of fresh biotite yielded highly disturbed Ar-release patterns with plateau ages typically older than most U/Pb ages. These old plateau ages are probably not a consequence of inheritance from xenocrystic biotites because Ar diffuses extremely fast at magmatic temperatures and ratios are reset within a few days. On the basis of (1) elevated and/or imprecise ⁴⁰Ar/³⁶Ar ratios and (2) a high mantle ³He flux in the Kos-Nisyros area (Shimizu, et al., 2005, JVGR), we suggest that biotite crystals retained some mantle ⁴⁰Ar that lead to the observed, anomalously old ages. In contrast, sanidine crystals from the only sanidine-bearing unit in the Kos-Nisyros volcanic center (the caldera-forming Kos Plateau Tuff) do not appear to store any excess ⁴⁰Ar relative to atmospheric composition (Bachmann et al., 2007a). The eastern edge of the Aegean Arc is tectonically complex, undergoing rapid extension and located close to a major structural boundary (Pe-Piper et al., 2005, JVGR). In such regions, which are characterized by high fluxes of mantle volatiles, Ar/Ar geochronology on biotite can lead to erroneous results due to the presence of excess ⁴⁰Ar and should be checked either against ⁴⁰Ar/³⁹Ar sanidine or U/Pb zircon ages.

1.1-P-59

Identification and Correlation of the Daisen-Kusatanihara Pumice Fall Deposit, Japan

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Daisen is a large Quaternary composite volcano in western Japan. After the deposition of widespread tephra, AT ash (29 cal ka BP), its last magmatic activities produced three lava domes (Karasugasen, Misen and Sankoho) and corresponding pyroclastic flows (Sasaganaru, Misen and Shimizuhara). We present the results of geological investigation, radiocarbon dating and EPMA analysis of volcanic glass shards for the Kusatanihara pumice fall deposit (KsP). The KsP have been found between the AT and K-Ah (7.3 cal ka BP) tephra in the cores from the Japan Sea (Miura et al. 1991). We found two fall units (KsP-L and -U) at the northeastern slope. The sharp boundary between them indicates that the eruptive column once ceased during the eruption. The KsP-L has a wider SiO₂ range (65 to 75 wt.%) than the KsP-U (70 to 76 wt.%). Harker diagrams indicate the KsP-L and KsP-U can be correlated with the KsP at the type locality and an ash layer in the core from Lake Ichi-no-Megata, Oga Peninsula (Yamada et al. 2007), respectively. The discovery of KsP-U at Oga Peninsula suggests that KsP-U has a wide distribution around

Japan Sea. The estimated eruption age from AMS ¹⁴C dating of planktic foraminiferal is about 20 to 22 cal ka BP (Domitsu et al. 2002). On the other hand, the ¹⁴C ages of the Shimizuhara pyroclastic flows (Fukumoto and Miyake 1994) overlying the KsP are scattered beyond measurement error (18,100±180 BP by Miura and Hayashi 1991, 17,440±150 BP and 17,440±100 BP by this study). The calibrated dates for the Shimizuhara pyroclastic flows are almost correlated to the ages of KsP obtained from marine core. AMS radiocarbon dating in this study was performed under the Common-Use Facility Program of JAEA.

1.1-P-60

Colli Albani Volcanic District Structure Revealed By Three Dimensional Gravity Field Modeling (Rome, Italy).

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Understanding the factors controlling the most recent hydromagmatic activity at the Colli Albani Volcanic District is crucial for the assessment of volcanic hazard in the densely populated area of Rome. At present, the area is characterised by almost continuous low-level seismic activity and by the presence of an intense deep CO₂ degassing process. In order to assess the inner structure of the volcanic district, we carried out a detailed gravity survey, more than 900 new prospecting gravity stations. 3D gravity modelling reveals the previously unknown geometry of the dense substratum of the Vulcano Laziale (VL) and evidences the presence of a collapsed structure beneath the caldera filled up with low density material. A complex system of faults surrounds the volcanic area. Many tectonic lineaments with prevalent Apennine and anti-Apennine directions can be singled out; some of these are quite coincident with the volcanic fault lines. This zone could have guided both the development of the volcano activity and the emplacement of the VL caldera and hydromagmatic maars. The VL caldera collapse area enclosed by these two structures is elliptical and about 20×30 km in size. Our observations suggest an asymmetric subsidence along the fault zone resulted in trapdoor subsidence in the western part. Other new information regards the Colli Albani structure. It consists of a circular volume of rocks around the Campi di Annibale volcanic vent and that extends down to the carbonate basement. It results to be denser with respect to the surrounding sedimentary cover of the Vivaro Plain and to the material located just along the central axis of the volcanic structure.

1.1-P-61

Petrochemical Characteristics of Gorely Volcano (Southern Kamchatka) Magmatic Series

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Gorely volcano is the largest eruptive center in Southern Kamchatka. It's comprised of several structural units.

Geochemical studies have been conducted on all structural units of the Gorely volcanic edifice to determine their genetic conditions. After geochemical analysis two evolution series were found. First, Pra-Gorely volcano is represented by suite of compositions ranging from basalt to rhyolite. Second, Young Gorely edifice is composed of only basalt, andesite and dacite. The reconstruction of chemical evolution trends shows that both volcanic series of Gorely volcano share the same genetic history with similar evolutionary stages. We suggest fractionation of an upper mantle peridotite as common means to produce both volcanic series as a result of which the evolution of all rocks was generated. The magmatic series of Pra-Gorely and Young Gorely volcanoes were formed under different geodynamic conditions. Between these two series was a powerful stage of caldera formation, during which 100 km³ of ignimbrites were emplaced. The 12-km diameter caldera collapse was the catalyst for large-scale reorganization of the volcanic feeding system. Nevertheless following caldera collapse, Young Gorely volcano was formed by activity inside the caldera and shows very similar evolutionary trends to that of Pra-Gorely volcano. It can be confidently stated that crustal components are practically absent in the evolution of the series, and the compositional range is attributed directly to the evolution of the magmatic melts of Gorely volcano. Microprobe analyses conducted on olivine and pyroxene phenocrysts of Gorely volcano lavas, show that there were at least two stages of crystallization during the evolution of magmatic melt. The two-stage character of initial magmatic melt evolution is confirmed by computer simulation results. The existing of this stage of crystallization testifies to shallow magmatic chamber presence which is responsible for generation of caldera and thick ignimbrite complex.

1.1-P-62

Magma Degassing during 7600¹⁴C Kurile Lake Caldera-Forming Eruption and its Climatic Impact

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Kurile Lake (Southern Kamchatka) was formed by caldera-forming eruption ~7600 y.a. (Ponomareva et al., 2004). Total tephra volume conservatively estimated of 140–170 km³ (70–80 km³ DRE) was dispersed over an area of >2 mln. km² (Ponomareva et al., 2004). The main goal of this study was estimation of volatile components volume injected into the atmosphere during Kurile Lake (KO) eruption and its possible climatic impact. The volatile content in magma before the eruption was estimated by direct measurements of H₂O, S, Cl and F contents in natural quenched glassy melt inclusions trapped by plagioclase phenocrysts. The volatile content in rocks after the eruption was estimated by analyses of matrix glasses in tephra. The amount of S injected into the stratosphere during KO eruption was about 2 times more than after eruptions of Krakatau (1883), Katmai (1910) and Mount Pinatubo (1991). Similar amounts of S degassing were defined for eruptions

of Huaynaputina (Peru) in 1600 ($\sim 2.3 \times 10^{10}$ kg of sulphur) (De Silva and Zielinski, 1998) and Tambora (Indonesia) in 1815 ($\sim 2.8 \times 10^{10}$ kg of sulphur) (Oppenheimer, 2003). As a summary, Kurile Lake's eruption (7600 ^{14}C) influx into the atmosphere is $\geq 3.7\text{--}4.2 \times 10^{12}$ kg of H_2O , $\sim 4.3\text{--}4.9 \times 10^{10}$ kg of Cl, $\sim 8.6\text{--}9.8 \times 10^9$ kg of F and $\sim 2.6\text{--}2.9 \times 10^{10}$ kg of S. This eruption must have had essential climatic effect, one of the most significant during Holocene. References: Ponomareva et al., 2004, JVGR; Braitseva et al., 1997, DES; De Silva and Zielinski, 1998, Nature; Oppenheimer, 2003, Progress in Physical Geography.

1.1-P-63

Evolution of a young composite volcano: the Vulcanello Peninsula (Vulcano, Aeolian Islands)

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Vulcanello Peninsula (Island of Vulcano) comprises a shoshonitic lava platform and a volcanic edifice made up of three, partly superimposed cones. The oldest two cones are shoshonitic in composition, the more recent one is trachytic in composition. New stratigraphic studies conducted on 25 sections, both natural outcrops and trenches dug through the tephra blanket of the Vulcanello Peninsula have been used to unravel the recent development of this young volcano. The field studies were integrated with petrographic, chemical and morphological data of products to correlate these deposits with the Vulcanello, Fossa Cone or Mt Pilato. Assessment of the explosive and effusive timing of each cone was made using tephrochronology and by new ^{14}C datings on selected charcoal fragments recovered from machinery-dug trenches revealed that Vulcanello formed between 1200 and 1600 AD and that the volcanic activity was coeval with the eruptions at La Fossa Cone (Vulcano) and Mt. Pilato (Lipari). We identified three eruptive clusters, each one produced a pyroclastic cone and led to the emplacement of a tephra unit and a lava field. The oldest cluster produced Violent Strombolian to Hawaiian eruptions, built-up the first cone and the Vulcanello lava platform. The second cluster, produced sub-aerial Strombolian cone, tephra unit and a off-shore pillow-lava field east of the peninsula. The third cluster, displays a complex evolution with an initial effusive episode of a trachytic lava flow, followed by steam-blast explosions, producing the third cone. Recognizing the evolution of Vulcanello is important to understand the hazard associated with a still-born, young composite volcano.

1.1-P-64

Ignimbrite-forming Eruptions On Terceira, Azores

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Ignimbrites of comenditic trachyte composition constitute a significant portion of the younger volcanic stratigraphy of the island of Terceira, Azores. The base of the most recent group of deposits, called the Upper Terceira Group, is marked by the Lajes-Angra Ignimbrite, an extensive ignimbrite sheet produced during the latest ignimbrite-forming episode some 20-23 k.y. ago. The Lower Terceira Group consists of ignimbrites and interstratified pyroclastic fall deposits and lava flows predating the Lajes-Angra Ignimbrite. Including the Lajes-Angra Ignimbrite, the exposed volcanic succession on Terceira includes at least seven formations containing ignimbrites plus two isolated exposures of other types of pyroclastic density current deposits. Most of these are from Pico Alto or, possibly, Guilherme Moniz, the middle pair of central volcanoes of the four that form Terceira. Radiocarbon ages complemented by $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations on anorthoclase crystals from several ignimbrites suggest a narrow period of ignimbrite-forming volcanism dating from c. 86 ka to 20-23 ka, which followed a period of predominantly effusive basaltic to trachytic/rhyolitic activity. However, a recurrence of ignimbrite volcanism on the island cannot be completely discounted. The results from this study also indicate that the $^{40}\text{Ar}/^{39}\text{Ar}$ method can be successfully applied to date anorthoclase crystals in volcanic rocks younger than 100 ka from Terceira, although it does not provide the same precision as radiocarbon dating at the younger age range of these volcanic rocks.

Reference: Gertisser, R., Self, S., Gaspar, J.L., Kelley, S.P., Pimentel, A., Eikenberg, J., Barry, T.L., Pacheco, J.M., Queiroz, G., and Vespa, M., 2010, Ignimbrite stratigraphy and chronology on Terceira Island, Azores, in GropPELLI, G., and Viereck-Goette, L., eds., Stratigraphy and Geology of Volcanic Areas: Geological Society of America Special Paper 464, p. 133-154.

1.1-P-65

Some Data on Different Volcanic Structures, Cenozoic Volcanoes and their Igneous Rocks

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We present some data on different Cenozoic volcanic structures and volcanoes, igneous rocks based on original and literature materials. Some data could be noted due to an eruption prognosis problem: 1. seismic materials could predict the very eruptions sometimes, e.x. S. America case. Also, there were optimistic results on Eurasia highest Klyuchevskoy volcano and Shiveluch stratovolcano eruptions, but, unfortunately, often after the very events. There are some data on a positive cor-

relation between quakes and some Quaternary eruptions in Kamchatka region (Pevzner, 2009). However, more studying need here. There are many questions, of course. 2. Surely, gas monitoring is a very optimistic. 3. Using of animals prognosis. 4. Complex analysis is an important including analysis of the very volcanic products, inclusions, glasses etc. Data on geoactivity migration could also help. Long term prognosis is a possible sometimes. We are very grateful to many geoscientists for a consulting and discussions.

1.1-P-66

Lava Dome Extrusion Into an Active Crater Lake: The 2007-2008 Eruption of Kelut Volcano, Java, Indonesia

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Kelut (Eastern Java, Indonesia) is an active andesitic volcanic complex with a summit crater lake that has been the source of some of Indonesia's most destructive and deadly eruptions (Smithsonian Institution, Global Volcanism Program). On 3-4 November 2007, a new lava dome appeared in Kelut's summit crater, protruding from the active crater lake. The eruption lasted for about six months, during which time some 35 million m³ of lava were expelled (BGVN 33:03, 33:07). Geochemical, petrographical and mineral chemical data indicate that the 2007-08 Kelut dome largely consists of highly crystalline, porphyritic basaltic andesite with 'phenocrysts' (~45 vol.%) of fragmented and complexly zoned plagioclase (An₃₆₋₉₃), clinopyroxene (Wo₃₅₋₄₇, En₄₁₋₄₉, Fs₁₁₋₁₇), orthopyroxene (Wo₂₋₄, En₆₄₋₇₃, Fs₂₄₋₃₂), frequently surrounded by thin (<0.5 mm) rims of clinopyroxene, and titanomagnetite (Usp₁₆₋₃₄) (in order of decreasing proportions) set in a microcrystalline groundmass (~55 vol.%) of similar mineralogy. Crystal Size Distribution (CSD) plot shapes of plagioclase are kinked, suggesting the presence of more than two distinct crystal populations. Plagioclase residence times, calculated using a growth rate of 10⁻¹¹ cm/s (cf. Higgins, 2006, Bulletin of Volcanology), range from ~40 years for the smallest measured 'phenocryst' size fraction (<0.4 mm) to ~260 years for the largest crystal population (>4 mm). This mixing process is possibly driven by episodes of rejuvenation of the crystal mushes at the interior margins of the lava dome. Micro-textural (mineral chemical) and CSD analyses of the other 'phenocryst' phases and groundmass microlites in the 2007-08 lava dome are in progress and will provide a more detailed picture of the complex pre-eruptive magmatic processes at Kelut and an improved understanding of magma storage and supply that will help identify the driving forces behind the volcano's recent activity.

1.1-P-67

Interpretation of Crystal Fractionation Processes, on Lavas from São Jorge (Azores) using the Principal Component Analysis Method

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Geochemists usually use bi-variant/bi-dimensional diagrams on geochemical analyses (major and trace elements) to characterize rock series because they deliver valuable geochemical and petrological interpretations.

Normally, variation diagrams with major element composition, using SiO₂ or MgO as the reference oxides, are applied to characterize magma evolution during fractional crystallization processes on volcanic rock series. SiO₂ or MgO are plotted versus all other oxides producing the typical 9 bi-variant plots, which allow comparison between volcanic rocks on the same rock series and/or between rocks from different rock series. A more extensive and complete analysis combining all oxides on a geochemical analysis, as for instance K₂O and P₂O₅, requires the examination of 35 variation diagrams simultaneously, making this task considerably difficult.

Principal Component Analysis (PCA) is a statistical technique that allows analyzing the behavior of several variables simultaneously, reducing then into a smaller set of variables, called principal components, without much loss of the information.

Seeking to overcome the abovementioned issue of the simultaneous analyses of all major oxides, PCA is applied to major element composition of several lava series from São Jorge Island on the Azores Archipelago. The applicability of this method as an integrated geochemical analysis and as a tool to distinguish between lava series is tested. Also, the pertinence of the use of PCA on the interpretations of the behavior of the lavas during differentiation processes will be addressed.

1.1-P-68

Short Residence Time For Alkaline Vesuvius Magmas In A Multi-Depth Supply System: Evidence From Geochemical And Textural Studies.

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Magma chamber chemico-physical conditions and magma residence time at high-risk volcanoes are crucial issues since they control the occurrence and size of future eruptions. In the order to define magmatic pressure - temperature conditions, and residence time at Somma-Vesuvius volcano, we carried out geochemical and textural studies on selected past eruptions representative of the whole volcano history. Our petrological model indicates a multi-depth magma chamber constituted by a deeper tephritic (350-400 Mpa) magma layer that fed strombolian and effusive eruptions during open conduit activity and a upper (200-250 Mpa) phonolitic level which supplied high explosive events that fol-

lowed closed-conduit repose time. This upper reservoir matches the inferred transition between sedimentary sequences and metamorphic basement, at this level the presence of a structural and lithological discontinuity can favor magma storage during closed-conduit period. Fractional crystallization during magma cooling associated with upward migration of less dense evolved liquids was the prevalent differentiation process. Our results indicate that huge steam exsolution occurred during the late crystallization stage of phonolites, thus accounting for the high Volcanic Explosivity Index (VEI) of eruptions supplied by these melts. Moreover, our CSDs data on phenocrysts reveal rapid crystallization and differentiation time for alkaline Somma-Vesuvius magmas (in the order of decades to few centuries). This evidence implies that the 400 km² partial melting zone detected by tomography study at 8-10 km depth beneath Vesuvius should consist of differentiated magma already capable to generate also large-scale (plinian) explosive events in case of renewal of the activity from the present closed-conduit state. Further, our CSDs data on micro-lites indicate rapid magma migration from the chamber toward the surface, thus suggesting that precursory activity could appear only short time before a major eruption.

1.1-P-69

A Novel Approach for High-Resolution Reconstruction of the Recent Eruptive Past of La Soufrière (Guadeloupe) Over the Last 8 000 Years.

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La Soufrière de Guadeloupe is an andesitic composite volcano characterized over the last 8 000 years by repetitive flank-collapse events, few magmatic eruptions and numerous phreatic events. Hazard assessment is biased on eruptions of significant magnitude that produce extensive and relatively thick deposits although numerous eruptions of moderate to low magnitude occurred. Unfortunately their deposits of limited extent and thickness disappear rapidly and are not taken into account in the geological record. We have developed a novel approach by using a manual sediment corer to obtain undisturbed sedimentary eruptive archives in sheltered areas on the volcano where a longer eruption record is likely to be preserved. We describe two cores (6.32 and 6.64m long) that extend over at least 8700 years and contain several thin tephra layers missing at the outcrop scale. We combine these new data with the analysis of stratigraphic sections on outcrops studied over the last decade to provide a more precise eruptive chronology for La Soufrière volcano over the last 8 000 years. This chronology is robustly constrained by 87 new ¹⁴C age dates that complete the existing ¹⁴C database. A multidisciplinary analysis (sedimentology, lithology, microtextures, magnetic susceptibility, and trace element analysis) of the sediment cores and field data has allowed us to identify hidden, and missing eruptions, and to re-interpret mis-identified eruptions. We have identified at least 2 new pumice fallout deposits

from moderate magnitude eruptions, several ash-cloud units from flank-collapse events already identified but associated with 3 distinct surge units. Thus, the number of Holocene magmatic eruptions has significantly increased compared to previous knowledge. The magmatic eruptive rate could be twice as important. This new data will allow a better determination of the recurrence, magnitude, intensity, and the spatio-temporal evolution of deposit types that define different eruptive scenarios and improve our hazard assessment.

1.1-P-70

Comparing the Processes and Timescales of Trachytic Magma Evolution in Active Volcanoes in the Azores, Portugal

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The Azores islands, Portugal, are one of the most active volcanic regions of Europe, and are home to ~240,000 residents who are at risk from future explosive trachytic eruptions. Our work focuses on geochemical and isotopic studies of recent trachyte pumice fall deposits on the most populous and volcanically active of the Azores islands, including São Miguel (Fogo, Furnas, and Sete Cidades volcanoes) and Terceira (Santa Barbara volcano). The trachyte deposits studied so far all exhibit significant chemical variability, generally with limited major element variations and substantial trace element variations including 2- to 3-fold variations in highly incompatible elements and up to ~200-fold variations in compatible elements. Chemical variations in all deposits are attributed primarily to fractional crystallization with sanidine as a dominant crystallizing phase. Strontium isotope signatures of whole-rock and constituent phases indicate variable importance of open system processes including syenite wallrock assimilation and magma injection and mixing. The deposits also vary substantially in the nature of the chemical zonation, with some representing simple monotonic variations throughout the deposit, and others exhibiting non-monotonic variations, interpreted to reflect complex magma chamber geometry and/or eruptive processes. U-series disequilibria studies of glass separates from some of the deposits provide estimates of pre-eruptive magma residence timescales, and suggest that, in some cases, the time necessary for magmas to evolve to the point of eruption can be as short as a few decades, and that the longer a magma resides beneath a volcano without erupting, the larger the resulting eruption. Continued studies on additional eruptions from these and other volcanoes will help to better understand these relationships in the future.

1.1-P-71
Spatial Forecast of Volcano Fracturing: The Example of Stromboli 2002-2003 and Piton de La Fournaise 2007 Eruptive Crises

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Since historical times, Stromboli volcano, in the Aeolian Islands, Italy and Piton de la Fournaise, on Réunion Island, Indian Ocean, are known to have a constant style in their explosive activity through times; a strombolian activity sometimes disrupted by paroxysmal events for the former and a hawaiian-strombolian activity sometimes disrupted by phreatomagmatic events for the later. The two volcanoes have been affected respectively in 2002-2003 and 2007 by major eruptive crises, leading to serious fracturing events, summit instability and/or collapse events, with huge implications in term of civil protection crisis management. Both volcanoes have been investigated, prior to the eruptive crises, by coupling self-potential, high resolution electrical resistivity tomography and subsurface temperature measurements in order to locate the preferential hydrothermal fluid flow paths. On both volcanoes, a several hundred meters long reiteration profile with one-meter spacing has been installed crossing the strongest positive self-potential anomalies evidenced in their summit area. Major fracturing and collapse events that occurred on the top of these two volcanoes crossed the area where self-potential anomalies reached the highest values. These results clearly pointed out that detailed self-potential studies allow forecasting precisely, with the top of self-potential positive anomaly, the place where a volcano can break during future eruptive crises. This information is of a major importance to locate the weakness planes on a volcanic edifice prior to an eruptive crisis and to improve monitoring strategy identifying key zone for installing future deformation stations.

1.1-P-72
Understanding and Strengthening the Smithsonian's Reporting-to-Preservation Process

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The *Bulletin of the Global Volcanism Network* is the Smithsonian Institution's monthly report on active vol-

canoes, publications that, with predecessors (*SEAN Bulletin* and *CSLP Event Report* post-cards), have for over ~42 years provided ~7,400 reports on 461 active volcanoes. The *Bulletin* reflects long-lasting partnerships and the willingness to share data among a supportive cadre of volcano watchers, both lay and professional. It presents preliminary data on topics including geophysical and geochemical observations, pre-, post-, and syn-eruptive behavior at various time scales, atmospheric impacts, hazards, damages, and fatalities. In an editing process involving an equivalent of about three full-time staff members, *Bulletin* reports undergo multiple in-house reviews and revisions. Post-publication errors are also corrected. The *Bulletin* functions as a primary vehicle for gathering, organizing, presenting, and preserving material in support of our Program's global database (the Volcano Reference File), which feeds the various editions of the book, *Volcanoes of the World* (3rd edition in preparation). The *Bulletin* serves a primary readership of professionals interested in active volcanism, but increasingly also aims to make technical and geographic details and terminology more accessible to the public, who visit our website in the millions annually (www.volcano.si.edu). There, readers can explore any of 1,585 volcanoes both in terms of the database and the entire set of published *Bulletin* reports on that volcano. Without the *Bulletin*, many reports might have remained incomplete or even lost to the modern record of volcanism. This poster provides an opportunity to interact with our correspondents. We look forward to discussing how we can continue to strengthen our partnerships, and to improve the content and accuracy of the *Bulletin*. New challenges include staffing limitations, and the need to improve the website's searching capabilities. Some growth areas include remote sensing, sensor arrays, and digital media.

1.1-P-73
Nd-Sr Isotopes in Quaternary Volcanic Rocks of Tabas (Iran)

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Quaternary volcanites are one of the last indicators of magmatism in Iran. Quaternary Volcanic rocks of Tabas located in southeastern Tabas town near the great and active fault of Nayband, and geologically they are part of Lut zone. According to petrographic, analyzing the EMPA and XRD studies, samples are mainly basalt that their texture are often porphyric and their Meseostare is microgranular and some have vesicle and any glass. Phenocrysts are often chryziolite olivine, augite, and plagioclase from labradorite to andesine. Considering field investigation and geochemical characteristics by XRF method and tectonomagmatic diagrams and Sr and Nd isotopes investigations, magmatic series these rocks are alkaline and some sub-alkaline from the type of sodic that thought to ascent, contamination with continental crust and the alkaline nature of a few of them has changed. The Nd and Sr isotopes quantities indicate a depleted mantle source for these basalts which have contaminated with crust rocks while rising. This magma has spent the normal trend of differentiation and in the beginning of Quaternary, following the extension move-

ments, some limited riftings have occurred in the intersection points of these minor faults and volcanic rocks have been erupted in the area.

1.1-P-74

Geophysical Study Of The Volcanic Seamounts In The North-Western Corner Of Venezuelan Basin (NE Caribbean)

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The Caribbean Large Igneous Province (LCIP) has been defined as a buoyant oceanic plateau formed in Cretaceous age which is covered by a thick layer of sediments forming extended basins (e. g., Venezuelan and Colombian basins). The igneous basement of this province has been studied in few outcrops in the Greater Antilles arc and offshore in the Beata Ridge area. However, this igneous province also can be studied offshore in the Venezuelan basin, where locally appear basement highs and conic seamounts with have intruded the thick sediment layer and are deforming the sea floor. These intruded bodies suggest a later volcanic activity in the inner Caribbean plateau but the intrusion mechanism and timing is still in question. During the spring of 2009 was carried out a marine geophysical survey aboard of the Spanish Research Vessel Hespérides in the south of the Hispaniola Island. The marine survey included the systematic acquisition of multibeam bathymetry, ultra-high seismic reflection profiles (TOPAS system), and potential fields (gravity and geo-magnetics). We use the acquired data in this cruise as well as reprocessed multi-channel seismic profiles to study the basement highs and volcanic seamounts in the north-western corner of the Venezuelan basin.

1.1-P-75

Quantification of The Mass Flux of H₂O Gas (Steam) from Active Volcanoes Using FLIR Thermal Imagery

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We describe a new H₂O gas flux measurement technique that utilizes continuously-recorded thermal images of volcanic plumes to estimate the H₂O gas flux. Results are compared with H₂O flux measurements obtained using other methods in order to verify our data. Essentially, the estimation of the H₂O emission rate is based on the mass and energy conservation equations. H₂O

flux is quantified from thermal image time-series of the volcanic gas plume by extracting the temperature and width of the gas plume from the thermal images, calculating the transit velocity of the gas plume, and combining the data with atmospheric parameters, measured on-site. These data are then input into the equations for conservation of mass and energy. Selected volcanoes for this study were Villarrica in Chile, Stromboli in Italy, and Santa Ana in El Salvador. H₂O fluxes estimated from the thermal imagery were 38 – 250 kg s⁻¹ at Villarrica, 4.5 – 14 kg s⁻¹ for Stromboli's Central Crater, and 166 – 214 kg s⁻¹ at Santa Ana. These compare with H₂O flux values estimated by other methods of 73 – 220 kg s⁻¹, 3 – 70 kg s⁻¹ and 266 kg s⁻¹, at the three volcanoes respectively. The good agreement between thermal-image-derived results and those estimated by other methods seem to validate this new method.

1.1-P-76

Global Diffuse CO₂ Emission from Volcanoes

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The role of Earth degassing in the atmospheric C budget and global climatic change is assumed to be significant at geological time (million years). At secular or lower time-scale, the C-gas output from the solid earth is considered negligible with respect to the biological and anthropogenic fluxes. However, a refined quantification of present Earth degassing is necessary for a better understanding of the present-day atmospheric budget. The contribution to the global atmosphere-ocean budget of CO₂ degassing remains virtually unquantified. Only recently, CO₂ degassing by extensional tectonism, and hydrothermal and volcanic activity has been considered an important factor in enhancing global greenhouse warming. Degassing by the volcanic activity and its contribution to the global balance of carbon has been studied by diverse authors. Nevertheless, at present there is a great uncertainty in the estimated values of global CO₂ emission by submarine and subaerial volcanic activity, varying between 100 and 200 Mt y⁻¹. Active volcanoes release to the atmosphere gases through plumes, fumaroles, and hot springs as visible emanations, but significant volcanic gas emissions can also occur through the surface environment in a diffuse form. Most of the studies on global CO₂ emissions to the atmosphere by subaerial volcanoes have not taken into consideration the diffuse CO₂ degassing process. Therefore, to provide a better estimation of the global CO₂ emission to the atmosphere by the subaerial volcanism, we have performed a significant number of direct observations on diffuse CO₂ degassing from volcanoes located at different tectonic and climate environments in Antarctic, Cameroon, Costa Rica, Ecuador, El Salvador, France, Germany, Italy, Japan, Nicaragua, Spain, Papua New Guinea, Philippines, Portugal and Rwanda. Preliminary results of this study indicate that a

better estimation of global CO₂ emission from subaerial volcanoes might be two or three order of magnitude higher than the current estimation.

1.1-P-77

Structural Control on Hydrothermal Fluid Circulations in Two Volcanoes of The Aeolian Archipelago, Stromboli and Vulcano (Italy)

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Electric resistivity tomography (ERT), self-potential (SP), soil CO₂ flux, and soil temperature have been used during various field surveys to investigate the inner structure, on key areas, of Stromboli and La Fossa cone, on Vulcano (Aeolian Islands, Italy). The measurements were performed on the volcanic cones with a spacing of 20 m or 5 m, along various profiles crossing some major structures of the edifices. The crater rims are underlined by sharp resistivity contrasts. SP, soil CO₂ flux, and soil temperature anomalies underline these boundaries which we interpret as structural limits associated to preferential circulation of hydrothermal fluids. The former craters and some particular lithological units strikingly enclose or guide hydrothermal circulations, which we identified on the base of low electrical resistivity values (from less than 200 Ω m to less than 20 Ω m in areas probably affected by strong hydrothermal alteration of the rock). Structures on Stromboli - like an impact crater or volcanic deposit levels - and on Vulcano - like former or recent crater boundaries, regional faults, a former dome unit - have been identified and strongly influence hydrothermal fluid circulation at the scale of the volcanic edifices. An original aspect of the study we carried out is the evidence of the extension of hydrothermal circulations in the whole volcanic edifice on Stromboli as well as on Vulcano, in particular in peripheral zones of the edifices with respect to the central hydrothermal system. These new multidisciplinary studies allow proposing a global model of the fluid flow inside an active volcanic edifice.

1.1-P-78

Diffuse H₂S Emission from Volcanic Areas

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SO₂ has been considered by volcanologist as the main sulphur species released by the global volcanic activity. However, H₂S is the predominant specie emitted by low-temperature degassing areas. Few studies on diffuse H₂S degassing have been carried out at volcanoes since most of the works have been focused on the CO₂, the second major component in volcanic gases after H₂O. In this work we present an attempt to improve our estimates on diffuse H₂S emission based on ground measurements at different volcanic areas of the world. Diffuse H₂S emission studies have been performed at the following sites: (i) summit cone of Teide volcano (9656 m²), Canary Islands, Spain, (ii) Cerro Negro volcano (0.5 km²), Nicaragua, Poas volcano (3.2 km²) Costa Rica, (iii) summit crater of Pico de Fogo Volcano (0.12 km²), Cape Verde, (iv) Taal Island (29 km²), Philippines and (v) Etna (2.9 km²), Vulcano (0.28 km²) and Solfatara (0.14 km²), all of them in Italy. H₂S efflux measurements were performed according to the accumulation chamber method by means of a portable Dragüer electrochemical H₂S sensor. Distribution maps we constructed based on the Sequential Gaussian Simulation (sGs) algorithms to estimate the total H₂S output from the studied volcanic areas. The total outputs of diffuse H₂S emission estimated for the different studied areas ranged from low values of 0.093 kg d⁻¹ and 0.16 kg d⁻¹ measured at Vulcano and Teide, respectively, and 242 kg d⁻¹ and 3884 kg d⁻¹ for Solfatara and summit crater of Etna, respectively. The global volcanic H₂S emission has been estimated based on airborne measurements in the range 0.41·10⁷ – 10.2·10⁷ kg·d⁻¹ (Halmes et al., 2002). This amount seems to be underestimated because the diffuse H₂S emission has not been considered. With this work we bring the importance of estimating the total output of diffuse H₂S emission from volcanoes and its contribution to the global volcanic H₂S emissions.

1.1-P-79

Towards an Understanding of Magmatic and Seismogenic Processes beneath Telica Volcano, Nicaragua.

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Quiescently active volcanoes, which exhibit high background levels of geophysical activity, do not have clearly distinct 'background' and 'unrest' states and as such present a challenge for detecting changes in volcanic behaviour. Sustained unrest at quiescently active volcanoes may be driven by sluggish convection

in a shallow magma chamber. This convection may drive high-background-rate LP seismicity observed at many quiescently active volcanoes, and may also result in surface deformation and high levels of volcanic gas emissions. Periodic fresh inputs of magma into the chamber may initiate an eruption. Several Nicaraguan volcanoes, including Telica, San Cristobal, Masaya and Momotombo, exhibit quiescent activity. Telica has had numerous historical eruptions, the most recent and notable of which was in December 1999 (VEI 2), and exhibits a high background level of activity with frequent explosions and a high rate of LP events. Telica is representative of many quiescently active volcanoes and is a good laboratory for the study of quiescent volcanism and high-background rate seismicity due to its level of activity and also due to ease of access to the volcano. In March 2010 researchers from University of South Florida (USA), The Pennsylvania State University (USA) and INETER (Nicaragua) installed a spatially dense network consisting of six broadband seismometers and eight high rate continuous GPS stations on Telica. These instruments will be deployed for three years to allow observation and analysis of multiple phases of quiescent activity. The results of this study will form the basis for a detailed model of quiescent volcanic processes, which will be applicable to other similarly active volcanoes worldwide to identify meaningful changes in behaviour and provide improvements to eruption forecasts.

1.1-P-80

Inner Structure of the Aso Caldera: Interpretations for Intracaldera Pyroclastic Flow Deposits

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Aso is largest caldera volcano in southwest Japan, erupted large-scale pyroclastic flows four times, Aso-1 (270 ka), Aso-2 (140 ka), Aso-3 (120 ka) and Aso-4 (90 ka). The Aso-4 pyroclastic flow, largest eruption (>600 km³) in Aso, forms present caldera (25 x 16 km). The Aso caldera was considered to have a funnel-shaped structure from gravity anomalies. But recent precise analysis of gravity anomalies of the caldera suggest that the gravity low has steep gradient inside the caldera rim and relatively flat bottom in central area (Komazawa, 1995).

We made precise observations from core samples of geothermal wells. The core samples were divided into five units. Lower breccia (200+m), welded tuff (200m), upper breccia (200m, with lake deposits) and volcanics of central cones (800m), in ascending order. The welded tuff is correlated to the Aso-4 pyroclastic flow from mineral assemblage and chemical composition. The lower breccia and the upper breccia are considered lithic-rich part of the pyroclastic flows. The lower breccia is intercalated with debris avalanche deposits composed of caldera wall rocks. The core stratigraphy and the gravity anomaly show that the caldera has a piston-cylinder type structure rather than a funnel-shaped structure.

1.1-P-81

The Late Holocene Collapse of Antuco Volcano: a Valley Confined Debris Avalanche Flow, Southern Andes, Chile

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Antuco volcano is located in the Southern Andes volcanic Zone, ca. 650 km south from Santiago. Its almost conically shaped edifice fills partially a volcanic depression within the remnants of the older Sierra Velluda volcano. At ca. 4.000 years BP (uncalibrated C¹⁴ dates on paleosoil horizons, both within and on top of the avalanche deposit) the ancestral edifice of Antuco volcano partially collapsed towards the NW generating a debris avalanche flow. The flow, initially directed towards the NW, encountered a high topographic barrier formed by glaciated basement rocks and pre-Antuco volcanoclastic rocks, and diverted towards the W, following the original drainage of the Laja River valley. Once in the fluvial valley, the avalanche flowed down without any secondary diversion for ca. 8 km when it finally stopped. The deposit shows the typical hummocky surface of debris avalanches, and is constituted mainly by volcanic rocks with different degrees of brecciation. Proximal and medial facies show in some places original internal stratigraphy of a paleovolcanic edifice partially preserved, as well as evidences of incorporation of material from the underlying sedimentary units on top of which the flow moved down. The partial collapse dammed temporarily the Laja River, increasing the water level of the Laja Lake. Research funded by Fondecyt project 1070162.

1.1-P-82

Geochemical Evidences that Unrest at Campi Flegrei Resurgent Caldera (Southern Italy) Is Due to Magma Emplacement and Degassing at Shallow Depth Plus Fluxing from a Deep-Seated Regional Body

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Volcanic calderas are affected by unrest episodes usually dominated by hybrid magmatic-hydrothermal system dynamics. Unrest episodes can evolve to eruptions of variable intensity, up to Plinian. Campi Flegrei caldera (CFC) is a type-location for this kind of activity escalation. CFC offers unique opportunity to join volcanological information to a long record of geochemical parameters. This allows understanding the role that magmatic system plays on variations displayed by the hydrothermal system. We model uneruptive unrest episodes as driven by *i*) the shallow emplacement (~4 km depth) of one volatile-rich magma batch ascending from a deep (≥ 8 km) magmatic body of regional extent, *ii*) subsequent gas separation with degassing driven by crystallization and *iii*) fluxing from the deep magmatic body. Our model matches three decades of geochemical constraints from fumarole discharges, as well as data from

melt inclusions of past CFc eruptions. Besides, magma physical properties demanded for modeled degassing conditions are in good agreement with existing geo-physical data. Our results open new perspectives to the definition of unrest scenarios at highly-populated CFc, as well as other resurgent calderas (e.g., Orsi et al., This Assembly).

1.1-P-83

Historical Basaltic Pyroclastic Flows on São Jorge Island (Azores): A High Volcanic Risk

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Pyroclastic flows are highly hazardous because of their devastating impacts on people and the environment around volcanoes. Most commonly, pyroclastic flows involve andesitic or dacitic lava and are associated with eruption-column collapses or failures of active, unstable lava domes (e.g., at Merapi, Colima, Mt. Pelée, Unzen, and Mt. St. Helens). However, basaltic pyroclastic flows are much more rare but have occurred (e.g., Aso, Fuji, Etna, Ulawun). For the Azores archipelago, two historical eruptions on São Jorge Island (1580 and 1808 A.D.) apparently produced nuées ardentes of basaltic composition, which killed about fifteen persons in 1580 A.D. and more than 30 in 1808 A.D. Historical accounts indicate that precursory earthquake activity preceded and accompanied both eruptions, which consisted of highly explosive phases alternating with brief effusive episodes. The most explosive events, of phreatomagmatic origin, generated basaltic pyroclastic flows. The 1580 A.D. eruption was described by the local people as “a terrible cloud that burn as fire” and also a glowing cloud that contained “globes of flame.” The 1808 eruption was described as a “fire typhoon that rose, making a frightful and glowing cloud.” Such descriptions in the chronicles are best interpreted as occurrences of pyroclastic flows. Unfortunately, because of intense weathering and agricultural disturbance, these historical pyroclastic deposits are not well preserved in the geologic record. However, prehistoric surges and block-and-ash flows with ¹⁴C datable charcoal (e.g., 2,880±60 BP) are recognized at several sites on São Jorge Island, demonstrating that repeated phreatomagmatic eruptions have occurred repeatedly in the geologic past. Thus, there exists a high probability of the recurrence of basaltic pyroclastic flows during some future eruption. Given the very steep slopes of this narrow, linear island and the very close proximity of populated areas to young volcanic centers, such flows would pose severe volcanic hazards.

1.1-P-84

Tenerife's Volcanic Tremor Signals Driven by Strong Atmospheric Pressure Changes?

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A seismic swarm in April 2004 was the first documented volcanic reawakening in Tenerife Island since the last eruption in 1909. During the following months and until mid 2005 there was an increased in CO₂ diffused emission and onshore earthquakes, some of them felt. LP events and long duration periods of volcanic tremor were also reported. It's been proposed by different authors that a deep injection of a small batch of magma that did not end in a volcanic eruption, followed by migration of hydrothermal fluids, could be the cause of the volcanic unrest. Since then, sporadic volcanic tremor signals are recorded in CCAN, a IGN seismic monitoring station situated in Las Cañadas, but the lack of onshore seismicity suggests a different origin. After evaluating and analyzing the barometric pressure record of an ACANMET meteorological station (La Laguna-475 m); atmospheric sounding data; NCEP reanalysis charts; CO₂ diffuse emission graphs from TFE01, a ITER geochemical station at the summit cone of Teide volcano; and seismograms and spectrograms records from CCAN, we propose that sporadic volcanic tremor signals are owed to great barometric pressure variations that could be showing a different scenery in Tenerife island volcanic system.

1.1-P-85

Structural Lineaments Inferred from Remote Sensing: An Application to Geological Mapping and Landslide Susceptibility Evaluation in the Island of Santiago

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The remote sensing data (optical and radar) was used with the purpose of identify the structural lineaments that crosscut the geological formations that composed the bedrock of the Santiago island (Cape Verde). Besides tectonics, this study also provided new insights to the evaluation of possible areas of landslide instability. The Cape Verde archipelago, located in the Atlantic Ocean some 500–800 km off the coast of Senegal. Hotspot activity around 19–20Ma or, alternatively, around 21–22Ma resulted in a large crustal feature rising 2 km above the oceanic floor, the so-called Cape Verde Rise, on which the Cape Verde Islands are situated. Santiago is an NNW-SSE elongated Island. The volcanic stratigraphy includes: (1) an older Volcanic Complex associated to proto-insular and submarine volcanism and (2) a sequence of volcanic formations and complexes dominated by subaerial volcanic events.

With the purpose of recognizing the structural lineaments and to contribute for a better understanding of the genesis and evolution of this island, remote sensing techniques were applied to data from sensors operating in the optical spectrum (ASTER). The studied image, level 1B, collected during the dry season (02-04-03), was geometrically corrected on the basis of the avail-

able topographic data and georeferenced to U.T.M. projection system with datum WGS-84. A digital elevation model of the island, with a pixel of 10 m, was built from topography and used in the lineament analysis. For this purpose directional filters were applied on the optical data as well as on the elevation data. The lineaments were traced automatically and by visual inspection; the Geomatica software (v10.1), from PCI, was used in both cases. A dense lineament network was interpreted, dominated by N10-30°E, N45-65°E, E-W, N50-70°W and N15-35°W directions. The N10-30°E and N45-55°E systems control the main morphostructural features, and seems to be the focus of the main volcanic eruptions. In the first case, 5 different units were identified. Field observations in all units outcropping in this region were carried out in order to determine qualitatively its cohesion, state of change and degree of fracturing, and these factors, combined with the slopes and tectonic alignments (recognized by remote sensing techniques and by direct observation) allowed to obtain through GIS modeling a map of regional susceptibility to mass movements. This map led to the identification of a high or very high degree of susceptibility to 18% of geographical area studied (ca. 145 km²), which should be taken into account for land planning purposes.

1.1-P-86

New Active Rhyolitic Eruption Centers, Eastern Foot of the Ecuadorian Andes

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Within the recently recognized Ecuadorian rhyolitic province (ERP) (Mothes and Hall, 2008; Hall and Mothes, 2009) and adjacent to the active andesitic volcanic chain of Ecuador's eastern cordillera, the discovery of the young Aliso volcanic complex at the eastern foot of the Andes extends the ERP 40 kms eastwards. There, it is separated from the Back-Arc alkaline volcanic zone only by an active tectonic fault zone (TFZ) that displaces the Northern Andean Block from the South American plate. The Aliso volcanic complex has a rough horse-shoe-shaped edifice, 20 km in diameter, that is drained eastwards by deep river valleys. Aliso's higher elevations (max. 4300m) were glaciated in the Pleistocene, however today a sub-tropical cloud forest prevails at its lower elevations (min. 1800m). The edifice's west flank remains inaccessible, but aerial photos show it to consist of many volcanic flow units inclined gently to the west. Along the eastern limits of the edifice where it is cut by the TFZ, five previously unrecognized volcanic centers are found (approx. 77°56'W; 0°33'S). Two of these, the Machangara and Cosanga centers, erupted basic pyroxene andesitic lavas (57.5% SiO₂ – 2.6% K₂O) that form isolated, flat-topped ridges between major valleys, apparently related to an early Aliso eruptive period. The other three centers, Holocene and Late Pleistocene in age, have only 800-1200m of relief, dome-like morphology, and occur only within the TFZ. Rhyolitic domes and dome-collapse deposits, ignimbrites, lava flows of Si-andesites and dacites, lahars deposits, and their re-worked products are all recognized; biotite-amphibole-sanidine are common minerals. From north to south these centers include El Dorado (74% SiO₂ – 4.3%

K₂O), Huevo de Chivo (76% SiO₂ – 4.4% K₂O), and Pumayacu (lavas: 61-66% SiO₂ – 4.3% K₂O and tephra: 75% SiO₂ – 5% K₂O). Pumayacu's latest eruption post-dates 2000y old cultural remains; it is an important source of obsidian found in nearby archaeological excavations. A biotite-hornblende granitic intrusion of mid-Pleistocene age outcrops in the NE corner of the complex and appears to be chemically related to the volcanic rocks.

1.1-P-87

Suggested Mechanism for Growing and Dismantle of Volcanic Islands.

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A new physical theory entitled "Yield and strength theory of materials" is applied to a simple model of the earth, allowing a better understanding of volcanic phenomena. In particular, growing and dismantle of volcanic edifices like Canary Islands. Liquid magma is generated by rock extrusion at the Gutenberg boundary. This happens by mechanical failure of the deep lower mantle induced by the large difference between the tangential and radial stresses. The magma violently escapes from the outer core producing a cyclone movement in the ionized liquid magma that is responsible for the earth magnetic variations. Magma raises by dykes progress up to 800 km above D". From this height up to Lehmann's discontinuity (231 km depth), magma raises by blob extrusion with preferred direction between 45° and 90° with zenith. At this discontinuity, a very thin melted layer is responsible for strong scattering of s and p waves at 15° surface. This liquid discontinuity marks the bottom of the asthenosphere. Magma blobs are absorbed by this layer producing deformation of the asthenosphere, heat flow to the surface and faults aperture. Hydro magmatic processes take place at rifts in mid oceans and produce the island elevations above the crust. The first stage of island growing allows fluid magma to open the way up to the surface through dykes. Hence, the first aerial emissions produce shielded volcanoes. As the dykes density and the thickness of the edifice increases, more difficult is for new dykes to grow through the enlarged crust. This stops the island growing. New dykes will spread out at Moho layer to some point bellow shore where the convex crust curvature and the smallest thickness will induce crust fracture and hydro magmatic activity near shore. This is in the origin of landslides with highest risk near most populated areas.

Session 1.2

1.2-O-01

Mechano-Chemical Model of the Caldera-Forming Eruption Initiation.

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Voluminous caldera forming eruptions have the strong-

est impact on the environment including man habitat. Interplay of several factors may cause accumulation and explosive eruption of the large volumes of silicic magmas. 2D numerical analysis demonstrates that regional faults may facilitate magma storage and general roof collapse at the strong enough overpressure (Simakin and Ghassemi, 2010). Closer consideration of the medium size calderas such as Ksudach and Academy Nauk (Kamchatka) confirms location of the correspondent magma chambers in the footing wall of the normal faults intersecting their roofs as predicted theoretically. Our simulation demonstrates also that magma cooling and solidification with volume shrinkage causes subsidence of the footing wall of the regional fault intersecting chamber roof while at the (seismic) unlocking of the normal fault in general position it's hanging wall moves downwards. Change of the movement sign occurs near caldera wall producing stresses and local fracturing hosting geothermal systems. On site observations on the Academy Nauk caldera (Leonov, 2009) confirms interpretation based on the calculations and satellite images analysis. Lost of coherence of the faulted roof exposing magma to almost ambient pressure is expected to occur at the fast enough magma pressure increase. Slow loading with years time scale would not lead to the high overpressures (up to 30-60 MPa) due to the viscous dissipation of deviatoric stresses. Intrachamber degassing stands for the most plausible candidate for such ultra-fast loading. CO₂ release into the water bearing magmas will cause water extraction into CO₂ rich bubbles. Our numerical modeling shows that nonequilibrium local vesiculation by this mechanism occurs even in the case of the net CO₂ undersaturation. Involvement of the CO₂ induced intrachamber vesiculation is anticipated for Tenerife (Granadilla) caldera forming eruption. References: Simakin and Ghassemi, 2010, Bull Volcanol; Leonov, 2009, J. Volcanol. Seismol.

1.2-O-02

Bomb and Ash Flow Deposits: Genesis and Case Studies

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Pyroclastic density current deposits are divided in two major types: pumiceous ignimbrites and block-and-ash flows. Other types of small-volume (<5x10⁷ m³) pyroclastic density currents are scoria-ash, spatter-rich, and bomb-and-ash flows. Examples of the latter type are

from historical eruptions at Asama (Japan), Cotopaxi (Ecuador), Tungurahua (Ecuador), Mayon (Philippines), Arenal (Costa Rica) and Fuego (Guatemala), and prehistoric examples at Aso (Japan), Tungurahua, and Fuego. The proposed forming mechanism is the existence of a lava pool in which an input in the magma triggers a "boiling over" process, Strombolian fountain eruption or a crater wall collapse. The resulting deposits are mostly composed by high- to moderate-vesiculated, cauliflower-breadcrusted bombs, confined to narrow valleys (30-200 m wide), with volumes of 0.2-30x10⁶ m³. The deposits are clast-supported, less frequent matrix-supported, and variations between both types, and a bimodal grain size distribution, poor in fine ash contents. The bombs (oblong or spherical, rare planar shape), up to several meters in diameter, can also be plastically deformed and imbricated with post-depositional vesiculation and even flow. The concentration and maximum diameter of bombs increase significantly from the base to the top of the deposit, and from the summit to the front, forming ridges and levees. The juvenile blocks and bombs make 60-90 vol. %, and the fine-ash depleted matrix represent about 20-60 vol.%. The faceted non-juvenile blocks (2-5 vol%) come from the crater walls (erosion or collapsed) and/or from the bulking process during the flow movement. Runout distances vary from 2 to 7.6 km, and the equivalent coefficient of friction between 0.28 and 0.65. In other cases, the deposits are transition to block-and-ash-flows or to scoria-and-ash flows. The recognition of these deposits provides a better understanding of small-volume pyroclastic flows in steep stratovolcanoes, which pose a high-volcanic risk for tourism development on highly visited volcanoes.)

1.2-O-03

Lake Monoun is Degassed, Lake Nyos is still to be Degassed

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Lakes Nyos and Monoun in Cameroon experienced a "limnic eruption" in mid-1980s. The eruptions were caused by accumulation of excessive magmatic CO₂ in the deep water of the lakes. Artificial degassing of the lakes has been successfully going on since 2001. At Lake Monoun the latest CO₂ profile indicates that the lake has been degassed to safety. The Monoun degassing system has already lost its gas self-lifting capability because pCO₂ has been reduced to a very low level in the bottom water. This will lead to CO₂ gas rebuilding, since the natural recharge is continuous. To avoid accumulation of CO₂ in the future, it is necessary to install a new system to pump out CO₂-containing bottom water to the surface. The pump of the system can be powered by solar energy. The system we envisage can remove the bottom water at a rate comparable with that of the natural recharge.

Degassing of Lake Nyos needs to be continued. CO₂ concentration of water at 203 m where water is tapped

is falling. This lowers the rate of gas self-lift, resulting in a longer degassing period unless the number of degassing pipes is increased. After gas self-lifting has ceased, a system for pumping the bottom water, similar to that proposed for Lake Monoun, will be eventually required to sustain the safety of the lake.

Noble gas systematics of Lake Nyos suggest that (1) the recharge water accumulates in a sub-lacustrine reservoir where magmatic noble gases mix with atmospheric gases carried by groundwater, and (2) judging from the ³He and ⁴He profiles which show a maximum at 180 m, the recharge water may be supplied to the lake mostly from the side-wall of the lake at that depth.

1.2-O-04

Modelling Pyroclastic Currents as Two Layers.

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The majority of existing numerical pyroclastic flow models utilize the same governing equations and physics to describe the flow throughout its depth. High concentrations at the base of the flow result in a collapse of any dilute cloud assumptions, due to a change in the governing physics for this more granular regime. We present a simplified two-layer pyroclastic flow model, which incorporates different physics to represent the dense and dilute regions of column collapse pyroclastic density currents. The governing physics in each layer is described by depth averaged isothermal bulk continuum conservation equations, where the avalanche is assumed to have a constant density. The two layers evolve separately, but are coupled through mass exchange as suspended ash in the dilute cloud settles into the underlying dense basal layer. Representative calculations of column collapses with this model indicate that the runout distance of the upper dilute current, and the associated runout time, increase with increasing column height and decreasing particle size. The independent runout of the basal flow exhibits opposite behavior to that of the parent dilute current, increasing with decreasing initial column height and increasing particle size. Observed runout distances can be calculated for basal flows using a Coulomb friction law, but deposit morphology is not well reproduced and is more realistic when an empirical slope-dependent sedimentation rate is included. Dominant flow behaviour is controlled by the rate of mass transfer from the parent suspension current into the dense underflow. Tall fine-grained column collapses transfer their mass slowly to the dense basal flow, and are well described by dilute cloud assumptions. Short coarse-grained columns transfer mass rapidly into the basal flow, such that the material propagates as a concentrated suspension for the majority of its travel distance and is better described by the physics of granular avalanches.

1.2-O-05

Rainfall-Triggered Lahars at Volcán de Colima, México: Surface Hydro-Repellency as Initiation Process.

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Volcán de Colima is currently the most active volcano in Mexico. Since 1998 intermittent activity has been observed with vulcanian eruptions, lava flows and growing domes that have collapsed producing several block-and-ash flow deposits. During the period of heightened activity since 1998 at Volcán de Colima, pyroclastic flows from dome or column collapse have not reached long distances, most of the time less than 6 km from the crater. In contrast, rain-induced lahars were more frequent and have reached relatively long distances, up to 15 km, causing damage to infrastructure and affecting small villages. In 2007 two rain gauge stations were installed on the southern flank of the volcano registering events from June through to October, the period when rains are intense and lahars frequent. By comparing lahar frequency with rainfall intensity and the rainfall accumulated during the previous three days, lahars more frequently occur at the beginning of the rainfall season, with low rain accumulation (< 10 mm) and triggered by low rain intensities (< 20 mm/hr). During the months with more rainfall (July and August) lahars are less frequent and higher peak intensities (up to 70 mm/hr) are needed to trigger an event. In both cases, lahars were initiated as dilute, sediment-laden streamflows, which transformed with entrainment of additional sediment into hyperconcentrated and debris flows, with alternations between these two flow types. A hydro-repellency mechanism in highly vegetated areas (i.e. evergreen tree types with considerable amount of resins and waxes such as pines) with sandy soils can probably explain the high frequency of lahars at the beginning of the rain season during low rainfall events. Under hydrophobic conditions, infiltration is inhibited and runoff is facilitated at more highly peaked discharges that are more likely to initiate lahars.

1.2-O-06

Lake Nyos Dam to be Reinforced

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In addition to the problem posed by the huge stock of CO₂ gas in Lake Nyos, its security and that of nearby communities is further threatened by the specific geological and geotechnical characteristics of the natural dam at its outlet. This 40m high dam, composed of poorly consolidated and relatively friable pyroclastic rocks, is subjected to mechanical and chemical ero-

sion. Its collapse could result in the release of over 50 million m³ of water resulting in a major flood with severe damage to the environment and downstream communities as far away as neighbouring Nigeria. Until recently, disagreement persisted amongst scientists regarding its age, the timing and potential to fail as well as suggested remedial measures resulting essentially from the absence of precise knowledge of its internal structure. Geological, geotechnical, geophysical, topographical and bathymetric as well as hydrological considerations indicate the need to reinforce it so as to preempt any future collapse and more importantly, preserve the huge Lake Nyos freshwater resource for tomorrow's developmental needs and generations. The project is currently being fine-tuned and work is expected to start soon.

1.2-O-07

An Investigation of the Runout of Volcanic Flows Using Laboratory Experiments and Discrete Element Simulations

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Volcanic debris avalanches and pyroclastic flows are gravity-driven flows of blocks and ash particles generated by collapse of part of the volcano structure. These flows typically follow the underlying topography, and runout for several kilometres with speeds in excess of 100 km/hr. The key questions from a hazard assessment perspective are how far and how fast these flows can move i.e. their mobility. Volcanic flows typically show a higher mobility than other geological flows for reasons not yet understood, and understanding and parameterising flow mobility is critical for volcanic hazard assessment.

We have designed laboratory experiments which consist of releasing granular materials on an unconfined chute that mimics the natural topography of a slope. We have also simulated the flow dynamics by numerical discrete element simulations using the code WinMimes developed at the Massachusetts Institute of Technology (MIT). Preliminary experiments have been focused on exploring the influence on runout (maximum downslope deposit distance) of how the granular material is released. We have compared the cases of one large volume released at once (single pulse) or of a progressive failure (the entire volume is divided in several constant periodic pulses). In the latter case, the final deposit characteristics depend on the individual smaller volumes and it is actually only the first pulse which determines the final runout, which remains constant for all the succeeding volumes. As a consequence it is only the first pulse which influences the mobility. Numerical simulations carried out at MIT confirmed these experimental results. In order to establish the limits of these findings, we will present results from additional experiments and further simulations where we vary the granular volume released in the progressive failure, and the material characteristics, including density and grain size.

1.2-O-08

Numerical Investigation of the Tsunami Induced by Pyroclastic Flow entering the Sea during the 1883 Krakatau Eruption

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The 1883 Krakatau eruption in Indonesia is a VEI 6 caldera-forming eruption that caused 36,000 death tolls, most of whom were suffered from a huge tsunami during a climactic phase. This eruption provides a good opportunity to examine impacts of devastating volcanogenic tsunamis on coastal human activities and oceanic environments. Although a lot of studies have challenged to reveal the tsunami generation mechanism, there have been problems with the following three major hypotheses: 1) caldera collapse, 2) phreatomagmatic explosion, and 3) pyroclastic flow entering sea. In this study, a pyroclastic flow hypothesis was focused on and numerically analyzed using two types of two-layer shallow water model which can simply describe the effects of interaction between pyroclastic flow and seawater. One of the models is for denser flow than seawater, and another is for lighter one. Parameter studies were conducted under the conditions that a pyroclastic flow has a density of 900-1100 kg/m³ and a mass flux of 10⁷-10⁸ m³/s enabling to explain a shoreline displacement as observed, and that the flow with a volume of 10-20 km³ erupts at the north of the old Rakata Island. The results show that computed wave heights of tsunamis are broadly consistent with historical wave data in coastal areas when the flow has a volume of 20 km³ and a mass flux of 10⁸ m³/s. In that case, at Batavia in the north of Java, the first 1.7 m positive peak arrived 2.7 hours after the climactic eruption with the wave period of about 1.7 hours. This wave characteristic well matches with a tide gage record. The result suggests that a voluminous pyroclastic flow entering sea would be a plausible mechanism of a huge tsunami during the 1883 Krakatau eruption.

1.2-O-09

Pattern and Causes of Cyclic Eruptive Behavior at Piton De La Fournaise Volcano after the 2007 Summit Caldera Collapse

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Piton de la Fournaise is one of the most active volcanoes on Earth, with an average (over the last 50 years) of one eruption every 8 months and short quiescence periods (1-6 years). Two major eruptions (130-150 Mm³) have occurred during the last 100 years (in 1931 and 2007), each culminating in the collapse of a small summit caldera. Unexpectedly, eruptive activity resumed quickly (about 1 year) after the 2007 climactic episode

and in less than 6 years after the 1931 event. After 2007, the reawakening occurred through two very similar cycles of summit intra- and circum-caldera activity (2008-2009; 2009-2010). Each cycle consists in an initial shallow intrusion (ca 1-1.5 km asl) associated with crack opening at the surface and formation of new fumaroles, then followed by three closely spaced small volume (<1.5 Mm³) eruptions. In each cycle, the last eruption represents the main event in terms of duration and magnitude. The integration of geophysical and geochemical data suggests that deep recharges (>6.5 km below volcano summit) occur several months before the volcano reawakening. Moreover, sustained feeding of the shallow plumbing system is recorded since 2000 by a general trend of increase in eruptive temperatures. Deep recharges of high-Mg basalts represent the key factor controlling the recent eruptive behaviour of Piton de la Fournaise volcano. On the contrary, shallow dyke propagation and the position of a specific eruptive fracture are mostly controlled by pre-existing discontinuities associated either with the 2007 caldera collapse event or with older circum caldera features (e.g. lava lakes, older fracture networks).

1.2-O-10

What Do Pyroclasts Tell Us About An Eruption?

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Despite recent advances by means of experiments and increasingly reliable monitoring methods, volcanic eruptions still remain highly unpredictable in what concerns the most likely type of activity and the duration of an eruption. This uncertainty hinders hazard assessment tremendously. In an effort to counter this problem, a comparison of natural deposits and pyroclasts from laboratory experiments has been undertaken.

Laboratory experiments open the possibility of substantial advances in quantitatively understanding fragmentation processes. We performed rapid decompression experiments at well-controlled conditions of pressure and temperature with samples from Unzen (Japan) and Popocatepetl (Mexico) volcanoes. The experimental pyroclasts have been investigated for their grain-size distribution and fractal dimension of fragmentation (D_f). This permits precise characterization and quantification of the fragmentation efficiency and its dependence on changing material properties and the physical conditions at fragmentation.

After each experiment, the grain-size distribution has been evaluated by dry sieving ($x > 250 \mu\text{m}$) and laser refraction ($x < 250 \mu\text{m}$). The open porosity of the used sample and the applied pressure define the fragmentation behaviour. Above a minimum combination of the two (fragmentation threshold), fragmentation is increasingly efficient. Fractal fragmentation theory was applied to each sample set by measuring the fractal dimension of fragmentation (D_f). We observe a general linear increase of D_f , i.e. the efficiency of fragmentation, with the energy for fragmentation, irrespective of the origin of a sample.

It emerges from this study that the investigation of experimental pyroclasts and the comparison with natural deposits greatly improves our mechanistic understanding of magmatic fragmentation. This may contribute greatly to an enhanced and case-sensitive hazard assessment. We are convinced that the fractal dimension may be utilised as a proxy for estimating the explosivity of volcanic eruptions. We are currently testing the suitability of iso- D_f or iso-explosivity contour maps.

1.2-O-11

Dynamics of Vulcanian Eruptions: New Insights from Fragmentation Experiments, Ballistic Analysis and Video Observations

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Vulcanian eruptions are frequent, short-lived explosions that are produced by rapid decompression of pressurized magma. These explosions often occur by the disruption of a dense caprock plugging the vent, which originates ballistic projectiles that are ejected at high velocities and represent a common hazard associated to this kind of eruptions. In order to improve hazard assessment, we need a better understanding of the relationship between porosity, gas overpressure, ejection velocities and maximum range of the ballistic projectiles. We present a 1-D model of Vulcanian eruptions that considers the energy balance in decompression of a pressurized magma below a caprock, followed by fragmentation and acceleration of pyroclasts. We tested the model via fragmentation experiments at 850 °C and initial pressure (<25 MPa) with a shock-tube apparatus. We measured the ejection velocity of a caprock propelled by the expansion of an underlying gas-particle mixture produced by in situ fragmentation by rapid decompression of natural samples. Then we combined this model with a ballistic model which considers drag coefficient data measured experimentally for volcanic particles. Finally, we applied the combined model to different Vulcanian eruptions at Popocatepetl volcano, Mexico, and calibrate it with the maximum range reached by the ballistic projectiles and their corresponding travel times measured from videos of the explosions. Our study relates the zones that could be affected by ballistic projectiles with the initial pressure, which can be estimated from seismic and geophysical monitoring, providing valuable information for more refined hazard assessment of active explosive volcanoes.

1.2-O-12

Rock Strength Data from the Cascade Range Volcanoes, USA

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The Cascade Range is a major mountain range in North America, extending for almost 1150 kilometers from southern British Columbia, through Washington, Oregon to northern California. They are comprised mainly of andesite lavas, dacite lava domes, ash, pumice and pyroclastic sediments. All the known historic eruptions in the contiguous United States have occurred from Cascade Range volcanoes with major eruptions occurring at Lassen Peak in 1914 – 1917 and Mt St. Helens in 1980, and 2004 – 2008. Beginning in the late 1990s until the present Mt. Rainier, Mt. Hood, Mt. Adams, Mt. St Helens, Mt. Shasta, and Lassen Peak have been studied as they exhibit edifice collapse, major debris flow activity, or a combination of both. The collection of strength data from individual volcanoes is critical in assessing past and potential edifice collapse.

Strength data for input into failure mechanism analysis utilized remote sensing to direct locations for sampling. Samples were laboratory strength tested (unconfined, triaxial and direct shear) and insitu rock mass discontinuity measurements were obtained from all six volcanoes. Comparing individual volcanoes the data show that rock mass strength differs from volcano to volcano based on degree of hydrothermal alteration, major discontinuity set orientations, and rock mass mineralogy on potential failure surfaces. Mt Rainier, Mt. Baker, and Mt. Hood show extensive hydrothermally alteration whereas Mt St. Helens lacks hydrothermal alteration though contains extensive areas of highly fractured rock. A summary of peak and residual friction values from fresh andesite and dacite discontinuities varies from 35 to 50 degrees (peak) with cohesion values varying from about 15 – 200kPa, residual values varied from 27 – 33 degrees. Hydrothermally altered andesite and dacite has a wide range in peak friction as a result of intensity and style of alteration, though residual friction values are markedly lower, 12 – 22 degrees, than peak friction values.

1.2-O-13

The 1886 Maar-Forming Rotomahana Segment of the Tarawera Eruption, New Zealand

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In 1886 an eruption began on Tarawera Mountain, in New Zealand, and subsequently extended along a fissure to the Rotomahana basin. On the mountain, the Tarawera eruption produced a fissure, fissure-rim cones and a widespread Plinian fall deposit. Along the Rotomahana segment, deep maar craters, now filled by Lake Rotomahana, were excavated, and about 0.3 km³ of country-rock rich tuff-ring deposits were emplaced around them, primarily by surges. Casualties from Rotomahana surges made this New Zealand's most deadly eruption. The Rotomahana fissure was excavated by phreatomagmatic eruptions, which produced a range of relatively dense basaltic fragments that are ubiquitous through out the deposit, but vary in proportion, abundance, and dominant grain size. The Rotomahana basalt fragments differ from strongly ve-

sicular basaltic fragments that were dispersed by the Tarawera eruption plume across the area of Rotomahana surge deposition and admixed into the surge clouds during deposition. Ongoing work is designed to determine the state of the magma at the time of its fragmentation along the Rotomahana sector. Composite bombs from the northeastern end of Rotomahana's fissure display complex histories of assembly and are preserved in a deposit only a few-metres thick, both suggesting low and unsteady rates of magma supply to the erupting fissure. The lag between the eruption's start on Tarawera and initiation of explosive eruptions along the Rotomahana segment could have resulted from slower rise of magma toward the latter, with small magma flux further reflected by the relatively high (commonly ~60-95%) proportion of wall-rock fragments in the deposits, particularly where groundwater occupied a hydrothermal system in thick volcanoclastic deposits cut by the fissure. The increase in eruptive violence that accompanied extension of the fissure to water-rich sites away from the initial eruption centre was mimicked at a smaller scale during the 1965 eruption at Taal.

1.2-O-14

Mega Rockslides in Canary Islands: Geomechanical Properties for Hyaloclastite Rocks in Tenerife and its Relation to the Stability of the Volcanic Island Flanks.

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The failure mechanisms that could originate the mega paleo-rockslides of Güimar and La Orotava in Tenerife (Canary Islands) are analyzed, based on the geomechanical site investigations carried out on the pre-failure volcanic materials of Tenerife island flanks. Geological and geomorphological modelling and geomechanical characterization of the materials are presented. Hyaloclastites rocks are forming the submarine substratum of the island edifice presenting a highly deformable behaviour. Preliminary stability analyses suggest potential failure surfaces in the hyaloclastite rocks.

1.2-O-15

Development of Flow Fields from Historical Eruptions in Tenerife

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Historical eruptions in Tenerife have been mainly effusive and strombolian. All have developed flow fields that on one occasion, during the 1706 eruption of Garachico, caused severe destruction. In the 100 years since the last eruption occurred, the population of the island has shown a 5 fold growth, which places some municipalities within the largest populated areas in Spain. Given the increased vulnerability that this growth implies, understanding the mechanisms that condition the evolu-

tion of lava flow fields is crucial for assessing the hazards posed by lava flows to these populations.

The study of the evolution of unconfined lava flows from historical eruptions on the island has shown 3 main stages in the development of flow fields. During the first stage, comprising the first 17-36 hours of eruption, the eruption produces a small number of lava flows (1 to 4 in the cases investigated) that advance down slope. Velocities recorded in this stage (for average slopes of 6°-9°), can be of the order of 0.12 m/s. This stage is followed by a period of 2-7 days during which the initial fronts stagnate and thicken by the continuous supply of material and the flow fields widen by lateral addition of flows but do not lengthen substantially (only in narrowly confined flows does this extra material contribute to the final length of the flow field). In the final stage, secondary flows generate through weak areas in the over thickened front of the flow field or from localised accumulations in levees. In the reconstructed eruptions this has occurred within the first seven days of eruption and after, at least 60 hours from the beginning of the effusion. Special precautions should therefore be taken during the two main lengthening phases: the first and the last stage of development of a flow field.

1.2-O-16

Magma Convection in Complex Reservoirs as Source of Geophysical Signals.

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Understanding magmatic convection and mixing inside volcanic reservoirs is of primary importance because such processes may be linked to magma chamber replenishment and thus trigger new eruptive events. In this work, a number of numerical simulations of the dynamics of magmatic fluids with different characteristics flowing in feeding systems of various complex geometries is shown. Alongside with that, geophysical signals originating from such dynamics are examined. Numerical simulations of magma dynamics are performed using the code GALES (Longo et al., 2006), which solves the two dimensional transient dynamics of multi-component fluids in compressible to incompressible regimes. The simulated domains include simple dykes, as well as more complex chamber+dykes systems representative of real volcanoes, in particular Campi Flegrei and Etna (southern Italy). Fluid dynamics results show complex patterns of magma convection and mixing, that cause variations of the pressure and stress fields in the simulated domain. Outputs of fluid dynamics simulations in terms of pressure and stress variations at the reservoir boundaries are propagated in the surrounding rock media. Wave propagation is performed both by means of analytical Green function integration, to provide first order results, and using a lattice Boltzmann numerical code, ELM (O'Brien and Bean, 2004). The latter allows to consider the whole three dimensional velocity and density structure of the volcanic edifice, as well as free surface and topography effects. Results show that pres-

sure oscillations associated to convection have characteristic time scales in the range of hundreds of seconds, and propagate in the surrounding rocks with wavelengths of the order of hundreds of kilometers: they can be recorded by modern broadband instruments. Such signals may represent a precise signature of potentially dangerous processes happening at depth, thus standardized methods for their detection and analysis should be set up at volcanic observatories.

1.2-O-17

It's All in The Matrix: Infrequent Cohesive Lahars at Cotopaxi May Increase Hazards

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Throughout the historical era, Cotopaxi volcano, Ecuador produced many eruptions and lahar flows following the Spanish conquest in 1532. Of these eruptions, most pyroclastic flows were rich in scoria bombs, but relatively poor in matrix. Impressive lahars formed from the destruction and ingestion of portions (~ 10%) of the then >1 km³ glacier. These often travelled hundreds of kilometers down high-gradient Andean stream channels. Due to the low cohesiveness and the granular-rich nature of these lahars, most transformed to hyperconcentrated streamflows by dilution with water—this transformation began around 40 km downstream of source. A smaller percentage of eruptions produced matrix-rich pyroclastic flows, that upon mixing with the glacier cap, resulted in distinct cohesive lahars that ultimately suffered little transformation in their fabric, until far downstream. While in transit such cohesive lahars were capable of transporting boulders 1-2 m diameter in suspension for great distances. At present, Cotopaxi's glaciers have receded dramatically and are highly fractured and probably more vulnerable to pyroclastic flow-provoked destruction and incorporation. In a future eruption, if fines-rich pyroclastic flows are generated, they could effectively mobilize the reduced glacier/snow mantle. The lahar's cohesive nature may promote accentuated bulking of the abundant debris accumulated in stream channels since the last major eruption 133 years ago. Because lahar dilution can not readily occur in a cohesive lahar, potential impact to communities and infrastructure far downstream could be far greater and broader. This is in spite of the fact that the glacier cover is greatly reduced and the water supply for future lahar generation may be less than during previous occasions.

1.2-O-18

Explosive Eruption History of Tenerife: Hazard and Risk Implications (Or, Where Should We Run to?)

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The basaltic oceanic island shield volcanic complex (12 Ma to present) of Tenerife, Canary Islands, developed a summit phonolitic magma chamber and vent system about 4 Ma. The early history of this phonolitic system is poorly known, but consists of both lavas and pyroclastic deposits, whereas the last 2 Myr has been marked by three major explosive eruption cycles, each caldera forming. The Ucanca cycle (1.59 – 1.07 Ma), is also relatively unknown, but contains numerous welded fallout deposits, some pyroclastic flow deposits and lavas. The Guajara cycle (0.85 – 0.57 Ma) involved the eruption of multiple fallout and pyroclastic flow units, including: the Arico Member (0.63/0.66 Ma, a widespread welded to non-welded ignimbrite; > 2.3 km³ DRE); the Abades Member (~0.60 Ma, three ignimbrites and a fallout unit up to 4 m thick, >1.6 km³ DRE), and the Granadilla Member (0.57/0.60 Ma, a fallout unit <10 m thick, a major ignimbrite <15 m thick; estimated volume >10 km³ DRE). The Diego Hernandez cycle (0.37 – 0.17 Ma) includes: the Aldea Member (0.32 Ma, fallout and multiple pyroclastic flow units, >3 km³ DRE); the Fasnía Member (0.31 Ma, multiple fallout, flow and surge deposits, 13.5 km³ DRE min. volume), the Poris Member (0.27 Ma, multiple fallout, flow and surge deposits, 3.5 km³ DRE minimum volume) and the Abrigo Member, representing the climactic eruption (0.20 Ma, multiple lithic rich ignimbrites; 5-6 km³ DRE?). Although dispersal was mostly to the south and east, major deposits are found all around the island. Major eruptions occurred on average every 30 ka, and lesser eruptions, which today would cause havoc to the island's infrastructure and population, occurred perhaps every 2 ka during the two youngest major cycles. The last known phonolitic explosive event was the Montaña Blanca eruption at 2 ka, part of the modern Teide-Pico Viejo stratovolcano edifice, which is a complex of lavas, and pyroclastic deposits, not unlike the DHF. Explosive and lava basaltic eruptions, occurring perhaps every 100 years, although small in volume represent significant hazards given the current population. Principal hazards on Tenerife are fallout deposits, pyroclastic density currents including pyroclastic flows which may enter the sea, as well as landslides which could both generate tsunamis. Building specifications must be improved and comprehensive emergency plans developed.

1.2-O-19

The Role of Pyroducts (Aka "Lava Tubes") In Determination of Lava Flow Hazards on Effusive Volcanoes

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Pyroducts (also called lava "tubes", "tunnels", or "pipes") is the preferred term to describe subsurface lava conduits that supply lava to pahoehoe flow fronts on effusive (chiefly basaltic) volcanoes. The term, based on eye-witness accounts, was coined and published by Coan in 1844. As pointed out by Coan, pyroducts insulate flowing lava from heat loss, and can transport lava

much greater distances than can surface channels. Pyroducts are an important factor in explaining the gentle slopes and great diameters of shield volcanoes on Earth and in extraterrestrial worlds. Their transport characteristics are important to understand lava flow hazards, especially on oceanic volcanoes. Basaltic eruptions usually begin with gas-rich, high-fountaining phases that chiefly produce 'a`ā flows. Such flows are characteristically viscous and thick. Long-lasting basaltic eruptions will, however, commonly transition after a few months to eruptive styles characterized by low fountaining activity and direct production of relatively fluid and thin pāhoehoe lava flows. Such changes in eruptive style favor the formation of pyroducts if production rates are steady, and give warning that lava flows may develop enhanced potential to flow long distances and to threaten populated areas much further from eruptive centers. Fortunately, such pyroduct-fed flows may also be more amenable to lava diversion counter-measures.

1.2-P-01

2007-2009 Solar Occultation OP-FTIR Measurements: The Magmatic Plumbing System of Mt. Etna

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In this short note we present the results of open-path Fourier transform infrared (OP-FTIR) spectrometric measurements of the gases released from Mt. Etna in the period 2007-2009. The objective of this investigation is to better understand the main processes which control gas release at this volcano in terms of the overall gas budget. During 2007-2009, SO₂/HCl and SO₂/HF molar ratios measured with solar OP-FTIR showed a progressive increase during an eruptive event started on May 13th 2008, and some peaks related to 2007 activity at the Southeast crater (SEC). Combining these molar ratios with the SO₂ flux, measured using a permanent UltraViolet spectrometer scanning network, constraints on the shallow degassing system of Etna can be derived. The cumulative amounts of SO₂ and HCl emitted by Mt. Etna indicate that while over brief periods of time these two gas may be uncoupled, over longer periods they behave in a close-to-bulk degassing manner, such that the totality of gas released is that which would be expected based on original and final volatile contents measured using petrological analyses of eruptive products. We propose that a decreasing in the observed SO₂ degassing relative to HCl indicates a process of deep intrusion, in which magma rather than ascending to the shallow (~3 km depth) conduit is stored at depth where it may later erupt. On the contrary, reduced HCl degassing indicates a reduction in magma supply to the uppermost 500m of the magmatic system, which may occur during a shallow intrusion. Over the investigated period we observed both these processes, but overall the system remained very close to bulk degassing, suggesting that such intrusions are temporary deviations from a system which can efficiently degas essentially all the magma that enters the uppermost 4-5km of the feeding system.

1.2-P-02
Tephra Fallout Hazards at Quito International Airport (Ecuador)

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Tephra fallout is the most widespread hazard posed by explosive volcanic eruptions. Recent studies showed that Quito International Airport in Ecuador is among the four airports in the world which are the most at risk from tephra fallout. However, this study represents the first quantitative analysis of potential tephra accumulation from future explosive eruptions from nearby volcanoes that have affected in the past and/or could potentially impact the airport in the future (i.e. Guagua Pichincha, Reventador, Tungurahua, Cotopaxi, Pulagua, Cayambe and Antisana). For each volcano, we compiled a database of eruption parameters (e.g. total volume of tephra, column height, total grain size distribution) for past explosive eruptions. Using these databases, we set credible boundaries of eruptive parameters for potential future eruptions from these volcanoes. We used the tephra2 model (Bonadonna et al., 2005; Connor et al., 2008) to forecast tephra accumulation at Quito International Airport following explosive eruptions from the volcanoes of interest. TEPHRA2 was coupled with Monte Carlo simulations to address the hazards from tephra in a fully probabilistic approach. Input eruptive parameters are randomly sampled within probability density functions for eruption mass, column height and grain size distribution. Probability density functions emphasize the natural higher frequency of smaller eruptions compared to larger ones. Wind data are randomly selected within a wind field database spanning a period of 5 years (wind profiles recalculated 4 times daily from January 2004 to December 2008 by reanalysis project, Kalnay et al., 1996). Output is cast as hazard curves of tephra accumulation at Quito International Airport from each volcano, and/or as the probability that tephra accumulation will exceed some threshold value (e.g. 10 kg/m² equivalent to 1 cm of tephra) over a region of interest.

1.2-P-03
Spatial Distribution and Recurrence Interval Analysis for Radial Vents of Mauna Loa Volcano (Hawai'i)

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Mauna Loa has experienced 39 eruptions since 1832 (Barnard, 1995), corresponding to an average recurrence interval of 4.5 years over this 177-year period. The source vents for the vast majority of eruptions at Mauna Loa are located at the summit caldera and along the two rift zones (about 90% of historical eruptions). However, geological mapping suggests that a total of about 54 linear vents (both subaerial and submarine) are located outside the summit and rift vent regions.

Historical eruptions from these radial vents include the 1843, 1852, 1859 and 1877 eruptions of Mauna Loa. All, but the 1859 eruption, followed eruptive activity either, at the summit caldera, or the rift zones, or both. Since the most recent eruption that affected Kona, in 1950, Kona communities have expanded higher on the flanks of Mauna Loa and more significantly, developed areas are now located at radial vents on Mauna Loa's western and northern flanks. Therefore, the opening of new radial vents and future lava flows from radial vents of Mauna Loa could impact strongly upon the fast growing Kona district. We present here a statistical analysis of available repose intervals between past eruptions, applying models including Poisson, log-logistic, and Weibull distributions, three models commonly used to forecast future volcanic activity, as well as a bootstrap with replacement approach. Furthermore, in order to determine possible locations of future radial vent opening, we use a nonparametric kernel density method (Jaquet et al., 2008; Connor and Connor, in press) to estimate the spatial density distribution of radial vents at Mauna Loa volcano.

1.2-P-04
2007-2008 Volcanic Debris Flows of the Nevado del Huila Volcano (Colombia) and Changes on the Glacier Surface after the Eruptions.

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Nevado del Huila Volcano (5364 m.a.s.l.), in the Colombian SW, is conformed in its top by four ice capped peaks. The only known historical activity of this volcano had been related with hot springs, fumaroles and low instrumental seismic activity until the eruptions of 19-II-2007, 18-IV-2007 and 20-XI-2008 took place. Ash columns, gas emissions and primary lahars of different magnitude were associated to these eruptions, affecting the Páez river valley and towns settled into it. Inundation heights and volumes of the lahars increased in each of the successive eruptions. Velocities reached by the lahars considerably varied and arrival times to the Betania Reservoir were approximately between 10 and 8 hours. With these eruptions, notable changes were also produced on the volcano's glacier mass, showing a drastic receding in the glacier area during all this reactivation stage. After the 20-XI-2008 eruption, a crater on the glacier area began to develop between the Central and South peaks and a dome was emplaced into it, however another new dome is currently growing beside the previously emplaced. With both the volcano reactivation and the domes growing, expectation on the Páez, Símbola and Magdalena river valleys is maintained because of the possible occurrence of new

lahars that can affect them.

1.2-P-05

Initiative to Develop a Probabilistic Model to Forecast Large Eruptions at the Popocatepetl Volcano, Central Mexico

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In this work we report a new research initiative to forecast large eruptions at the Popocatepetl (Popo) volcano, Mexico. Popo is a 5450 m high volcano and it is one of the most active volcanic edifices in North America. After nearly 70 years of quiescence, in December 1994, Popo reinitiated a new episode of volcanic activity. The volcano is located in a densely populated region, at about 70 km from Mexico City downtown, and approximately 40 km from the city of Puebla, with hundreds of towns and villages within a 60 km radius from the crater. For these reasons, it is important a permanent monitoring of the geophysical activity of the volcano. We will study the local seismic activity by estimating the Times of Increased Probability (TIP) from data recorded by the local seismic network from 1988 to 2009. Also, we will analyze the variations of coda wave attenuation and the properties of the background seismicity (daily and cumulative number of seismic events, energy release, etc.). These parameters will be analyzed using probabilistic methods as the simple and multiple isotropic dispersion technique. To complete our research, we will incorporate to our model measurements of SO₂, ash fall, geomagnetic variations, and eruptive-column heights. These parameters may increase the probability of a successful eruption forecasting. Once the input parameters are automatically incorporated into the model, a probabilistic weight will be assigned to each of them using Bayesian networks with the purpose of determining the inter-dependency among all analyzed parameters. With these procedures, we will identify multiple variables probabilistically associated to important volcanic activity at Popo.

1.2-P-06

Hazard Maps of Pyroclastic Density Currents of San Salvador Volcanic Complex, a Tool for Long-term Forecast in El Salvador

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More than 1 million people live within the area of the San Salvador Volcanic Complex (SSVC); a composite stratovolcano with 25 flank vents. The main edifice Bquerón volcano (BV), which is considered one of the most dangerous volcanoes in Central America, is nested within the old San Salvador volcano, and had its last eruption in 1917.

This study extended the eruptive record of BV to 21 eruptive events. BV was formed by the superposition of lava flows and fall, surge and pyroclastic flow deposits between 36 and 3 ka. G1 sequence (<36 ka) is the product of a large explosive eruption and is considered as the beginning of BV construction. Six new pyroclastic sequences overlying G1 were identified. During the last 3 ka, the eruptive activity shifted to the surrounding areas of the main edifice, with both effusive and explosive eruptions. Seventeen secondary vents were generated and three explosive events took place from the central crater, including the 1917 eruption. The other two, Talpetate I and II events (cal. 1031±29 AD and cal. <1214 AD respectively), produced mainly surge deposits, suggesting the predominance of phreatomagmatic activity from the central vent and a change in eruptive style.

Detailed stratigraphy of a 137 outcrops in SSVC is described. The pyroclastic flow deposits of BV main sequences are outlined and isopach maps of the surge deposits are presented. Three hazard scenarios for surge and pyroclastic density currents are defined, integrating historical, stratigraphic and volcanological data. Then, hazard maps are produced on a GIS basis using the simulations obtained through FLOW3D and TITAN2D modeling software.

These maps can be useful tools for local authorities to improve their mitigation efforts. Together with the ash fall and ballistic projectile hazard maps produced recently, they can also be applied to land use planning and educational programs.

1.2-P-07

A New Numerical Model Describing Ballistic Trajectories and Collisions

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The determination of trajectories and travel distance of ballistic particles is crucial to our understanding of the jet phase of volcanic plumes and assess proximal hazards of explosive eruptions. In particular, travel distances can be used to determine the initial velocity of volcanic plumes and is necessary to define the evacuation zone of moderate explosions (e.g. Vulcanian and Strombolian style).

Detailed observations have shown that a large parts of ballistics ejected during Strombolian eruptions collide before reaching the ground. However, most existing models describing ballistic trajectories do not include

the effect of particle collision. We have developed a numerical model for ballistic sedimentation to investigate the effects of particle collision on travel distance, velocity change, particle trajectory and distribution on the ground.

Our new model can implement ballistic process fully analytically in three-dimension by using a discrete-event method. There are three types of events: particle burst, particle-particle collision and deposition. In between these events, we calculate the particle trajectory. Our analytical model is more efficient than numerical approach because it is based on a time scale of collisions instead of small arbitrary time steps.

We have investigated the ballistic process statistically by using many particles. Initial conditions such as the launching velocity, the launching direction and the particle grain size are stochastically sampled from a Gaussian distribution.

Our preliminary results show that particle collision significantly affects particle deposition. In fact, the number of collisions increases as the number of particles increases and the number of particles depositing farther distances increases with the number of collisions.

Numerical simulations are compared with observations of Strombolian eruptions. (Vanderkluyzen et al., this meeting)

1.2-P-08

Inversion of Tephra Deposits: Insights to Plume Shape and Sedimentation Magnitude

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Tephra fallout poses a major threat to communities residing close to explosive volcanoes. Plume and sedimentation models have been used to evaluate the hazard from explosive eruptions; however, those models depend on several poorly constrained parameters, such as exit velocity and grain size distribution, as well as major simplifications of the plume shape. Here we present exploratory analyses of tephra data to understand sedimentation processes and ultimately enhance real-time forecasting of explosively erupting volcanoes. In this approach we invert measured tephra distributions to a set of point sources in xyz space. The distribution of point sources that minimizes the least squares residues of deposit thicknesses gives insights into the shape as well as sedimentation magnitude of the volcanic plume. In solving the inverse problem no assumptions are made about mass discharge rate, exit velocity, the total mass/volume erupted, or sedimentation rate dependence on height. Residual calculations are also used to constrain parameters such as mass of tephra fallout and dispersion coefficients. The method has been tested with a synthetic data set to evaluate the sensitivity to input parameters. In a second set of computational experiments we applied the method to the well documented Ruapehu eruption on June 17, 1996. That eruption was characterized by a strongly wind advected plume, and selecting fallout point sources that resemble the plume shape allows new insights into the sedimentation proc-

ess. The resulting relationship of tephra abundance to distance-to-vent provides a tool for real-time hazard evaluation: our computer model of the evolving volcanic plume enables scientists to rapidly estimate the spatial distribution of tephra fallout, helping hazard managers and authorities assess the risk to their communities.

1.2-P-09

Large Explosive Event from an Unknown Volcano in the Central Cordillera of Colombia.

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In Colombia, Volcanic hazard studies began 25 years ago when Ruiz volcano reactivated. Criteria as historical records of eruptions and volcanoes near population were taken into account when setting priorities for conducting volcanological studies, but there are still many volcanoes which are little or not known. In the Central Cordillera a major eruptive unit has been identified, whose characteristics indicate that it has been generated by a large explosive volcanic activity. The identified deposits consist of a thick sequence of pyroclastic density currents (ignimbrites up to 100 m thick, minor pumice flows and pyroclastic surges), pumice falls deposits up to 6 m thick at about 10 Km from Cordillera Axis, and lahars. Locally, the sequence underlay the most recent products generated by Sotar volcano (37 Km SE from Popayan city, and currently under study), however, the known distribution of deposits as well their characteristics, suggest that these are not related to the activity of this volcano, but some other eruptive center in the area. South of Sotar there are others volcanoes that, due to being further away from population centers, or the lack of information about historical eruptions or thermal manifestations don't have any volcanological studies yet: Sucubn volcano, 8 km south of Sotar, is a 2 km diameter dome filling a Caldera; 15 km from the above is Cutanga, which is a eroded calderic edifice; extensive Ignimbritic sheets, dated on 7 m y, have been associated to its activity, finally, 12 Km south from this one, lies Chontillal volcano a semi-destroyed edifice. It is important to clarify the volcanic source of these deposits and to draw attention to the presence of a volcano with a huge explosive potential that could threat large areas in Colombia, and thus evaluate the need to begin volcanological studies aimed to the hazard assessment and zonification as well as monitoring.

1.2-P-10

Identifying Factors Important for Assessing Lahar Hazard on Galeras Volcano, Colombia

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Lahars on Galeras volcano are a little studied phenomenon and research on their possible effect on the in-

infrastructure around the volcano is limited. Here the key factors regarding the hazard posed to the Alfonso Lopez Pumarejo Bridge are identified by combining observations from previous lahars and deposits in the field with computer simulations of lahars. The bridge connects the small town of Consacá, to the west of Galeras, with Pasto city to the east, and provides a vital transport link, especially with regard to evacuation. Recent lahars within the valley are characterised as hyperconcentrated flows, which may originate by the remobilisation of pyroclastic fall deposits on the steep volcano sides by heavy rainfall, by landslides of hydrothermally altered rock or by incorporation of material in the valley as floods progress downstream. More sediment-rich debris flows could be formed by dome collapse or by a landslide on a scale much larger than seen in hundreds of years. The geophysical flow simulation program TITAN2D¹ was used to model flows of different volumes to determine the size of flow needed to undermine the bridge supports and bury the bridge. The program was designed to model one-phase granular flows. In this study, the effect of water on flow was replicated by lowering the basal friction in the simulations. Once the basal friction angle is decreased to less than 10°, the results become unreliable and the flows are no longer constrained by topography. Previous studies² have shown that the run-out for simulated flows with basal frictions of 10° is much smaller than observed in real flows. Approximate velocities for hyperconcentrated flows of different heights were calculated using the Manning equation³. These results compared favorably with the estimate of velocity from a flow in the valley in 2004 and are therefore used to discuss the effects of flows on the bridge.

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1.2-P-11

TephRANDO: a Tool for Hazard Assessment of Tephra Accumulation

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Comprehensive risk-mitigation planning is based on thorough hazard assessments. However, the compilation of hazard maps is typically complicated by the acquisition of input data and identification of hazard scenarios. Hazard maps for tephra accumulation make no exception as they are based on the processing of dedicated wind and stratigraphic data. We present a MATLAB tool designed to facilitate the compilation of hazard assessments for tephra accumulation: TEPHRANDO, which is based on the advection-diffusion model TEPHRA2 and is composed of three modules. The first module is designed to acquire and process input data required to run TEPHRA2 and identify hazard

scenarios. The second module is designed to calibrate and run the model TEPHRA2 either in a deterministic (for isomass maps) or a probabilistic mode (for hazard maps and hazard curves). This module can run either on one processor or on a computer cluster. The third module processes the model outputs to compile hazard maps and hazard curves, which can easily be exported to GIS platforms or Google Earth for further risk analysis. Hazard maps and hazard curves can be compiled for single-event scenarios (e.g. One Eruption Scenario, Eruption Range Scenario) or long-lasting activity (i.e. Multi Eruption Scenario). As a case-study, we present a complete hazard assessment for Cotopaxi volcano, Ecuador. First, we have assessed the most likely eruptive scenarios and their recurrence probabilities for variable time windows based on field data, literature information and the Smithsonian catalogue. Second, we have compiled hazard maps for different VEI classes and 12 years of wind data. Hazard curves were also compiled for critical geographic areas (e.g. Quito, Latacunga). Such a comprehensive hazard assessment is the base for any reliable and efficient risk analysis and mitigation planning.

1.2-P-12

Hazards from Channel-Confined Hyperconcentrated-Flow Lahars

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Lahars are important hazards downstream of volcanoes. Those large enough to exceed the capacity of their channels, whether debris flows or hyperconcentrated flows, threaten human lives, buildings, and other infrastructure with potential dynamic impacts by boulders and other debris, high fluid drag forces, and inundation by saturated sediment. Such overbank hazards are recognized in many at-risk communities. Smaller lahars remaining confined within channels, particularly those of the hyperconcentrated-flow type, occur more frequently than large lahars and appear less threatening because they are channelized. Yet rapid vigorous bank erosion and channel avulsion are hazardous consequences of channelized hyperconcentrated flows that often are not recognized.

Hyperconcentrated flows can transport up to 30 times more sediment (mostly sand) than water floods in the same channel at similar discharges, they have flow velocities 10 – 30 % faster than water flow at equivalent depths and slopes, and they are highly turbulent—only slightly less turbulent than water floods under similar conditions. These characteristics, documented in hyperconcentrated-flow lahars at Mount St. Helens, Mount Pinatubo, and Mount Ruapehu, imbue hyperconcentrated-flow lahars with significant erosive power. Lateral erosion rates of up to 3 m/min have been documented in channels on sandy floodplains. In addition, hyperconcentrated-flow lahars can rapidly deposit large volumes of sediment on channel beds, which leads to channel shoaling, widening, and avulsion that can shift channels laterally hundreds of meters during passage of a single lahar.

Severe damage to buildings and other infrastructure

on floodplains can result either from bank undercutting and collapse or from flooding resulting from rerouted river channels. Levees and dikes built to contain lateral erosion by lahars have been shown to be ineffective unless they are armored with rock or concrete revetments. More awareness is needed of the potential threat from channel-confined, hyperconcentrated-flow lahars.

1.2-P-13

The Last 40 ka Eruptive Cycle of Ilopango Caldera Deposits: a Settlement for the Metropolitan Area of San Salvador (El Salvador)

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The Ilopango caldera (IC), occupied by the homonym lake, is considered one of the most active volcanoes in El Salvador, due to an extensive record of plinian and effusive eruptions during the last 40 ka. The two million inhabitants of the Metropolitan Area of San Salvador (AMSS) are mainly settled on the interstratified felsic products of IC and the andesitic-dacitic deposits of the San Salvador Volcanic Complex (SSVC). Four large plinian IC eruptions occurred in the last 40 ka. The products of these events are generally labeled as "Tierras Blancas" (TB, white soils), and were recently dated through tephrochronology (Kutterolf et al., 2008). The youngest Tierra Blanca Joven, which products are mainly fall and pyroclastic flow deposits (cal. 429±107 AD), were the better studied (Hart & Steen-McIntyre, 1983; Vallance 2004). TBJ has the larger volume and distribution in relation to the others TB, and represents the most catastrophic event in Central America during pre-Columbian times. Dacitic domes within and around the lake indicate that the explosive eruptions could be subsequently accompanied by effusive events, as is the case of the Islas Quemadas formed in 1879-80 eruption. Recent work done at 130 outcrops on TB4 (<36 ka), TB3 (<30 ka) and TB2 (<16 ka) sequences allows to constrain their distribution and better characterize the deposits that formed them. In addition, an advance of the general stratigraphy in the AMSS, where the products from IC, SSVC, and others monogenetic vents are interstratified, is presented. The explosiveness of the IC eruptions and the lake within the caldera represent a significant hazard condition for the AMSS. It is necessary to better define the volume and distribution of the identified deposits, as well as to improve the understanding of eruption dynamics and recurrence, in order to design useful tools for risk and land use management.

1.2-P-15

Geological Risks Related to Volcano-Dynamic of Ischia Island

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During the last eight centuries the island of Ischia was hit by earthquakes, volcanic eruptions and floods, producing heavy damages and fatalities. Eruptions did not have strong impact on the humans as the latest occurred in 1302 A.D., in an almost uninhabited land. Earthquakes, since 1228 caused about 3200 victims, while floods since 1910 produced tens of fatalities. Giant landslide occurred in the last 10 kyr as highlighted by the recent geophysical investigations of the sea bottom, where large debris avalanches deposits have been found.

In the last fifty years the Ischia population is grown very fast, nowadays about 56.000 people live in the island and 4 million of people visit it during the year. Thus, this area represents a high geological risk territory.

All the shallow and deep processes, from landslides to earthquakes, can be related to the volcano-dynamic of the island, which is characterised by the presence of a shallow magmatic body emplaced after a large ignimbrite eruption (55 ka BP). Starting from about 33 ka, the magma body has migrated up to the present level, about 1 km b.s.l., producing 800 meters of uplift of a central block in the island, the Mt. Epomeo. The uplifted block was faulted and raised at high rate, more than 3cm^y⁻¹, producing its gravitational instability. Seismic energy has been radiated along the northern structures bordering the Mt. Epomeo, while magma migrated along the fractures, producing explosive and effusive eruptions.

To obtain a complete representation of geological risks we have done an integrated analysis of catastrophic events occurred in the island and its tectonic, volcanological and morphological features. Our analysis shows that the northern sector was affected by the heaviest damages due to earthquakes and floods, while gravitational instability affected both northern and southern sector.

1.2-P-16

The Coalescence, Bulking, and Debulking, of Lahars at Semeru Volcano, East Java

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We present multi-parameter recordings of lahars at Semeru Volcano, East Java. Through the use of two observation sites c. 510 m apart, we define the conditions under which bulking (entrainment of sediment and pore water), and debulking, occur in these rain-triggered lahars. The survey location, on the Curah Lengkong River, is situated c. 11.5 km from the summit. The localized channel is a 30 m-wide box-valley with a gravel and lava base, representing an ideal geometry for high

density measurements of active lahars. Instrumentation included pore-pressure sensors to measure stage, a 3-component broad-band seismometer to provide insight into sediment content and collisional behavior, video-cameras for flow velocity and rheology, and direct suspended-load sampling. In 2008, a total of 8 rainfall-induced lahars were recorded, lasting 1-3 hours with heights of 0.5-2 m, peak velocities of 3-7 m/s, and discharges of 25-250 m³/s. Flows ranged from hyperconcentrated streamflows (<40 wt.% sediment) to coarse debris flows (50-60 wt.% sediment). The recorded flows were commonly composed of partly coalesced, discrete, and unsteady gravity current packets, most likely originating from multiple lahar sources, which can be traced between instrument sites. As these lahars travel downstream, the individual packets coalesce and the flow develops a more organised structure. In addition, packet changes have been used to determine internal variations between sites, leading to the identification of volumetric bulking and wave shortening. Initial debulking of lahars between sites may reflect drainage into the dry substrate. Our results lead to the first quantification of bulking and debulking by lahars along a channel reach. From this, we recognize that overall total estimates of bulking may be misleading, because intra-event variations can be significant enough to increase the site-specific inundation and associated hazard.

1.2-P-17

Identifying the Driving Forces behind Recent Pulsations in Activity at Merapi Volcano, Central Java, Indonesia

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Merapi (2911 m) is one of the most dangerous and persistently active volcanoes in Indonesia. Over the last century, activity has been dominated by the extrusion of crystal-rich basaltic andesite lava, forming lava domes, which frequently produce block-and-ash flows (BAFs). These BAFs pose a permanent threat to over 1 million inhabitants living in the surrounding area. The most recent eruptive period began in April 2006 with the extrusion of a new dome, after five years of previous quiescence. At the peak of activity, BAFs travelled 7 km, resulting in two fatalities. Subsequently, further flows were emplaced, producing at least eight overlapping BAF deposits¹ followed by a few months of reduced dome growth.

Pulses in activity could be directly related to changes in the deeper magma supply or in degassing during ascent. Previous petrological investigations suggest a correlation between microlite growth and extrusion rate from rocks erupted in 1994-1995². To further investigate this, the deposits of the recent eruption have been sampled in detail, with collection of juvenile products spanning the entire eruptive episode, including samples gathered from the dome during 'background' activity in August 2008. Here, we present detailed micro-textural and crystal size distribution (CSD) analysis of selected

samples from the 2006-08 episode, which further test the relationship between extrusion rate and microlite size distribution as well as examine the role that dome residence time plays in textural evolution. We also present the results from preliminary phase equilibria experiments, designed to elucidate deeper storage conditions of the main phenocrystic phases.

An improved understanding of the magma storage and supply will identify the driving force behind recent eruptive pulsations. Petrological monitoring should therefore play a significant role in hazard assessment at Merapi and other dome-forming volcanoes.

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1.2-P-18

Mobility of Pyroclastic Flows and Rock Avalanches

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Rapid mass movements of rock fragments are among the most hazardous natural phenomena. The ability to foresee their mobility is important when assessing natural hazards in volcanic regions. The dynamics of granular flows is however a challenging multivariate problem. Among the variables that affect their mobility we can include grain size and flow volume. Unfortunately, there are no generally accepted scaling laws describing these phenomena with the certainty to have taken into consideration all important aspects of nature. There are also different ways to assess mobility. Some authors, for example, adopt the distance travelled by the flow front or other arbitrary distances which are inappropriate for energy budget considerations because these flows deform during motion and deposition. Because of the difficulties inherent in direct field observations of these catastrophic events, we resort to laboratory experiments where granular material is released down a chute whose shape is similar to the profile of Mayon Volcano in the Philippines. Our experiments show that in flows of angular rock fragments, the smaller the grain size (all the other things equal), the larger is mobility. Importantly, this mobility is assessed measuring the distance travelled by centres of mass. Particle image velocimetry analysis of high speed video camera images shows also that the smaller the grain size, the smaller is the agitation of the fragments. This can explain the increase of runout distance as grain size decreases because fragments that are less agitated dissipate less energy. This should also explain why larger flow volumes are known to be more mobile. The larger the volume, the relatively smaller is the mass of a fragment with respect to the total mass of the flow so that fragments of larger flows are less agitated and for this reason dissipate less energy. Reference: Cagnoli and Romano, JVGR.

1.2-P-19

CO₂ Discharge and Volcanic Risk in Italy

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Abstract body. Italy offers a unique opportunity to investigate localised solid/fluid transfer of C towards the surface. Italy emits $2.5\text{--}5 \times 10^{11}$ mol. a^{-1} of CO_2 . Additional evidence for CO_2 fluxing in Italy includes diatremes and maars that contain carbonatite, mellilitite and mantle nodules. 10^{20} kg of solid C is stored in the deep Earth, while the flux of C-O-H at the surface may catastrophically change. Mantle/core outgassing is considered to have a $\delta^{13}\text{C}$ of about -5% . Italian carbonatites have $\delta^{13}\text{C}\%$ between -8 and -4 , R/Ra up to 7.33 (plume-type values). Fresher Italian carbonatites have $\delta^{13}\text{C}$, $\delta^{18}\text{O}$ and $\delta^{11}\text{B}$ values of -6.7% (-4.8% intrusive), $+10.2\%$ ($+10.3\%$ intrusive) and -5.9% , respectively (mantle values). The change from natrocarbonatite to Ca-carbonatite at Oldoinyo Lengai is accompanied by a change in $\delta^{18}\text{O}$ from $+6.5\%$ to $+25\%$, while $\delta^{13}\text{C}$ remains unchanged. Nyerereite inclusions from Italian carbonatites suggest that similar processes contributed to $\delta^{18}\text{O}$ evolution. Radiogenic mantle end-members, detected in Italian carbonatites, are related to deep alkali-carbonatites and metamorphic reactions with pyrope harzburgite. A specific concourse of geological causes is required to produce the above features, which together imply geologically instant mantle decompression, concentration of volatiles in a melt phase and explosive detachment from the source (diatresis). Magmatic convoy ascent needs to be 10–30 m/sec. to prevent mantle xenoliths settling. The only realistic agent of acceleration is deep-seated concentration of volatiles in fluidised system with a high proportion of carbon dioxide. The nature of the Italian ultra-alkaline rocks implies that the high concentration of juvenile propellant resulted in extremely violent volcanic activities and that the potential volcanic risk implied by carbonatite occurrences and CO_2 explosion along the Apennine structural trends must be re-evaluated in terms of this factor. The proposed carbonatite eruption triggering mechanism may generate LP supersonic shocks in the mantle, which would be possibly recognised as a precursor of surface eruption.

1.2-P-20
Diversity within the Juvenile Component of the Abrigo Ignimbrite, Tenerife: a Record of Phonolitic Magma Eruption Dynamics during Caldera Collapse

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Juvenile clasts within pyroclastic deposits record dynamic processes occurring within the magma chamber and conduit during explosive eruptions, which define the starting conditions for many of the associated hazards (e.g. eruption plume fallout, pyroclastic flows). The ~188 ka Abrigo Ignimbrite is the product of the last caldera-forming eruption on Tenerife; signalling the end of an explosive phonolitic magma cycle, which also pro-

duced at least 14 earlier plinian eruptions. The Abrigo Ignimbrite is characterised by a diverse suite of juvenile clasts, that vary in a) geochemical composition across the basanite-tephriphonolite-phonolite range, including banded and chemically mixed varieties; b) crystallinity, from aphyric (<5 vol % crystals) to porphyritic (5 – 60 vol % crystals) to crystal mush (60 – 95 vol % crystals); and c) vesicularity, from incipiently vesicular glassy clasts to highly – extremely vesicular pumice. Cognate syenite clasts are also present. Pumice clasts exhibit a wide range of vesicle morphologies and bulk textures (e.g. spherical to tubular morphologies; glassy filaments and stringy textures; interconnected vesicles; advanced vesiculation around crystals; strained and contorted vesicles; bulk shear zones). Highly to extremely vesicular (both spherical and tube vesicle varieties), aphyric to porphyritic, phonolitic pumice is ubiquitous and dominant throughout the Abrigo Ignimbrite, whereas less common varieties are generally stratigraphically and regionally controlled. In contrast, the underlying pre-Abrigo fall deposits have a limited juvenile clast diversity consisting solely of aphyric, phonolite pumice (spherical >> tube vesicles). The increase in juvenile clast diversity with the Abrigo eruption is attributed firstly to the onset of caldera collapse which caused widespread withdrawal from a heterogeneous magma chamber and development of multiple conduit-vent systems. Secondly, juvenile clast textural types reflect the intermediate viscosity associated with the ascending phonolitic magma, which controlled the nature of vesicle growth, shear towards the conduit walls, fragmentation and post-fragmentation processes.

1.2-P-21
3-D Numerical Simulations of Eruption Clouds: Flow Regimes at the Column Collapse Condition

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During explosive eruptions, the eruption cloud ejected from the volcanic vent generates an eruption column and/or pyroclastic flow. Since the risks caused by pyroclastic flow and eruption column are entirely different, the determination of the critical condition between pyroclastic flow and eruption column ("the column collapse condition") has been a central issue of volcanology and hazard science. According to the simple 1-D models of eruption column, the column collapse condition is primarily determined by the Richardson number: a critical value of L_0^5/m_0^2 for a given magma, where L_0 is the vent radius and m_0 is the mass discharge rate (Kaminski and Jaupart, 2001). In order to test this hypothesis, we carried out numerical simulations of explosive eruptions using a 3-D pseudo-gas model by Suzuki et al. (2005). On the basis of 50 simulation results, we identify four flow regimes; eruption column with fountain structure (radially suspended flow), eruption column with jet structure, pyroclastic flow collapsing from a fountain, and pyroclastic flow collapsing from a jet. The boundaries of these flow regimes are defined by two conditions: the column collapse condition and the condition for the formation of fountain. From the flow regime map

it is inferred that the effective values of the Richardson number along these boundaries decrease as the exit velocity exceeds the sound velocity of the gas-pyroclast mixture. For the same Richardson number, the eruption cloud with an exit velocity higher than the sound velocity tends to form a fountain structure. The development of the fountain structure reduces the efficiency of entrained air, which enhances generation of pyroclastic flow. It is suggested that the column collapse condition is explained not only by the Richardson number but also on other parameters such as the Mach number. References: Kaminski and Jaupart, 2001, JGR; Suzuki et al., 2005, JGR.

1.2-P-22

Direct Observation of Magmatic Suspensions Brittle Onset and Crack Healing: Implications to Volcanoes Eruptive Dynamics.

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The brittle-ductile transition of magmas remains an unsolved question and a central challenge for modern geology. Understanding magmatic failure is of the first importance for who wants to predict deep earthquakes or eruptive transitions. Nevertheless, magmas brittle onset is interlocked with the fluid tortuosity generated by the crystal network, the strength of this network and the stress applied. This complex micro-structure can be simplified with a macro-scale approach and applied to volcanic systems.

We addressed this question through series of failure tests in torsion and compression. These tests were performed with haplo-granitic synthetics containing 7% sodium mole excess. Additionally, natural magmas from Mt Unzen lava dome have been used to confirm the first results. Experiments have been repeated for various crystal fraction (0.2 to 0.65), viscosities of the interstitial melt (1E9-1E12 Pa.s) and confining pressure (0-300MPa).

The results support the hypothesis that cracks preferentially ignite in the liquid phase until a crystal fraction of 0.65. On a macro-scale magmatic suspensions mostly react as fluids until their maximum packing fraction. It implies that their brittle onset can be accordingly predicted.

A second major observation of our results is cracks resorption. Cracks lifetime depends on the ability of the melt to heal (function of the relaxation-time and viscosity), the strength of the crystal network to preserve cracks and the confining pressure applied. Playing on the healing ability of the melt we prove that the confining pressure influences more the cracks lifetime than their brittle onset.

Scaling back this hypothesis to natural scales and past volcanic eruptions, we obtain a good criteria for eruptive transitions which makes possible to estimate for which effusion rate magmas will start cracking. We

expect to extend this idea to a wider range of natural examples and believe in building a brittle criteria completing the forecasting tool panel.

1.2-P-23

Displacements across the Trecastagni Fault (Mt. Etna) and Related Seismicity.

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The geodynamic framework of Mount Etna is characterized by a compressive stress regime, trending roughly N-S, due to the Eurasia-Africa plate collision, and an extensional regime trending roughly E-W. The volcano edifice has formed at the intersection of two regional fault systems, having NNW-SSE and NE-SW trends respectively and the complex interaction between regional stress, gravity forces and dike-induced rifting, seem to have a role in the eastward movement of the Mt. Etna unstable eastern flank. In this context the Trecastagni-Tremestieri Fault system seem to identify one of the structures that bound southward unstable sector, while the Pernicana Fault is the unique northern boundary. The Trecastagni Fault (TF), in particular, is a NNW-SSE tectonic structure, which develops between Trecastagni and San Giovanni La Punta, is characterized by evident morphological scarps and movements of normal and right-lateral type that directly interests the SP 8/III° road and numerous buildings. Starting from 2005, TF is monitored by using continuous wire extensometers and by carrying out periodic direct measurements across the northern and central sector. Since 2005 until September 2009, measurements show that TF has been characterized by a continuous extension at about. 2-3 mm/y.

During the October-December 2009 period, the TF dynamic accelerated up to 5.5.mm/y and was accompanied by several shallow, low magnitude earthquakes that has been felt by local people. We analyzed some aspects of this seismicity also by using data of two temporary broad-band stations installed nearby the structure. Finally we discuss the TF hazard and its behaviour inside the dynamic of the Mt. Etna unstable eastern flank.

1.2-P-24

Mapping of Lava Flows for Hazard Assessment at Mt Etna

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Mt Etna is one of the most active and studied volca-

noes in the world. Lava flows generated during flank eruptions can potentially damage the towns located at medium-low elevations. In the last century, the town of Mascali was destroyed by lava flows in 1928, conversely in 1971, 1981 and 1991 Fornazzo, Randazzo and Zafferana towns were threatened respectively. Tourist facilities have been destroyed, with serious damage to the local economy in the 2001 and 2002-03 eruptions. Recent results concerning: (i) the updated catalogue of eruptions, (ii) the better knowledge of the structure of the volcano, and (iii) the considerable progress in the numerical simulation of lava flows, allow us the mapping of lava flows for hazard assessment at Etna. The hazard map provides the probability that given areas will be affected by potentially destructive volcanic processes. The effort to obtain the probabilistic lava flow hazard map consists of different steps. In the first step a spatial open vent probability map is computed considering the main volcanic structures of Etna, as fractures, dikes and faults. Then, to characterize the expected eruptions, a probability of eruptive event type is estimated on the basis of a volcanological database representing the last 400 years of activity. Finally, the paths of lava flows are calculated using the MAGFLOW Cellular Automata model. Numerical simulations are elaborated to realize the hazard map, taking into account both information on overlapping of lava flows, and their occurrence probability. For each simulation, the hazard related to a generic point is computed as a sum of the product of the defined probabilities of occurrence if it is affected by the simulated lava flow. The accuracy of the results depends on the reliability of the simulation model, on the quality of input data and on the different probabilities of occurrence.

1.2-P-25

Effusive Activity and Parasitic Vent Location at Somma-Vesuvius, Italy

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Somma-Vesuvius in southern Italy is largely perceived as an explosive volcano, though the study of the historic activity shows Vesuvius as a primarily strombolian centre with the majority of eruptions comprising small to medium explosions and lava effusions. The lavas can be broadly grouped into two categories – slow, short, wide flows and faster, long, narrow ones. Whilst those in the first category are largely restricted to the upper cone, long lava flows have repeatedly inundated coastal towns. To increase the understanding of the formation of these flows of such different behavioural characteristics and possible relations between the magma source and flow development, an analysis of the composition and crystallinity of the historic lavas is undertaken.

Although the majority of eruptions take place at the summit crater, effusive activity has also occurred at lateral and eccentric fissures and vents low on the flanks of the volcano. The potential for eruption from vents away from the crater must be understood and appre-

ciated in hazard and risk assessments, as this has a significant influence on the timings of emplacement of volcanic products within populated areas, and will increase the hazard posed by products that are otherwise often considered of low impact– for example the short, wide lava flows. Investigation of potential vent locations is undertaken with the use of scaled topographic gelatine models, to study how the gravitational stresses affect the propagation of dykes beneath the volcanic edifice, with the aim of understanding how this may increase the susceptibility of certain areas to host parasitic vents.

It is expected that this multi-disciplinary approach to studying the formation of lavas and vents at Vesuvius will enable a greater understanding of the activity and the hazard posed by this infamous volcano.

1.2-P-26

Forecasting the Evolution of Lava Flow Fields

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Lava flows are the most common volcanic feature on Earth and pose a constant threat to human life and infrastructure. Aa flows are characterised by the formation of channel levees which strongly influence overall flow field morphology. The formation, overflow, breach and collapse of lava levees can result in the restructuring of channels within a lava flow field and therefore have many implications for lava hazard management. In addition to topography, there are several parameters which control the formation of channels such as effusion rate, volume and rheology. The degree to which these parameters control the development of levees can vary with each eruption. A series of experiments using paraffin wax as an analogue for lava have been designed to investigate the parameters influencing the formation and collapse of levees. Initial experiments consistently reproduced morphologies commonly seen in natural systems such as new channel formation, lateral migration of levees and overflows. The experiments showed that, similarly to flow fields, wax flow fields reach their maximum extension within the early stages of effusion and that flow field growth after that time is restricted to lateral spreading through overtopping or breach of levees. However, it was observed that increasing the angle of slope and/or effusion rates delayed the occurrence of overtopping or breakouts to the latter stages of the effusion and at greater distances from the vent. This behaviour is indicative of the effect of cooling rates on overall flow-field morphology. A reduction in the down-slope progression of a flow in which material continues to be effused can be related to the retarding effect of solidified crust and the up channel accumulation of lava once the flow front has become immobile, leading to the formation of breaches and lateral extension of the flow field – a process observed both in the field and during experimentation.

1.2-P-27

Exploring Intensity-Magnitude Relationships in Vulcanian, Subplinian and Violent Strombolian Eruptions

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Assessment of volcanic hazards depends on accurate reconstructions of past eruptive activity. Non-witnessed eruptions are typically characterized by field-based parameters that are converted to eruptive features (magnitude and intensity) through the application of dispersal models. However, determination of these parameters is sensitive to the data collection technique applied. For example, there is no standard approach for estimating deposit volumes (magnitude). Methods based on the exponential decay of deposit thickness (Pyle 1989; Fierstein and Nathenson 1992) can significantly underestimate the total volume, particularly for eruptions that produce a significant amount of fines, whereas power law thinning assumption can overestimate volumes if applied to widely dispersed or fines-poor deposits (Bonadonna and Houghton, 2005), or if the original content of fine ash is low. This problem may be particularly acute in the case of mafic arc eruptions, where the fine ash content may be limited. Additionally, there is little agreement on the best way to obtain the clast size data required as input to models used to estimate column height (intensity). Finally, there is no predictable relationship between eruption magnitude and intensity, which has made standardization of eruption classification difficult. In particular, we note that mafic eruptions with high intensities but small volumes have been variably classified as vulcanian, subplinian, or plinian, while mafic eruptions of moderate intensity and volume may be classified as strombolian, violent strombolian or subplinian. To address this problem, we suggest that the duration and continuity of activity be considered (e.g., Pyle, 2000), as well as the volumetric proportion of fall deposits to other eruptive products. For example, the steadiness and duration of eruptive behavior reflect conditions within the magma transport (conduit connectivity and magma rheology) and storage (volume, composition and depth of storage) systems, while effusive magma volumes record the extent of pre-eruptive degassing.

1.2-P-28

Evaluation of Various Resolution Digital Elevation Model (DEM) for Numerical Simulation of Volcanic Debris Flow

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Numerical simulation has been used for hazard assessment of volcanic debris flow in Japan. Numerical simulation strongly relies on digital elevation model (DEM). Recently, it became possible to generate a high-resolution DEM with the remote sensing technique, for example LiDAR. In this study, we evaluated the difference

of resolution between high resolution DEM and medium resolution DEM at Aso volcano, in Japan. Our used data are as follows: ALSDEM (acquired by airborne laser scanner (LiDAR); 10m mesh), GSIDEM (generated by interpolation of 10m contour map; 10m mesh), ASTER GDEM (MITI/NASA; 30m mesh) and SRTM4 (NASA/USGS; 90m mesh). In the case of the result of ALSDEM and GSIDEM, flood hazard zone is spread along valley and drainage channel. ALSDEM is the most useful in our used data, because it can represent microtopography such as drainage channel, road, sabo facilities, etc. If we want to estimate the effect of sediment control dams or embankments, it is possible to estimate the effect using ALSDEM. GSIDEM is less-accurate around volcanic fan because it generated by interpolating low-density contour lines. Therefore, flood hazard zones are wider than the result of ALSDEM around volcanic fan. On the other hand, flood hazard zones of ASTER GDEM and SRTM4 are spread far and wide. In the case of the result of ASTER GDEM, flood hazard zone is affected by large structures. ASTER GDEM can represent large civil engineering structures such as roads and embankments. ASTER GDEM and SRTM4 are effective only if we need to estimate flood hazard zones roughly or quickly. This study was performed under the sponsorship of JNES Fundamental Research Project on Nuclear Safety. (JNES: Japan Nuclear Energy Safety Organization)

1.2-P-29

Fallout Hazards Associated with a Possible Renewal of Explosive Activity at Cerro Blanco Volcanic Complex, Austral Puna, Argentina

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Cerro Blanco volcanic complex is the youngest high-silica caldera complex of the Southern Central Andes. Two different periods of activity are identified. The first period (~72 ka BP) is characterized by voluminous ignimbrite-forming eruptions that generated the "Piedra Pomez" field (> 20 km³). At least one of these eruptions produced a tephra fallout. The second period (~20-15 ka BP) produced two smaller ignimbrite fields. During the last phase of the second period a dome was extruded at the caldera margins, and there were numerous phreatic explosions along a local fault system. At present there is some thermal activity and pipe and diffuse degassing at the center of the caldera. INSAR and high precision GPS measurements reveal that the system is currently subsiding at a rate of ~3 cm per year. Preliminary broadband seismic analysis indicates activity at ~7 km depth. Although the area around the volcanic complex is inhabited, a renewal of activity of the volcanic complex would have a tremendous impact on the region, especially in the more distal areas (>100 km) where several settlements exist. For these reasons, we investigated the effects of a potential tephra fallout

eruption. On the basis of the volcanological records, we define two eruptive scenarios - violent strombolian and sub-plinian eruptions, respectively. For each scenario we assess the associated fallout hazard. Ash fallout is modeled using a semi-analytical model and statistical wind field record. Simulations allow us to determine which areas could be affected, and the potential impact on main infrastructures, regional airports and national and international air traffic lines

1.2-P-30

Eruptive History of the Fossa Cone (Vulcano, Southern Italy) of the Last 1000 Years: Detailed Stratigraphy and Eruption Scenarios

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The Fossa Cone (Vulcano, Southern Italy) produced historical eruptions associated with a variety of eruptive styles and intensities and has been recently characterized by signs of unrest. We conducted a new detailed field-study of the Fossa Cone deposits based on both natural outcrops and artificial trenches, with the aim of elucidating the volcanic history of the last 1000 years, assess the distribution of tephra, revise the emplacement mechanisms and characterize the associated eruptive styles. Results confirm that a wide spectrum of eruptive styles, from small scale effusive to medium-intensity explosive activity, has been produced by the main crater and subordinately by lateral vents. We identified three main eruptive clusters, with a total of fifteen eruptive episodes. That events occurred in rapid sequence within each period causing tephra accumulation around the cone. In contrast, primary deposits were remobilized in between periods generating secondary lahars and producing the rise of the ground level in the northern sector. The age of different clusters was constrained using new ¹⁴C dating and previously published radiocarbon and archeomagnetic data as well as tephrochronology associated with the Vulcanello center. Results suggest that the first cluster was characterised by close coupling of magma and gas producing sub-Plinian & violent Strombolian activity and finally it experienced effusions of residual magma. The second cluster was dominated by full decoupling of gas from a stationary magma body, producing gas-eruptions. The last cluster was characterized by the partial coupling between gas and rising magma, producing a series of steam-blasts followed by Vulcanian explosions (comprising the "1888-1890 Vulcanian eruption"). Recognizing the origin of these deposits is important to understand the actual associated hazard. The time scale of 1000 years appears to be representative of the spectrum of potential hazardous phenomena that Fossa Cone is susceptible to produce in the future.

1.2-P-31

Unravelling the Deposit Architecture of Block-And-Ash Flows: A Multi-Parameter Approach

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Block-and-ash flows (BAFs) are among the most dangerous volcanic phenomena. Formed by the collapse of viscous lava domes, BAFs are common at subduction zone volcanoes, but are arguably nowhere as frequent as at the persistently active Merapi volcano (Indonesia), the type volcano for this volcanic phenomenon. BAFs preferentially follow topographic pathways and typically comprise two components, a high-density basal avalanche (capable of transporting blocks several metres in diameter) and an over-riding, dilute ash cloud. During the 2006 eruption of Merapi, BAFs separated from the main channel, overspilled valley margins and spread across densely populated non-valley regions on the volcano's flank, causing havoc in areas considered relatively safe from such flows. This eruption has illustrated once again that the behaviour of BAFs remains difficult to predict, demonstrating the need for an improved physical understanding of their transport and depositional processes to ultimately improve assessment of their local hazard potential. In this paper, we present preliminary results of an interdisciplinary study of the 2006 BAF deposits of Merapi, integrating (1) field data of the pristine deposit characteristics recorded immediately after the eruption, (2) sedimentological data collected at exposed deposit sections; (3) subsurface information of the deposits (up to several metres depth) obtained independently from the presence of exposures by ground penetrating radar; (4) preliminary data of the complete clast size range, clast orientation and deposit fabric determined using photo-statistical methods, (5) surface morphological data from high-resolution satellite photography and (6) advanced digital terrain model analysis. This multi-parameter approach has the potential to overcome some of the inherent limitations of traditional field-based investigation methods of BAFs and opens a unique perspective that will provide a detailed picture of the three-dimensional deposit architecture of BAFs. The latter is regarded as a significant step forward in our understanding how BAFs are emplaced.

1.2-P-32

Volcanic Hazards of Hydroclastic Eruptions in Densely Populated Areas: The 1000 Year Old Nejapa Maar Eruption on the Outskirts of Managua (Nicaragua).

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Nejapa Maar (2.5 x 1.4 km, c.120 m deep), a prominent maar along the 15 km long Holocene Nejapa-Miraflores Lineament (NML), is the source of the youngest (c.1 ka BP) widespread basaltic tholeiitic tephra as shown by isopachs and isopleths (Rausch and Schmincke, in press). The deposits cover the area of the present western suburbs of Managua, the highly vulnerable capital of Nicaragua, where more than one third of the country's population resides (c.1.3 million).

The moderate vesicular lapilli-rich (>90 vol.%) Nejapa Tephra (NT) was fragmented by shallow interaction of vesiculating magma with external water, erupted in moderately high eruption columns (>7-10 km) and was dominantly deposited as dry to damp, warm to cool fallout. Minor surge transport is inferred from fine-grained, locally cross-bedded tephra beds exposed in morphologic-tectonic depressions chiefly north of Nejapa Maar and west of Asososca Maar.

Although the minimum total magma volume of erupted NT is relatively small (~0.1 km³), the recurrence of an eruption of similar magnitude and eruptive and transport mechanisms at an eruptive vent along the Nejapa-Miraflores Lineament would be a major hazard and risk to western Managua and Ciudad Sandino, due to their proximity to NML. Specific volcanic hazards and risks generated during Nejapa-type eruptions are: (1) Ballistic impacts of blocks up to 1 m in diameter at distances at least up to 1 km from the vent, which could severely damage buildings; (2) Fallout deposits consisting dominantly of relatively dense cauliflower-shaped lapilli, 1 m thick at a distance of c.5 km and 10 cm thick at c.12 km from the vent, would lead to collapse of structurally weak roofs, common in Nicaragua; (3) Surges devastating infrastructure in proximal areas. In view of the past frequency of eruptions along the NML (roughly every 1000-2000 y.), further eruptions are likely to occur in the near future. Reference: Rausch and Schmincke, JVGR, in press.

1.2-P-33

System of Alert early in the Concepción volcano, Isla de Ometepe, Nicaragua

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As part of the project Integral Administration of the Risk for the Reduction of Natural Disasters in the Island of Ometepe, financed by Care International, I Toss (European Union) and COSUDE (Swiss Body of Aid), INETER has been integrated in the evaluation, education and instrumentation for the Concepción volcanos and Wood. INETER has elaborated maps of threats in the Concepción volcano and they based on these maps were created shops and forums of education so much for the team of Care, like for the municipalities in function of a mockery in the face of volcanic eruptions that it was made 2010 in January.

In order to collaborate with the mockery maps of routes of evacuation considering an eruption of type violent strombolian like her happened in the years 40 in the Concepción volcano. Maps of routes of evacua-

tion for the fall of ashes, ballistic, flows lava flows and piroclastic flows is contemplated in the study. Equally the instrumentation in the Island was created contemplating 6 seismic stations of short period, 2 cam-web, a MiniDOAS team in order to measure the gases SO₂ in real time and 2 meteorological stations ince in the volcano lahars in winters periods takes place

1.2-P-34

Bombs Behaving Badly: Deviation of Bombs from Ideal Ballistic Trajectories

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tromboli is an active volcanic center in the Aeolian Islands (Italy) that has been exhibiting the same type of activity at least since the 7th century A.D. Typical activity at Stromboli is characterized by transient eruptions venting tephra tens to hundreds of meters from the vent, a style of volcanic activity to which the island has given its name. In particular, Strombolian eruptions have come to be associated with the ejection of incandescent juvenile particles along ballistic arcs. We collected thermal infrared footage of over 300 eruptions at Stromboli in May and June 2008 and manually traced the trajectories of ~100 individual bombs in two of these eruptions. We find that 20-25% of the analyzed trajectories deviate significantly from predicted ballistic parabolas, traveling horizontally up to twice as far as expected. Furthermore, we observe oscillatory cooling behaviors of the bombs, with periods of ~1s, while the bombs are airborne. We interpret the cooling curves as resulting from the twisting and ripping of the bomb's surface during travel, periodically re-exposing the hotter core of the particle to the atmosphere, and infer the divergent bomb trajectories to result from the collision of pyroclasts within the eruptive fountain. Current volcanic ballistics computer models do not account for particle collisions and thus severely underestimate the maximum landing distance (and temperature) of volcanic bombs; our results thus have significant implications for the mitigation of ballistics-related volcanic hazards.

1.2-P-35

Sulfur Dioxide (SO₂) Emission Rates of Masaya and San Cristóbal Volcano (Nicaragua) During 2009 Inferred from Stationary and Mobile Mini-DOAS Measurements within the NOVAC Project

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Masaya volcano is an active volcano located 20 km from Nicaragua's capital city, Managua. The volcanic complex includes the craters Masaya, Nindirí, San Pedro, San Fernando, Comalito, Santiago, as well as other satellite cones. The San Cristóbal-Casita volcanic complex is located about 100 km NW from Managua. Violent Strombolian eruptions occurred in July 1684 and August 1685. The present activity is characterized by important degassing and sporadic explosions. This work presents the results of sulfur dioxide gas emission measurements conducted in Masaya and San Cristóbal volcanoes, by using stationary and mobile mini-DOAS measurements during various months of 2009. We used the Dual-Beam Mini-DOAS instrument developed within the NOVAC (Network for Observation of Volcanic and Atmospheric Change) project, funded by the European Union. The systems are operated by the Instituto Nicaragüense de Estudios Territoriales (INETER). The daily SO₂ gas emission rate of Masaya, obtained from mobile measurements carried out along the western side of the volcano (Ticuantepe-La Concepción road) during the months of April, July, August, and October 2009, vary between 220 and 1525 t/d. The stationary scanning system installed in the site Nancital observed fluxes between 326 and 1148 t/d in the period September-October 2009. In the case of San Cristóbal, we performed mini-DOAS traverses on the western side of the volcano (Chinandega-El Piloto road) during April, July, September, and October 2009, and observed fluxes between 231 and 1249 t/d. The scanning system installed in Station Hill station provided fluxes between 1149 and 1139 t/d during September-October 2009. This poster highlights the operability and importance of the NOVAC systems to better keep tracking of the permanent eruptive activity of these two volcanoes in Nicaragua.

1.2-P-36

Dusty Shear Current: The Twin Towers Collapse = Pyroclastic Density Current: Volcanic Column Collapse

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Pyroclastic density currents (PDCs) are ground hugging gas-particle flows that move at high velocity down a volcano and over the surrounding terrain. They can be generated when a hot volcanic gas-particle mixture at first is injected into the atmosphere, then it collapses by impacting the ground and forming fully turbulent shear currents or PDCs. A mechanism analogous to volcanic column collapse was observed in the catastrophic event of the Twin Towers (Manhattan, New York City, USA) collapse on September 11, 2001. In the collapse, the fragmented material of cement, metal, glass fell vertically and impacted the ground very close to the axis of the towers. The impact pressure was all constrained in a shear stress that drove the development of dusty shear currents. The propagation inside the streets at Manhattan occurred in a fully turbulent regime, be-

cause a rapid entrainment of atmospheric air in the cloudy flow allowed the material to be transported in turbulent boundary layer shear flow mainly by suspension. Although the analogy is only visual and qualitative, both the dusty currents and PDCs can be referred to as the disperse flows of multiphase physics with Reynolds number of the order of million. The only experience of particle-laden turbulent flows that propagated inside a city is related to the tragic event on September 11, 2001. The dusty currents interacted with the buildings at Manhattan and the turbulent, multiphase flow behavior caused flow separation and recirculation around the buildings. The Twin Towers collapse showed that a collapse few hundreds of meters high is able to generate fully turbulent, dilute shear currents that interact with built-up areas. Similar mechanisms of flow-building interaction could be hypothesized during volcanic column collapse, where the collapse is few hundreds of meters to kilometers high.

1.2-P-37

Numerical Study of the Effects of Structural and Rheological Assumptions on Ground Deformation Inversion.

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Understanding the source of ground deformation of restless volcanoes is an important step toward a better assessment of the volcanic hazards. The inversion of recorded data is a powerful tool to infer features of the source responsible for such deformation. It is a computationally complicated and costly procedure due to the complexity of the rock domain and the number of unknown variables such as source position, shape and extent. As a consequence, inversion methods are normally based on models that simplify the source geometry and/or rock properties. We have examined the degree to which the complexities of the rock matrix may be neglected when interpreting data associated with awakening episodes. The ground deformation associated with a volume change at depth has been simulated through a numerical code based on a discrete elastic lattice method (O'Brien and Bean, 2004) which accounts for the presence of complex topography, rock heterogeneities and fractures/faults. We have computed the deformation due to the same source but different rock models, from homogeneous to heterogeneous with fault discontinuities and topography. These synthetic data have been then inverted through a commonly used model (Davis, 1986) that accounts for a point pressurized cavity of ellipsoidal shape, arbitrarily oriented in an homogeneous half-space. The results show that the inversion of ground deformation data is very sensitive and that the assumption of simplified models (i.e. ignoring rock heterogeneity) can lead to a wrong interpretation of the ground deformation itself, in particular in term of the source mechanism and magnitude. The present study highlights that the incorporation of realistic rock models is crucial for determining the correct source of volcanic ground deformation. A possible solution could be the use of Green's function

calculated for the specific site under-investigation but it involves a large computational cost.

1.2-P-38

Understanding the Relation between Pre-Eruptive Bubble Size Distribution and Observed Ash Particle Sizes: Prospects for Prediction of Volcanic Ash Hazards

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Recent advances in measuring pre-eruptive bubble size distributions (BSDs) from ash particle surface morphology now make it possible to calibrate ash fragmentation models for prediction of pyroclastic characteristics of concern to human health and infrastructure. The same magma bodies can generate various eruption products ranging from coarse bombs to fine ash, with a wide range of fractionation between these end members that in turn depends on the pre-eruptive bubble size distributions. We have devised a method to produce spatial models of bubble textures that match inferred BSDs of pre-fragmentation magma in the eruption column based on conditions of 1-stage bubble nucleation and random nuclear spacing, with either of two bubble growth schemes- (1) unconfined growth in the absence of neighboring bubbles, and (2) limited growth in a melt volume shared with neighboring bubbles. These scenarios lead to different BSDs, thus controlling fragmentation thresholds and patterns. BSD leads to the thickness distribution of bubble walls and plateau borders, so we can predict the size distribution of ash particles formed by rupture of thinnest inter-bubble films, as well as the fraction of compound fragments or clasts derived from parcels of magmatic foam containing thicker walls. As such it is possible to determine the magmatic conditions that lead to eruptions with a high fraction of fine ash of concern to volcanic hazards and respiratory health.

1.2-P-39

Spatial Distribution and Lithofacies of Pumiceous-sand Tsunami Deposits

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Spatial distribution and lithofacies of pumiceous-sand tsunami deposits are significantly different from those of sandy tsunami deposits. The deposit is a mixture of pumice and beach sand; both are transported and deposited inland by a tsunami. The origin of the pumice in the layer is drift pumice, reworked pumice, and primary pumice fall-out during the tsunami run-up. This unique sediment layer is often observed in near-source tsunami deposits of volcanic origin. Landward thinning and landward fining, those are common for sandy tsunami deposits, are not typical features of these volcanism-induced tsunami deposits.

Tavurvur Volcano, Rabaul, Papua New Guinea, broke into an eruption on October 7th, 2006, and generated a series of local tsunamis. The tsunami inundation area is covered by pumice-rich tsunami deposit. Commonly, the pumice is accumulated in the uppermost part of the layer, and the base of the deposits is sandy. The tsunamis eroded the top of the ash layer deposited before the tsunami occurred. Along the inundation boundary, a distinct belt of accumulated pumice is created. Pumice boulders are also distributed in the inundation area. The origin of these pumice are drift pumice because there are no pumice fall-out layers landward of the tsunami limit. Pumice boulders are not broken, and impact craters are not created around them. Average density of the pumice is about 0.8 g/cm³. Tsunami heights indicated by the deposit distribution are 5-7 m. In Rabaul, similar local tsunami and tsunami deposit are observed during the 1994 eruption series.

It is important to investigate spatial distribution and sedimentary features of tsunami deposits including volcanic ash or pumice to identify and evaluate past tsunamis in tectonically active regions such as Hokkaido-Kuril-Kamchatka. Characteristic tsunami deposits including specific volcanic materials are useful to correlate tsunami deposits associated with one event at different survey sites.

1.2-P-40

Developments in Analysis of Basaltic Ash Applied to Recent Activity At Stromboli and Etna Volcanoes

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Volcanic ash is widely distributed and therefore generally safe to collect in real-time, however, there is a paucity of published studies focused on characterizing the textural properties of ash (relative to larger clasts), probably because its small size makes ash inherently difficult to analyze. Advances in analytical techniques coupled with recent high levels of activity at Etna and Stromboli have offered a unique opportunity to sample and analyze of basaltic ash particles. We present data on analysis of basaltic ash from a variety of eruptive conditions: eight samples of ash collected from a weak ash-producing event at Etna on 24 November 2006, and ash from a variety of activity during the 2007 eruptive crisis at Stromboli (ash emission, paroxysmal explosions and lava-sea water).

A JEOL JSM 6500 Field Emission Scanning Electron Microprobe (FE-SEM) was used to image and quantify millimeter- to submicron-scale features of ash particles. Beside qualitative observation of the particles, semi-automated FE-SEM data include particle morphoscopy (area, perimeter, compactness, equivalent diameter) and surface chemistry. The morphoscopy data can be compared to grain size data collected by conventional techniques, while the surface chemistry data can be considered a proxy for component analysis, more typically performed using a binocular microscope, as it reflects the degree of crystallinity and alteration of the

particles. Preliminary data indicate that insight into the particle source and eruptive dynamics of both volcanoes can be obtained from detailed analysis of the ash. In particular, the different sources of ash at Stromboli have highly distinctive alteration signatures, while the Etna samples exemplify the potential of the approach to discern subtle differences in ash particles from the same plume collected at different locations, thus outlining relatively small-scale plume zonations.

1.2-P-41

Insights into Degassing Behaviour of Vesiculated Basaltic Magmas: an Example from Ambrym Volcano, Vanuatu Arc

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We performed a series of X-ray computed microtomographic experiments as well as permeability measurements on scoria clasts collected from a deposit of recent mild explosive activity of Benbow crater, one of the two active craters of Ambrym volcano. The goal was to reconstruct and visualize the texture of rocks in 3D and to quantify vesicularity, permeability, vesicle sizes, shapes and distributions in order to understand how gas moves and is lost in these magmas. We found that vesicle distributions span a range of volumes between 10^3 to $10^{10} \mu\text{m}^3$ and correlate with sample vesicularity. Distributions related to samples with vesicularity <0.68 can be fit by power laws with an exponent 1 ± 0.2 ; distributions with vesicularity >0.68 can be fit by power laws with exponents near 1.7, as well as by exponential fits. The former distributions do not exhibit a markedly large-volume vesicle, this type of vesicle becomes more evident in these distributions with increasing vesicularity; the latter distributions exhibit a very pronounced large vesicle with a volume up to more than three orders of magnitude larger than all other vesicles in the distribution. Finally, vesicle number density negatively correlates with vesicularity: less vesicular samples have the highest number density, and the number of small-to-intermediate sized vesicles is larger compared to very vesicular samples. This is because in vesicular samples most vesicles coalesce into the large vesicle present in these samples, decreasing the overall total number density. Darcian permeability varies between 10^{-10} and 10^{-13}m^2 ; it is higher in the more vesicular samples. When compared with vesicle distributions of scoria samples from explosions at Stromboli, the Ambrym vesicle distributions highlight several differences, suggesting that magma original volatile content and rheology potentially affect gas flow in basaltic magmas from different tectonic settings.

Session 1.3

1.3-O-01

Location of Low Frequency Signals Associated to Volcanic Explosions of Volcán de Fuego de Colima Using Broad Band Semblance Analysis.

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Volcanic explosions of Volcán de Fuego de Colima have been analyzed using broad band sensors. The spectra analysis indicated the presence of a low frequency signal, with energy between 0.1 and 0.4 Hz, which preceded the aerial effects, the explosion. These signals appear in the main of the cases around 1 minute before the visual observation of the explosions, and can be considered as premonitory, or the initial triggering of the explosion in depth.

In the present study we have analyzed this Long Period phases and located them using the semblance procedure. The source of these signals is located in depth, around 4 km below the summit zone and in a extend zone of a tens of cubic kilometres. This zone is coincident to the region previously located using seismic antennas and analyzing seismic phases with frequencies over 1 Hz. Also volcano-tectonic earthquakes have been located in the same region.

Conclusions indicated that this region is the main candidate to be considered the genesis of the moderate vulcanian explosions that regularly occurred in the Volcán de Fuego de Colima.

1.3-O-02

New Insight on the Increasing Seismicity during Tenerife's 2004 Volcanic Reactivation

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During 2004, the island of Tenerife (Canary Islands, Spain) underwent a significant increase in seismic activity, probably related with a reawakening of the volcanic activity. This seismicity is now analyzed from a new point of view, in order to improve our knowledge on such phenomena and to develop new tools for future seismic crisis. The 240 earthquakes located onshore between 2004 and 2008 were classified by means of techniques of seismic signal correlation, resulting in a few number of significant families. The location of the events of each family seems to be the same, with the presence of two major seismogenetic zones located NW and SW from Teide-Pico Viejo complex. A relocation of the seismic events using hypoDD algorithm has shown new char-

acteristics of the seismicity including the depth distribution of the different families. The seismic catalogue has been fulfilled with more than 400 additional events, which were recorded only in one seismic station, and thus, impossible to be located. Each of these events has been characterized by the location of its family and by a magnitude computed by comparison of the seismic signal with those events having a properly computed magnitude. The Gutenberg-Richter curve demonstrates a completeness of this enhanced catalogue for magnitudes as low as 1. The analysis of the time evolution of the seismic families shows an alternation of the seismic activity from SW and NW regions, starting in January 2004. In the basis of the methods developed in this work, a technique for a semi-automatic seismic analysis algorithm included in a volcano monitoring system is proposed.

1.3-O-03

Monitoring of Changbaishan Tianchi Volcano for the 10-year Period: Results and Implication of Magmatic Activity

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Tianchi volcano, in Changbaishan (Ever White Mountain) area, is located in the Northeastern China at the boundary between China and Korea. Both previous geological study and historical records indicate that Tianchi volcano has experienced several explosive eruptions at large scales, in which one explosive eruption occurred in about 1200 AD is believed as one of the largest eruptions in the world In last 2000 years with an estimated eruption volume in the range 15 to 30 km³ of magma and formation of a caldera with a diameter of 5 km. Since the establishment of Changbaishan Volcano Observatory in 1996, a comprehensive monitoring of magmatic activity of Tianchi volcano has been carried out in order to understand the magmatic processes and potential risk of explosive eruption in future. Based on the 10-year period (1999-2009) monitoring by means of seismology, ground surface deformation, volcanic gas geochemistry, and satellite thermal infrared remote sensing, we observed the ascent process of magma at Tianchi volcano during 2002-2005. Our observation is strongly supported by the following evidences. 1) Increase of number of earthquakes per month from less than 10 events before 2002 and after 2005 to greater than 70 events in period of 2002-2005, which suggests about 10 times increase in seismic intensity; 2) Distinctive horizontal expansion near the crater of Tianchi volcano from GPS observation, and 46mm upward displacement near the crater from leveling survey between 2002 and 2003; 3) Increase of ³He/⁴He ratio in gas from hot springs near Tianchi volcano; and 4) Intensive thermal anomaly during 2002 -2005 from satellite thermal infrared remote sensing analysis. These monitoring evidences mentioned above suggest a magma inflation

and upwelling activity in the magma chamber. Such magmatic activity may be attributed to the intensive subduction of the Northwest Pacific plate toward the Eurasian plate.

1.3-O-04

Seismicity Associated to the Reactivation of Nevado del Huila Volcano, Colombia.

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Nevado del Huila Volcano (NHV), started a new eruptive cycle after more than 500 years of quiescence. On November 2006, several earthquakes of ML >2.5 were located to the south of volcano. Background seismicity started to increase from December 2007. On 18th February 2007, Volcano-tectonic (VT) earthquake swarms, and Long-period (LP) earthquake swarms, as well as Hybrid (HB) earthquakes, and a special kind of earthquakes named here "Multi-event" (ME), preceded a phreatic eruption, which produced two cracks at the top of the ice capped volcano and a huge lahar. On april 18th 2007, another phreatic eruption occurred with similar seismic pattern than that on 18th February 2007. A lahar of larger magnitude than previous, was produced as well.

On 21th November 2008, a phreato-magmatic eruption occurred preceded by the occurrence of many "drum beat"-type earthquakes, tremor (1.3 Hz), VT, LP, HB, and ME. After the eruption, a dome was observed at the top of the volcano (4x107m³). On May 2009 a new intrusion of magma started with several deep VT earthquakes (ML>4.5), located beneath summit and to the south. On November 2009, after an increase of seismicity, VT, LP and ME, a dome of larger size than previous (1x108 m³) was extruded, and continues growing up today (January 2010). From this seismic analysis we argue that ME earthquakes seems to be associated to small bursts, and they are the most characteristic seismic signal occurring few days previous to volcanic eruptions at NHV.

Coda Q and b-value analysis were done for VT earthquakes. Temporal changes were observed for both parameters, related with changes in volcanic activity. These changes in the mentioned parameters, suggest that NHV activity could be related to changes in phase inside volcano; that is, increase and decrease of fluids (gas and/or magma) and solids (ash mainly).

1.3-O-05

Seismicity Associated to Emplacement and Destruction of Domes at Galeras Volcano, Colombia, 1989-2009.

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Galeras volcano (GV) has shown interesting seismic features during last 20 years. Three events of dome emplacement and destruction have been recorded into three periods: 1988-1993; 2004-2007, and 2008-april 2009, and a period of magmatic eruptions without dome, between June 2009 – January 2010.

A repetitive seismic pattern was observed for the three periods of emplacement and destruction of domes, associate to four stages;

Stage 1: magma Intrusion, characterized by volcano-tectonic (VT) earthquake swarms far from active crater, with $M_L > 3$; deep LP earthquakes and spasmodic tremor of low frequency (1-2Hz). Stage 2: Cleaning of plumbing system, characterized by seismic signals associated with ash emissions, tremor and VT seismicity of different sizes, as well as many other seismic signals of different types, called here “Sancocho” (typical Colombian soup made of many vegetables), such as “tornillo”-type earthquakes, LP, hybrids (HB), spasmodic and harmonic tremor, all of them occurring together.

Stage 3: Emplacement and growth of dome, characterized by the occurrence of many LP, located around active crater, and tremor in less proportion.

Stage 4: Dome destruction, characterized by a sudden reduction of seismicity, related probably with an obstruction of conduits at shallow depths. “Tornillo”-type earthquakes with tendency to reduce the frequency contents; large amount of microfractures at shallow depths. This seismicity occurs before vulcanian eruptions, which destroy the dome totally or partially. After this stage, the volcano becomes stable for a while.

From last year (2009), GV have erupted ten (10) times. The seismic pattern observed, have allowed to alert and evacuate people previous to eruption, from few days to several weeks in advance.

1.3-O-06

Database and web-interface for an early warning system at Stromboli volcano

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Stromboli volcano (Aeolian Islands, Italy) is one of the most active volcanic islands on Earth. The typical activity is characterized by regular explosions emitting small volumes of lava spatter and pyroclasts up to 50–100 m above the craters every 15–20 min; this type of behavior has become synonymous with the volcano. Strombolian explosions are occasionally interrupted by major explosions and paroxysmal events., i.e., more violent bursts leading to eruptive columns, several hundred meters high above the craters, and often causing abundant fallout of ash, bombs and blocks. On the other hand, effusive activity and landslides can also occur. These events represent a serious risk for the tourists and for the local population.

In the framework of the ‘V2-Paroxysm’ project funded by the Dipartimento di Protezione Civile (DPC-INGV 2007-2009), a systematic study was launched aiming at integrating and reorganizing the large mass of data collected by the monitoring network on Stromboli. The final goal was to recognize short term precursors

of explosive and effusive eruptions at Stromboli. A database has been created to collect all the parameters related to the volcano activity measured by different ground network (seismic, geochemical, infrasonic, thermal camera and GPS) starting from 2006. The relational database structure has been developed compliant to WOVodat international standard. Specific tables have been formatted for each type of measurements and instruments in order to query the database through a web-interface. The interface has an upload area to populate the database and a visualization tool for multi-parametric time series charting. Final step of the project is the creation of the early warning system. The preliminary prototype will be presented.

1.3-O-07

Exupéry: a mobile Volcano Fast Response System (Exupéry VFRS)

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Despite ever increasing efforts to monitor active volcanoes many of those are still very poorly or unmonitored, even in highly populated areas. In case of volcanic unrest or even a volcanic crisis quickly assessing the situation is therefore often very difficult due to the little information that is available for that specific volcano. With vastly increasing possibilities in communication technology and managing huge data volumes mobile systems become more and more an option to be used as a crisis management tool in volcanology.

Here we present a newly developed volcano fast response system which overcomes several of these shortcomings. The core of the system is a novel database (SEISHUB) that allows for the collection of data of various kinds, i.e. simple time series data like seismic data, gas measurements, GPS measurements, as well as satellite data (SO₂ flux, thermal anomaly, ground deformation). Part of the collected data may also come from an already existing network. Data from new field instruments are transmitted through a wireless network that has been specifically designed for the volcano fast response system.

One of the main difficulties with such a multidisci-

plinary data set is an easy access to the data. This is provided through a common Web based GIS interface which allows various data layers being simultaneously accessed through a Web Browser. The underlying software is designed in such a way that it only uses open source software, so it can be easily installed on other systems not having to deal with purchasing proprietary software. Aside from this the system provides tools to analyze the incoming data (e.g. earthquake classification, rapid moment tensor inversion, deformation modeling, an automatic alert level system) which are currently under development.

1.3-O-08

NOVAC – Network for Observation of Volcanic and Atmospheric Change, present status and results

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The NOVAC project, funded by European Union, was started in October 2005 with the aim to establish a global network of stations for the quantitative measurement of volcanic gas emissions. The network is based on a novel type of instrument, the Scanning Dual-beam mini-DOAS. Primarily the instruments will be used to provide new parameters in the toolbox of observatories for gas emission estimates, geophysical research and hazard assessment. In addition, data are exploited for other scientific purposes, e.g. global estimates of volcanic gas emissions, regional to global statistical analysis, and studies of atmospheric chemistry. In particular large scale validation of satellite measurements of volcanic gas emissions will be possible, bringing spaceborne observation of volcanoes a significant step forward.

The Scanning Dual-beam Mini-DOAS instrument is capable of real-time automatic, unattended measurement of the total emission fluxes of SO₂ and BrO from a volcano with better than 5 minutes time resolution during daylight. The high time-resolution of the data

enables correlations with other geophysical data, e.g. seismicity, thus significantly extending the information available for real-time hazard assessment and research. By comparing high time resolution gas emission data with emissions from neighboring volcanoes on different geographical scales, or with other geophysical events (earthquakes, tidal waves) mechanisms of volcanic forcing may be revealed. The spectra recorded by the instrument will also be used to derive data that complement global observation networks related to climate change and stratospheric ozone depletion research.

The network today encompasses 55 instruments installed on 21 volcanoes, including some of the most active and strongest degassing volcanoes in the world.

The project and its present status will be presented as well as results from some of the volcanoes.

1.3-O-09

Hidden Tectonic Framework Of The Summit Of Mt. Etna (Sicily, Italy) Revealed From Soil CO₂ Efflux And Soil Temperature Surveying.

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Mount Etna in Sicily (973 km²), the most active European volcano, is known as one of the largest contributors of magmatic CO₂ released to the atmosphere. A significant part of this gas is released in diffuse form through the volcano's flanks, along faults and fractured zones, particularly around its summit (about 3350 m). Etna is also characterized by significant and often dramatic slope failure of its eastern flank, which is thought to trigger summit collapses and some lateral eruptions. In order to map the faulted areas near Etna's summit and to study possible weak zones, a diffuse CO₂ efflux survey was carried out at Mt. Etna in October, 2008. A total of 1442 sites were surveyed for soil CO₂ efflux and soil temperature over an area of about 9 km² that included most of the summit part of Mt. Etna above 2600 m a.s.l. The results show the presence of several degassing faults in all of the surveyed area except its west part, which seems to be structurally stable. Most of the degassing faults start from the summit craters and run parallel to the borders of the eastward collapsing sector of the volcano. Many of them are related to the development of the South-East Crater, but others seem to be related to a large buried crater rim, probably a remnant of the 1669 collapse crater formed during the largest eruption in the last 2000 years. Some degassing faults are not accompanied by thermal anomalies, thus suggesting that the gas source is too deep and/or the ground permeability is too low to allow high-enthalpy fluids to reach the surface before their condensation. These "cold" faults bound the anomalous degassing ar-

eas to the west, therefore they would be relatively new and shallow, suggesting a progressive westward shift of slope failure.

1.3-O-10

Combining Traditional Observational Methods And Multiparameter Monitoring Of Renewed Activity At Soufriere Hills Volcano, Montserrat

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A range of techniques have been utilised at the Montserrat Volcano Observatory (MVO) to monitor the renewed activity in late 2009 and 2010. This renewed activity has involved ash venting, dome growth and collapse forming pyroclastic flows. There have also been a number of vulcanian explosions involving radial fountain collapse and a large partial dome collapse on 11 Feb 2010, during which there were several explosions and a lateral blast.

No single technique is on its own enough to understand these events and we have used a wide range of technology to understand this activity.

One of the most useful tools for monitoring has been a thermal camera (FLIR) installed at MVO which acquires 2 frames sec has allowed night-time documentation of activity, especially dome growth, which has been liable to change on an hourly basis. Understanding changes in the location and intensity of dome growth has been vital in managing and forecasting hazardous activity in the short term.

We illustrate the integration of monitoring techniques through examples such as the partial dome collapse event of 11 Feb 2010, a complex event which developed over two hours. Unravelling the sequence and nature of the events that took place was only realised by combining seismic, infrasound and thermal camera imagery together with time lapse photography and standard visual observation.

It is clear that straightforward detailed visual observation of volcanic activity is still one of the most valuable and informative methods of volcano monitoring and when integrated with technological methodologies is possibly the only way to fully reconstruct volcanic events. At MVO such visual observations are logged through a LAN based interface that can be interrogated at a later date.

One important lesson from the recent activity is that all monitoring data needs to be available and reviewable in real time.

1.3-O-11

Evidence of Fracture Reactivation integrating Volcanological, Structural, and Seismic Data Recorded at Mt. Etna, Italy

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We merge volcanological, structural, and volcanic tremor data to shed light on a fissure system opened on the upper SE flank of Mt. Etna, Italy, in 1989. The system propagates to about 6 km from the Southeast Crater (SEC), and although it is formed by dry (non-eruptive) NNW-SSE fissures, it was active throughout several eruptive episodes after 1989, such as in 1991-1993 and (at least in part) in 2001, 2004-2005, and 2006. Particularly, we focus our attention on a paroxysmal eruptive episode on 24 November 2006, which encompassed different eruptive styles, such as lava fountaining and effusion, and violent Strombolian explosions, involving several eruptive vents on and near the SEC. This event was documented by detailed field and aerial surveys and remote video cameras. The characteristics of the seismic radiation are analyzed considering: frequency content, wavefield properties, and centroid location of the volcanic tremor source. The synoptic analysis of volcanic phenomena and volcanic tremor data document that: i) an aborted intrusion of magma rose to ~2000 m above sea level in the late evening of 24 November, along the NNW-SSE direction from below the SEC towards the 1989 fracture system, ii) the fissures opened in 1989 strongly affected, approximately 17 years after their formation, the modality of propagation of the seismic energy radiation within the upper volcanic edifice. Besides the role played by the 1989 system on the properties of seismic radiation in 2006, the present study allows to postulate probable links between contiguous fault systems in the upper SE flank of Mt. Etna. Based on the structural framework on a volcano-wide scale, our results do indeed sketch out a hitherto unknown continuity of some faults affecting the southeastern flank, which might also shed some light onto the complex phenomenon of flank instability in the eastern sector of the volcano.

1.3-O-12

On the Shallow Crustal Structure Underneath Harrat Al-Madinah

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Harrat Al-Madinah Quaternary lava field, a part of the vast Cenozoic monogenetic volcanic field in western Saudi Arabia, is immediately contiguous to the boundaries of the major city of Al-Madinah. Two volcanic eruptions only ~600 years apart occurred close to the city, and their flows reached the current city bounds. The youngest of these erupted only ~750 years ago and was preceded by a swarm of felt seismicity, the strongest of which was estimated to be of magnitude ~5. The City is currently expanding right into the Harrat lava field,

exposing it to a significant volcanic and seismic risk. A fundamental requirement arises, therefore, for a detailed local crustal model underneath the Harrat that would permit refined seismological investigations for quantitatively assessing potential volcanic-associated seismic hazard. A spatial autocorrelation (SPAC) survey comprising three concentric triangular arrays having 0.5-2Km aperture sizes was carried over the oldest lava flow in Harrat AlMadinah using 4 broadband sensors simultaneously recording for periods exceeding 10 hours for each array. Vertical-component SPAC ratios of the arrays were directly inverted for shear wave velocity using the variation on the neighborhood algorithm of Wathelet et al. (2005). The inversion indicated the presence of a low velocity, high Poisson's ratio (~0.4) zone at a depth exceeding 10Km, probably indicating a state of partial melting. This zone underlies a zone of non-molten rocks where several magnitude 3 earthquake hypocenters were located during a seismic swarm that occurred in 1999 close to the location of the current SPAC arrays. This might imply that the swarm was the result of a magmatic unrest and points to the potential volcanic and volcanic-associated seismic hazard threatening neighboring communities and the major nearby city of Al-Madinah. The recent volcanic unrest and seismicity in Harrat Al-Shaqah to the northwest are reminders of such a threat.

1.3-O-13

Degassing activity fluctuation before eruptions at Sakurajima volcano, Japan.

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The mechanism of Vulcanian eruption is thought to be closely related to a degassing activity. The fluctuation of degassing activity is inferred as a precursor of an eruption (e.g., Iguchi et al., 2007). A decrease of volcanic gas flux before an eruption due to sealing of the conduit was suggested by video camera monitoring and conventional volcanic SO₂ flux measurements. The conventional SO₂ flux measurement, however, does not have enough time resolution in order to observe the detailed SO₂ flux fluctuation before the moment of the eruption directly. Recently, imaging techniques of SO₂ in a volcanic plume by using UV cameras were developed (Mori and Burton, 2006; Bluth et al., 2007). Since these methods can acquire SO₂ flux with frequencies of the order of 1 Hz, we can observe SO₂ flux fluctuation corresponding to eruptions. In this study, we may present SO₂ flux fluctuation before the eruptions by UV cameras observation and conventional SO₂ flux measurements at Sakurajima volcano, Japan, in December, 2009 and in January, 2010. On December 1, 2009, the SO₂ flux time series obtained by UV cameras and conventional methods denoted relatively same values. For almost all eruptions, there were not clear precursors of eruptions. The eruption with strong air shock, however, was preceded by a monotone decreasing SO₂ flux by half in 5 minutes. This fact suggests that the big eruption with strong air shock has a sealing process, but the small one does not. Therefore, the decrease of SO₂ flux

might be a useful indicator for a bigger eruption. More quantitative treatment for relation between gas fluctuation and other geophysical observations remains to be solved.

1.3-O-14

Monitoring the 2003-2010 Explosive Activity of Stromboli by Video-Recording and Field Data Analysis

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Stromboli is one of the most active volcanoes in the world due to its persistent Strombolian activity, consisting of mild to moderate explosions from a variable number of active vents (usually from two to six) in the crater terrace, a flat area in the upper portion of the volcanic edifice. Stromboli is also visited by people from all over the world who come to reach the summit and watch the extraordinary spectacle of the ordinary explosive activity. This is periodically interrupted by less frequent (up to several times per year) explosions of higher energy or paroxysms, and effusive eruptions (one event every 4-10 years). This wide spectrum of volcanic activity has recently caused major hazards to residents and tourists on the slopes of the island, necessitating increasing attention by volcanologists and civil defence authorities and improvements in the volcanological surveillance system of Stromboli.

In this work, we present results deriving from the monitoring performed by video-recording analysis and continuous field surveys from 2003-2010, a period characterised by two effusive eruptions (2002-03 and 2007), at least six paroxysms (the largest on 5 April 2003 and 15 March 2007), several high energy explosive events and an extremely variable ordinary activity in terms of intensity and explosive frequency. The INGV camera network allowed characterizing the type and frequency of ordinary explosions with a detail never before achieved, suggesting that Strombolian explosions display a wide range of intensity that approaches small-scale paroxysms. Furthermore, field surveys have enabled observing morphological variations in the crater terrace and recovering tephra samples, whose different types were related to the explosion style. We show that the integration of all the collected data may help to investigate the relationships between the pattern of ordinary activity and paroxysmal events and to appropriately address the monitoring of Stromboli.

1.3-O-15

Micro-Raman spectroscopy as an effective tool for real-time monitoring of volcanic products

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Real-time petro-chemical monitoring of eruptive products represents a difficult task because it requires rap-

id acquisition of accurate information on a number of samples large enough to be representative of the ongoing processes. On the other side, the rapid detection of changes in magma properties (mineral paragenesis, crystal and melt composition, residual volatile contents) provides crucial information on fundamental processes occurring in the magma plumbing system. Micro-Raman spectroscopy represents an effective tool for fast and accurate analysis of crystals, glasses and fluids with high spatial resolution (1 mm) and requires only minimum sample preparation. Recent spectrometers are relatively low cost and robust to be installed in a volcanological observatory or deployed in the field. Lava, pyroclasts, minerals, ash shards, Pelé hairs can be easily analyzed in a few minutes thus providing the needed dataset for a preliminary, but exhaustive, characterization of freshly sampled eruptive products. Usually, micro-Raman spectrometry allows an easy identification of most mineral phases and provides semi-quantitative information on mineral chemistry. Recent developments of quantitative Raman procedures for the analysis of natural glasses further extends the potentiality of this technique for the monitoring of volcanic products. We review the analytical procedures and the reference diagrams defined for the determination of 1) bulk composition, 2) oxidation state, and 3) dissolved water content of volcanic glasses. These procedures are then applied to the analysis of eruptive products from active andesitic and basaltic volcanoes.

1.3-O-16

A New Cycle of Activity At Mt. Etna (Sicily, Italy) During 2009, Revealed from Diffuse CO₂ Degassing and Crater Emissions of SO₂ and Halogens

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In 2009, Mt. Etna (Italy) activity was characterised by the end of a long-lasting flank eruption started on 13 May 2008 and by the opening of a new summit degassing vent on the E flank of the South-East crater on 6 November. This was preceded by a sequence of significant anomalies in volcanic degassing, detected by periodic measurements of soil CO₂ efflux on the east flank of the volcano, continuous measurements of SO₂ flux from five fixed monitoring stations, and periodic FTIR measurements of the SO₂/HCl and SO₂/HF molar ratios in the volcanic plume. Since April 2009, soil and crater emissions showed a progressive increase marked at least by two major steps, in April-May and September-October. Increases were not observed simultaneously; in fact, they were detected first in soil CO₂ emissions and then, a few days/weeks later, in crater SO₂ flux. Only minor increases of HCl and HF crater fluxes were observed between November and December. The highest SO₂ and halogens fluxes were recorded in coincidence with the opening of the November 6 vent. The degassing behaviour of the volcano in 2009 is consistent with the

differential release of magmatic gas species, according to their different solubilities, from a magma body rising from ~5 km depth to the surface. Our results suggest the start of a new phase in Etna's activity, in which the new vent might reflect improved efficiency in the release of magmatic gas through the main feeding system, supplied by a magma body stored at depths between 4 and 2 km. If degassing at the new vent will remain steady-state, thus forming a stable feeding system, then its opening might represent the eastward migration of the South-East crater activity with the likely formation of a new stable summit cone.

1.3-O-17

Increase in Eruptive Activity at Showa Crater and Deep to Shallow Magma Movement at Sakurajima Volcano, Japan

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Explosive activity at Minamidake summit crater of Sakurajima Volcano, Japan began in 1955 and the eruptivity continued >50 years counting 7900 Vulcanian eruptions. The main magma reservoir of the Sakurajima volcano is located at a depth of 10 km near the centre of Aira caldera, northern part of the Sakurajima. The magma reservoir inflates in dormant period and deflates after violent eruptions in 1914, 1946 and after 1980's. The eruptive activity gradually decreased after the peak of explosivity in 1985. On the other hand, ground around the Aira caldera has inflated since 1992, indicating accumulation of magma of 9x10⁷ m³. The seismicity of A-type earthquake increased in 2003 and 2004 at SSW part of the Sakurajima and NE part of the Aira caldera, suggesting accumulation of strain around the volcano. In June 2006, eruptive activity at Showa crater at the eastern flank resumed after ca 60 years dormancy from the last lava effusion in 1946. Eruptivity was intermittent at the initial stage, however explosive activity remarkably jumped up in July and October 2009. Tilt change and amount of volcanic ash shows that magma flux rate increased from <1x10⁵m³/mo to 2x10⁵m³/mo in July and 3x10⁵m³/mo in October. The number of explosive eruptions and weight of volcanic ash ejected from the crater amounted 580 and 3.2x10⁶ tons, respectively, in 2009. The explosive eruptions at Showa crater are 1-2 orders smaller than those at the Minamidake crater. Inflation tilt and strain changes are observed associated with individual explosion. The ground deformation can be explained by deep (d=3km) and shallow source (d=1km). Deep source shows stable inflation – deflation pattern. Shallow source inflates with fluctuation and rapidly deflates in short term after start of explosions.

1.3-O-18

Ground-Based Imaging Cameras For Monitoring Hazardous Gas and Particle Emissions From Volcanoes

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Monitoring of hazardous emissions from volcanoes can be done in a cost effective, efficient and quantitative manner using advanced imaging camera technology. Two new systems have recently been developed and tested utilizing Ultra-Violet (UV) and Infrared (IR) CCD imaging cameras. EnviCam uses UV light to quantify SO₂ gas, particles and aerosols in 9 separate bands, while CyClops measures IR radiation in 4 separate bands to measure SO₂ and respirable ash particles. The advantage of the IR system is that it can be used day or night in a 24 hr autonomous manner. Both systems are portable and can be operated off 12 V, in a low power mode, controlled via a PC and operated at stand-off distances up to 10 km. The principles of the measurements and operating modes of the cameras are provided. Measurements from imaging cameras are also presented for some example volcanic field experiments and the advantages and usefulness of the cameras are described in the context of early warning systems for volcanic hazards and for routine monitoring at remote and dangerous environments.

1.3-O-19

Towards Mid-Term Eruption Prediction of Izu-Oshima Volcano, Japan: Characteristics of Magma Accumulation and Soil CO₂ Concentration Variations

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In order to make successful mid-term or long-term eruption predictions, we need to detect particular precursor processes operating in magma-plumbing system. By integrating the precursors to the 1986 eruption of Izu-Oshima volcano, we proposed that the accumulation of magma had continued for more than 10 years until 1980, and then basalt magma started to rise up through the well-developed conduit. Since 1989, we have detected the secular reinflation of the volcano and further revealed the repeated deflation-inflation cycles. The rate of secular inflation has decreased exponentially, while the amplitude and duration of the cycles increased. We naturally suppose that the volcano inflation is caused by the supply of magma from depths. What is the origin of the deflation? There are two possible processes causing the deflation, magma drain back and the contraction of magma due to degassing. In either case, the inflation- deflation cycle indicates the accumulation and relaxation of magma beneath the volcano and is closely related to the way of magma achievement of the conditions to start its rising up toward the eruption. The elucidation of deflation- inflation cycles may throw light on understanding the precursory processes. To monitor the degassing of basaltic magma accumulating beneath the volcano, CO₂ is most helpful because CO₂ separates from melt at the earliest stage of accumulation. In September 2005, we started continuous monitoring of soil CO₂ concentration at the eastern part of the summit of Izu-Oshima volcano. We observed the correlated increase of soil CO₂ concentration during not only the periods of accelerated inflation but also those of defla-

tion of the volcano. Degassing of the accumulated magma might cause the deflation. The amplitude increase in the deflation-inflation cycles might indicate the volume growth of CO₂ over-saturated region at the upper part of the magma reservoir of Izu-Oshima volcano.

1.3-O-20

Remote FTIR observation of volcanic gas composition for recent eruptive activity of Showa crater at Sakurajima volcano, Japan.

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Sakurajima volcano, located in the southern part of Kyushu Island, Japan, is one of the most active volcanoes in Japan with frequent eruptions and Vulcanian explosions. Until 2006, the eruption activity had been centered at Minami-dake crater. After the re-awakening of Showa crater, at the upper Eastern flank of Minami-dake, in June 2006, the eruptions are now mostly occurring at Showa crater. The eruptive activity of Showa crater is recently getting more frequent and number of explosions from the crater exceeded 500 per year in 2009. In order to understand the current gas composition of Sakurajima volcano, we carried out open-path FTIR measurements with solar occultation method (Francis et al., 1998) using MIDAC AM system FTIR. The observed HCl/SO₂ ratio ranged 0.09-0.26 and fluctuated with time. This fluctuation is due to changing of mixing ratio of the two end members, namely the plumes from Showa and Minami-dake craters. By using the sun setting just behind Minami-dake and Showa craters as the light source, we were able to estimate HCl/SO₂ ratios of the respective craters. Our results showed that HCl/SO₂ ratios of the two craters in Nov.-Dec. 2009 were clearly different and HCl/SO₂ ratio of Showa and Minami-dake craters were ~0.1 and >~0.25, respectively. This difference is probably reflecting magma plumbing system of Sakurajima volcano and indicating the difference of degassing conditions of the two craters.

1.3-O-21

From Hydrothermal- to Magmatic-Dominated Fumarolic Gas Discharges: the Recent Volcanic Crisis of Turrialba Volcano (Costa Rica)

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On the 4th of January 2010 a loud explosion was heard at the top of Turrialba (the southernmost active volcano of Costa Rica, with a summit consisting of three nested craters: East, Central and West). This explosion was followed by three other blasts, likely related by phreatic eruptions. These events are the last explosive episodes at Turrialba after the 1864-1866 eruptions and represent the current results of the unrest that Turrialba is suffering since 2001, when a drastic compositional change of fumarolic fluids occurred, passing from typical hydrothermal conditions, dominated by H₂O, CO₂ and H₂S

and subordinate H_2 and CH_4 , to a transitional hydrothermal/magmatic stage, characterized by presence of SO_2 , HCl and HF . After 2005, a further increase of magmatic gas species was recorded, marking the evolution to a magmatic-dominated phase. A drastic increase of the fumarolic fluxes, mainly concentrated in the West crater, and the appearance of new fumaroles between the East and West crater and in the outer S and SW flanks of Turrialba, were also observed. A volcanic plume, occasionally up to 2 km high and clearly visible from the capital city San José, is presently persisting on the summit, causing both damages to vegetation and crops and respiratory problems to the inhabitants living in the nearby villages. Interestingly, new fumaroles have also appeared at an altitude of 2600 m, i.e. about 700 m meter lower with respect to the crater summit, along the regional NE-SW oriented Ariete fault. These gas discharges, dominated by H_2O , CO_2 and H_2S , maintain the helium isotopic signatures of the crater summit ($\approx 7.7R/Ra$), suggesting a magmatic reservoir system similar to that feeding the summit fumaroles.

The geochemical, although discontinuous, monitoring of the Turrialba crater gases has revealed a successful and cheap tool to trace the evolution and forecast the forthcoming activity.

1.3-O-22

The WOVOdat Database, Data Formats and WOVoml Structure

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As unrest may lead to eruption, evacuation may be necessary to minimize damage and casualties. The decision to evacuate people is usually based on the interpretation of monitoring data. Over the past several decades, monitoring of volcanoes has used more and more sophisticated instruments. A huge volume of data is collected in order to understand the state of activity and behavior of a volcano. WOVOdat, the World Organization of Volcano Observatories' Database of Volcanic Unrest, will capture historical volcanic unrest and make it freely web-accessible, for reference during volcanic crises and for basic research on pre-eruption processes. WOVOdat will provide context within which scientists or observers can interpret the state of their own volcano, during and between crises. WOVOdat will facilitate comparative studies and pattern recognition of the precursory activities from different volcanoes. The WOVOdat Project is being hosted by the Earth Observatory of Singapore (EOS) for at least 2009-2013. Sources of data for WOVOdat vary widely from published references to openly available online observatory data. Data population is greatly facilitated by the availability of an SQL database in volcano observatories and an open data sharing policy. However, each observatory has its own data formats and data structure. To make the upload system more flexible for different formats of data, WOVOdat adopts an xml format called WOVoml (see documentation in www.wovodat.org) as an intermediate file for data uploading. Element naming in WOVoml follows the order designed in

WOVOdat 1.0 except that the field names are translated into simple English. A translator is available for those who prefer to keep xml element names as in WOVOdat 1.0. Converting scripts translate data into WOVoml prior to uploading into the WOVOdat MySQLdatabase.

1.3-O-23 - Keynote lecture

CORrelation SPECTroscopy (COSPEC): The First 40 Years

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In 1970, in Boston, Massachusetts, a panel of 12 Nobel Prize recipients awarded the Industrial Research IR-100 to the COSPEC as one of the most outstanding instrumental developments of said year (1970). The COSPEC was developed by applying astronomical techniques (such as those used to detect water vapour on Venus) to the measurement of gases and vapours of geophysical interest, e.g., SO_2 and others. Its development was financed by NASA, and its design was part of the author's Ph.D. work at the University of Toronto. In 1974, Prof. Richard Stoiber of Dartmouth College began applying the COSPEC to the measurement of SO_2 volcanic emissions as an indicator of eruptions, and the rest is now history. What made the COSPEC different were its ruggedness and its portability. Previously, spectroscopic instruments belonged in the lab mounted on highly stable platforms. The COSPEC, however, was designed to operate under rough field conditions, yielding the maximum Signal-to-noise Ratio in any kind of spectroscopic measurement; furthermore, it could compensate the fluctuations in natural radiation backgrounds automatically. This left the user free to concentrate on his/her measurements. Recent developments in photo sensors and the miniaturisation of components allow for an updating of this instrument, while maintaining its basic virtues: ruggedness and highest sensitivity for the measurement. This presentation will review how the COSPEC works, why it is still the most sensitive and reliable sensor on the market (albeit the heaviest!), and what the latest developments in this instrument are.

1.3-O-24

An accurate and robust method for automatic phase picking of volcano-seismic signals based on adaptive sub-band processing.

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Nowadays, any volcanic monitoring network stores a great amount of seismic data every day. Commonly the first step in the data processing implies the detection and identification of the volcanic events which are present in the signals. The accuracy with which this work is done determines the results of many seismological applications, like earthquake location or tomography. In this work we present a picking algorithm based on

adaptive multi-band processing including noise-reduction techniques. The aim of the algorithm is to obtain accurate phase picking of volcano-seismic signals, with accuracies of the order of the sampling period when allowed by the signal-to-noise ratio. In order to provide the phase picking, the algorithm performs a sub-band based envelope detection making use of a filter bank. Then, the noise is adaptively reduced for each band and a global envelope is recomposed from the de-noised sub-band envelopes. Finally, a non linear optimal filtering is applied to this envelope in order to obtain a characteristic function which allows accurate phase picking of volcanic signals. The proposed picking method has been evaluated with a database of seismograms, containing seismic signals at different signal-to-noise ratios. The method provides accurate results even for low signal-to-noise ratios.

1.3-O-25

Towards an Unsupervised HMM-based Automatic Classification System: Application to a Joint Database Built from Colima, Popocatepetl and Deception Seismo-Volcanic Events.

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Active volcano monitoring tasks and large unlabeled databases demand automatic non-supervised methods in order to detect and classify events. In scenarios involving population risks a reliable event classification can be the key to reduce the response time of an early warning system. The Hidden Markov Models (HMM) theory introduced by Baum et al. (1966) is becoming the most useful solution to build efficient classifiers for volcano-seismic events (Ibáñez et al., 2010). The aim of this work is to develop an automatic robust classification system based on HMM. Given the parallelism between volcano-seismic events and speech signals (Benítez et al., 2007) borrowed ideas from the Automatic Speech Recognition (ASR) area (Rabiner, 1989) are taken in order to build a joint database including events from Colima, Popocatepetl and Deception active volcanoes which mimic multi-speaker ASR databases ability for achieving independent classification models able to transcribe the speech of an unknown speaker. In our case, models trained using the joint database should be able to detect and classify in a non-supervised way events of other volcanoes which doesn't belong to the train corpus.

We have made a preliminary study building a complex database used to test the robustness of a continuous HMM-based recognition system. More than 195 hours of data from Colima (4687 events), 138 (2101 events) at Popocatepetl and 26 (3955 events) at Deception were registered at short period and broadband stations in

volcanic crisis periods. In order to evaluate the system reliability, a method to assign class confidence scores to each recognized event has been used (Cortés et al., 2009). Cross validation tests were performed in the joint corpus to measure recognition results for each volcano gathering the main challenges to overcome.

1.3-O-26

Permanent and Real Time GPS Network at Piton de La Fournaise, Ile de La Réunion, Example of the November 2009 to January 2010 Eruptions.

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The volcanological observatory implemented since 2002 a dense permanent GPS network on Piton de la Fournaise volcano (PdF), which is composed today by 2 basis stations, five permanent stations around the summit craters and five stations at the base of the central cone about 1.5 km away from summit. Five additional stations on the east flank of PdF have been added through the recent Undervolc program. Fifteen stations are equipped by Topcon GB-1000 GPS instruments, two stations are equipped by Trimble NetRS GPS instruments. Energy is produced by solar panels. For the precise determination of the sites by differential GPS, data were collected every 30 seconds and daily files were stored in the GPS memory, before being transmitted to the observatory by Wifi technique via 1 to 3 relay stations over distances up to 20 km and in one case via an MPLS network. We have basically two data transfer types: a non-real-time daily data file transfers at 0 pm and RTK (Real Time Kinematic) data streams. The daily data files are automatically converted every day to standard RINEX files and an automatic differential processing is applied to all permanent stations using the "GITG" base station. In RTK mode, the base station sends a real time correction signal to the permanent receivers in the field. Each receiver then computes and sends its corrected coordinate with centimeter level accuracy to the observatory. We will present here recent data from the November 2009 to January 2010 eruption series at Piton de la Fournaise. Ground deformations of up to 17 cm in horizontal and up to 20 cm in vertical direction had been recorded during the seismic crises and fissure openings and real time GPS data at the observatory allowed a quick localization of the eruptive vents.

1.3-O-27

Applied SWOT Analysis for the Volcano Warning System in the Canary Islands

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The usefulness of SWOT analysis is not limited to profit-seeking organizations. It is a strategic planning method used to evaluate the Strengths, Weaknesses, Opportunities, and Threats involved in a project or program. An

auditing of the volcanic warning system in the Canary Islands by applying a SWOT analysis had been recently carried out. A poor funding, a non-coordinated volcano monitoring program supported by public funding, an unequal territorial distribution of technical resources for volcanic monitoring, a dispersion of the personal dedicated to the volcano surveillance, and a poor volcanic risk perception by the administration are several of the observed weaknesses. On the contrary, the highlighted strengths are a moderate increase of human power and technical resources for the volcanic monitoring during the last years, a multidisciplinary program for the volcanic surveillance, the existence of human resources with working experience on volcanoes more active than those in the Canaries, etc. Among the external factors, several opportunities had been identified such as the unanimous declaration by the Spanish Senate and Congress as well as the Regional Canary Islands Parliament demanding to the National and Regional Government to establish urgently the Volcanological Institute of the Canary Islands (IVC), a territory with a high accessibility, the existence of useful infrastructures for volcano monitoring such as galleries (horizontal drillings), etc. On the contrary, the main observed threats are the archipelagic nature of the territory, a poor volcanic risk perception by the population, and the existence of elements or lobbies inside the public administration against of establishing the IVC. After crossing the observed strengths, weaknesses, opportunities, and threats several strategies were clearly came out such as (i) the urgent establishment of the IVC with the sufficient human and technical resources, (ii) the need to promote educational programs on volcanic risk awareness for the society (administered and administrators), etc.

1.3-O-28

Chemical and Isotopic Variations of Fumarolic Discharges at Teide Volcano, Canary Islands, Spain

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Tenerife is a volcanic island of the Canaries and host at its center Teide, a 3720 m.a.s.l. stratovolcano. Weak fumarolic activity currently occurs at the volcano summit. In April 2004, an increase of seismic activity within Tenerife Island and its surroundings was recorded by IGN (Spain's National Geographic Institute). Regional earthquakes changed from moderate-to-low seismic events, whose epicenters were located in an offshore area between Gran Canaria and Tenerife islands, to a mixture of volcano-tectonic events occurring in the northwestern sector of Tenerife island and close to Teide volcano. The chemical and isotopic compositions of the Teide fumarolic discharges have been periodically collected since July 2004. Gas samples collected in 1994, 1997 and 2003, and diffuse CO₂ efflux measurements from

the soil carried out at the Teide summit between 1999 and 2009 are also considered in this study. Fumarolic gases, which in the 90's were characterized by chemical features typical of hydrothermal fluids, have shown significant compositional changes, mainly consisting of the appearance, in April 2004, of HF, HCl and SO₂, whose concentrations followed a decreasing trend up to date. Hydrogen and CO concentrations have displayed temporal patterns similar to those of the highly acidic gas species, whereas CH₄ has shown an opposite behavior. The chemical evolution of the Teide fumarolic fluids, coupled with the observed increase of CO₂ soil fluxes, suggests that the seismic-volcanic crisis recorded in spring 2004 have triggered an increase of convective heat flux from magmatic system of this volcano. After this event, the pre-crisis conditions, i.e. typical of a stable hydrothermal system, seem to have, at least partially, restored.

1.3-O-29

The Recent Seismicity of Campi Flegrei Caldera (Italy)

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Campi Flegrei caldera is located in a very densely populated area. Half of the city of Naples lies within the caldera rims with about 350000 people living on this active volcano. For this reason the surveillance of this volcano requires advanced monitoring techniques in order to forecast even minor eruptions. The area was interested in the period 1982-84 by an unrest crisis with more than 16000 earthquakes and about 2m of ground uplift. Most of the quakes were felt by people and two with M=4 caused damages to the buildings. After this episode the seismicity rapidly waned and the ground started a downlift phase. In 1989, 1994, 2000 and 2006 this trend has been interrupted by minor episodes of ground uplift accompanied by small magnitude seismic swarms. In all these occasions swarms of Long-Period events were also recorded. We present an analysis of the seismicity linked to these episodes comparing it with other geophysical and geochemical data. The results shows that these minor episodes are related to rapid fluid flow from a geothermal reservoir, whose pressurization is the cause of the ground uplift. The Long-Period events shows a remarkable similarity over a range of about 20 years (1989-2008) suggesting a stability in their source. Furthermore statistical analysis on the time-space-magnitude distribution of the volcano-tectonic events shows that their hypocenters are located in the area where most of the geothermal activity occurs suggesting a strong connection between fluid pressurization and rock fracturing processes.

1.3-O-30

Cape Verde Volcano Observatory (OVCV): A New Challenge for Reducing Volcanic Risk at Cape Verde

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The Cape Verde Volcano Observatory (OVCV) is becoming a reality and a new challenge of our society for improving its effort on volcanic risk mitigation at Cape Verde. The Laboratório de Engenharia Civil (LEC) is the actual organization in-charge of volcano monitoring in Cape Verde, but the recommended actions for reducing volcanic risk not only imply volcanic surveillance work but also mapping volcanic hazards and volcanic emergency plans. Therefore this new joint effort from the Laboratório de Engenharia Civil (LEC), the Universidade de Cabo Verde (UNICV) and the Serviço Nacional de Protecção Civil (SNPC) to establish the OVCV is a great and marvellous national challenge for reducing volcanic risk in Cape Verde. This OVCV has already received the congratulations from several geoscientists as well as becoming a member of the World Organization of Volcano Observatories (WOVO). This joint effort is open to other national institutions which are willing to be part of this national challenge for reducing volcanic risk in Cape Verde. The OVCV's volcanic surveillance program includes a permanent instrumental network (VIGIL project) for monitoring seismicity which was donated by the PortugueseAID Agency due to increased awareness of volcanic hazard in Fogo Island following the 1995 eruption. Discrete volcano monitoring observations has been recently established thanks to the SpanishAID Agency (AECID) to provide a multidisciplinary approach for the volcanic surveillance in Cape Verde. These regular observations imply geophysical, geochemical, and geodetic measurements. The SNPC is in-charge for the communication of the volcanic alerts in Cape Verde after being provided by the OVCV. The volcanic alert system consists of a three colour alert levels: Green, Yellow and Red. Recently a volcanic alert system panel for the population donated by the AECID has been installed at Cha das Caldeiras. Several projects and proposals will enhance the OVCV future work.

1.3-O-31 - Keynote lecture

New Mass Increase beneath Askja Volcano, Iceland: a Precursor to Renewed Activity?

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Askja is an active central volcano located on the NS

trending en echelon rift zone marking the mid-Atlantic plate boundary in North Iceland. Our new gravity change data indicate that the previous long term trend of magma drainage has reversed. Between 2007 and 2009, gravity unexpectedly increased in the region, equivalent to a mass increase of ca. 0.68 X10¹¹ kg. This contrasts with our earlier gravity change observations which showed two periods of mass loss, between 1988 and 1995 there was a 1.6 x 10¹¹ kg mass loss and a further mass loss occurred between 1995 and 2007 of 0.5 x 10¹¹ kg. These mass losses have previously been interpreted in terms of magma drainage and since the recent increase is rapid and similar to the pattern of the decrease in terms of both magnitude and lateral extent, we attribute this increase to new magma intrusion. To the NE of Askja, seismic and ground deformation data suggest that there may have been magma movements below the rift since 2006 which may relate to the reversal of the magma flow at Askja we report here. It is possible that the new gravity increases observed at Askja reflect accumulation of magma beneath the caldera and thus may herald a new phase in the activity at this volcano which last erupted in 1961.

This paper will compare the results such as these from a variety of volcano types and consider when and how gravimetric and geodesy can help resolve ambiguities in sub-surface processes.

1.3-O-32 - Keynote lecture

High Definition Seismic Tomography of Active Volcanic Islands Using Active and Passive Experiments.

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The complex seismic structure of volcanic environments can be resolved through out the use of active and passive seismic tomography experiments. Travel time seismic tomography resolves low- and high-velocity anomalies that can be associated to different characteristics of the area, as the presence of partial molten materials, cooling dikes, intrusions, hidromagmatic alterations, piroclastic deposits, etc. Seismic tomography depends on illuminating the target with a large number of seismic waves from many angles. Good ray geometries can be difficult to achieve with local seismicity because they tend to be clustered. Therefore it is necessary to perform active seismicity to cover this lack of data. In general there are practical difficulties associated with acquiring large active-source data sets. However studies in the marine environment have a big advantage because they can take advantage of airguns to generate a high density of sources.

In the present talk we will show three examples of seismic tomography of active volcanic islands, one of them using earthquake sources, Sao Miguel Island (Azores), and two with active sources using airguns data, Deception island (Antarctica) and Tenerife Island.

We determine the three-dimensional distribution of P- and S-wave velocities for Central Sao Miguel Island (Azores, Portugal) by tomographic inversion of local earthquake arrival times. We use P- and S-phases from 289 earthquakes recorded by a network of 20 seismometers. The model shows good resolution in the shallow-

est 5–6 km, as illustrated by different resolution tests. There are several velocity anomalies, interpreted as pyroclastic deposits, intrusive bodies, geothermal fields, and the effects of tectonics. A low Vp zone marks Furnas caldera, probably evidencing volcanoclastic sediments with development of intense geothermal activity. Another lowVp zone extends in correspondence of the highly fractured area between Fogo and the north coast. Conversely, strong positive anomalies are found south of Fogo and northwest of Furnas. They are interpreted in terms of high-density deposits and remnants of a plutonic intrusion. These interpretations are supported by the distribution of Vp/Vs, and are consistent with previous geological, geochemical, and geophysical data.

In January 2005 an extensive seismic survey took place in and around Deception island, to collect high quality data for a high resolution P-wave velocity tomography. A total of 95 land and 14 ocean bottom seismometers were deployed and more than 6600 air gun shots were fired. As a result of this experiment, more than 70000 travel time data were used to obtain the velocity model, which resolves strong P-wave velocity contrasts down to 5 km depth. The joint interpretation of the Vp distribution together with the results of geological, geochemical and other geophysical (magnetic and gravimetric) measurements allows us to map and interpret several volcanic features of the island and surroundings. The most striking feature is the low P-wave velocity beneath the caldera floor which represents the seismic image of an extensive region of magma beneath a sediment-filled basin. Another low velocity zone to the east of Deception Island corresponds to seafloor sedimentary deposits, while high velocities to the northwest are interpreted as the crystalline basement of the South Shetland Islands platform. In general, in the tomographic image we observe NE-SW and NW-SE distributions of velocity contrasts that are compatible with the regional tectonic directions and suggest that the volcanic evolution of Deception Island is strongly conditioned by the Bransfield Basin geodynamics.

During the active seismic experiment in January 2007 in Tenerife island, more than 6500 air gun shots were recorded on a very dense seismic local network (150 seismic stations) giving us the unique possibility to image the volcano edifice in unparalleled detail. The station distribution was chosen according to the following criteria: 1. To have a higher possible density of station coverage in the area of Las Cañadas – Teide – Pico Viejo; 2. To create at least two straight lines of sensors in the N-S and E-W direction crossing the island to be used as 2-D seismic profiles of the area; 3. To avoid any type of cultural noise (isolated but easily accessible locations). Recent results resolves the structure of the island from the surface to a zone located 10 km below the sea level with high resolution. These images indicated the high velocity contrast between areas that can be interpreted as a function of ancient structures, recent historical eruptions, intrusions, alteration and fracturation of the region.

1.3-P-01

Results of study of deep underground structure of mud volcanoes in North-Western Caucasus by means of geological and geophysical methods

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Results of complementary geological and geophysical studies of mud volcanic phenomena in North-Western Caucasus (Taman mud volcanic province) are presented. Geophysical field works have been carried out in 2005 – 2009 on the two different mud volcanoes: the Gora Karabetova and the Shugo mud volcano. Usage of methods of vibroseismic sounding, traditional magneto-telluric sounding and relatively new method of low-frequency microseismic sounding allows obtaining several independent vertical cross-sections for the two different mud volcanoes down to the depth of 25 km. For the two different mud volcanoes their deep subsurface structure has been revealed and discussed with respect to regional tectonic settings, geology and geomorphology. The Gora Karabetova mud volcano is one of the most active mud volcanoes in the Taman peninsula with primarily explosive behaviour while the Shugo mud volcano's activity pattern is different, explosive events are rare and both types of phenomena may be explained by the configuration of their feeding systems, tectonic position and deep pathways of migration of fluids. References: A.L. Sobisevich, A.V. Gorbatiykov, and A.N. Ovsuchenko. Deep Structure of the Mt. Karabetov Mud Volcano // *Doklady Earth Sciences*, Vol. 422, No. 1. pp. 1181-1185. A.V. Gorbatiykov, M.Yu. Stepanova, and G.E. Korablev. Microseismic Field Affected by Local Geological Heterogeneities and Microseismic Sounding of the Medium // *Izvestiya, Physics of the Solid Earth*, 2008, Vol. 44, No. 7, pp. 577–592. DOI: 10.1134/S1069351308070082. A.V. Gorbatiykov, A.L. Sobisevich, and A.N. Ovsyuchenko. Development of the Model of the Deep Structure of Akhtyr Flexure-Fracture Zone and Shugo Mud Volcano // *Doklady Earth Sciences*, 2008, Vol. 421A, No. 6, pp. 969–973. DOI: 10.1134/S1028334X0806024X.

1.3-P-02

Radon and CO₂ Emissions in Different Geological Environments as a Tool for Monitoring Volcanic and Seismic Activity in Central Part of Colombia

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²²²Rn (radon) and CO₂ emissions in soil has been measured during a lapse time of several years in three different geological environments at the central part of Colombia, namely Nevado del Ruiz Volcano (NRV), an active volcanic area, Coffee Axes (CA), an active tectonic zone, and Cerro Machín Volcano (CMV), a zone starting a volcanic reactivation process, in order to compare levels of emissions and to monitoring volcanic and seismic activity. Three networks were deployed, with a total of 16 stations.

NRV zone showed the highest values of radon emission, followed by CMV and finally CA. Temporal changes of radon and CO₂ emissions were detected for CA

and CMV, related with seismic activity. Although NRV showed stability during the studied period, in agreement with steady tendency in radon emissions, high levels of radon emission were detected. This could be related with the level of activity of NRV, which is still in an active stage. For CMV, some temporal changes were detected,

$^{222}\text{Rn}/\text{CO}_2$ ratios were calculated for several stations. Ratios were similar for the three zones, and temporal changes in that ratio were associated with seismicity at NRV, AC and CMV.

Regular measurements of radon and CO_2 emissions are a good tool for monitoring volcanic and seismic activity in this region. A base line of data is an important initial step to understand the phenomena; therefore, it is necessary to continue with the program of regular measurements in this region.

1.3-P-03

Cerro Machín Volcano, Colombia: an Example of Monitoring an Unrest Volcano Becoming Awake.

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Cerro Machín Volcano (CMV), is an active dacite volcano, in the Central part of Colombia (2700masl). It is one of the most dangerous (explosive) volcanoes in Colombia. A dome of more than 2Km diameter is present at the active crater (tuff ring). Last eruption was about 900 years ago. Cataclysmic eruptions have occurred every 1000 years.

Since 1989, INGEOMINAS, started the monitoring of this volcano. Up to date, it is one of the most well instrumented volcanoes in Colombia. Since 2005, an increase in its activity started. Changes in seismicity, deformation and geochemistry, have been observed. Several seismic crisis have occurred. The last one (Nov/2008) lead to evacuate more than 1000 people, living around and inside the volcano.

Thermocouple, magnetometers, acoustic system, broadband as well as short period seismic stations, EDM network, electronic tiltmeters network, radon and CO_2 in soil network are installed around and inside the active crater. Fumaroles and hot springs sampling is done as well. All these variables are measured routinely at CMV. Main seismic activity is related to VT earthquake swarms, occurring regularly beneath the dome (2-5Km depth). Increase in native sulfur in hot springs and fumaroles, as well as increase in radon and CO_2 in soil have been detected. Deflation toward SW of the dome, which is the structural weakest zone of the volcano, has been observed too.

Hazard map shows a wide zone being potentially affected by secondary lahars, which travel more than 100Km from the source. On the other hand, more than 1 million people could be affected by an eruption of this volcano. Therefore, continuous monitoring is clue for alerting on an impending eruption. Few volcanoes in the world, have been monitored intensely previous to a reactivating period. We believe that CMV is a good example of monitoring an unrest but potential active

volcano leading to awake.

1.3-P-04

Pressurization During Slug-Driven Strombolian Eruptions: Insights From Models, Experiments, and High Speed Observations.

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Strombolian-type eruptive activity is characterized by the recurrence of mildly-explosive events associated with bursting of gas slugs rapidly ascending in low-viscosity magma. Gas source conditions, dominantly the release depth and volumetric fraction, are dominant factors controlling slug overpressure and hence variations of eruption style and intensity as observed at the surface.

We use the parameterization adopted by James et al. 2009 (J. Volcanol. Geotherm. Res., 180, pp. 81-88) to build a simplified analytical treatment that describes the conditions under which a gas slug rising in a cylindrical conduit becomes overpressured. We quantify the transition from non-overpressured to overpressured slugs and find that it depends on the mass of gas in the slug and a geometrical factor (A') related to the thickness of the liquid film draining down the conduit around the rising slug. Even if our approach explicitly excludes dynamic viscous and inertial effects on rising slugs, liquid viscosity indirectly affects A' and must be taken into account to estimate slug overpressure at bursting. We validate our model against experimental observations on the ascent of slugs in vertical cylindrical conduits of various diameters, filled with liquids with a range of viscosities. As expected, slug rise velocity is controlled by A' and is not affected by variation in slug length.

Our experiments demonstrate that an increase of liquid viscosity significantly increases both A' and the slug length during ascent through the conduit, while an increase in conduit radius reduces both A' and slug length; this effect becomes more pronounced with increasing liquid viscosity.

Applying typical source conditions inferred for Stromboli, in terms of volume of released gas and source depth, our results perfectly match with new particles velocity data obtained from novel high-speed video recording of single strombolian eruptions.

1.3-P-05

Phreatic Activity At Poás Volcano: Inferences From The Chemical Evolution Of Fumarolic Fluids

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Poás is a composite volcano in the Cordillera Central of Costa Rica. Recent eruptive activity has been characterized by frequent phreatic and phreato-magmatic events. The most relevant episodes dates back in the early '80s, when fumaroles with outlet temperatures up to 1000 °C were recorded at the pyroclastic cone, formed in 1953-55, bordering the southwestern shore of the lake, and in 1988-1991, a period marked by intense fumarolic activity that dried out the hot acidic crater lake hosted within the Active Crater, revealing the presence of vents emitting native sulphur. The following period, up to 2005, represents a relatively quiet stage, with low-temperature (<120 °C) fumaroles seeping out from the pyroclastic cone and the northeastern inner scarp of the crater. In 2007, a new phase of activity has started, with an increase of the fumarolic degassing and a significant decrease of the lake water level. A relatively small phreatic event, likely related to the collapse of a *hornito* constituting the vent of one of the main active fumaroles, occurred in May 2006, giving rise to a ~160-m long flow of molten sulphur. In April 2008, a new jet-type fumarole with temperature slightly higher (109 °C) than that of boiling water appeared at the base of the pyroclastic cone. In the following months, the chemical-physical features of this fluid discharge have shown an extremely rapid evolution. In November 2009, an outlet temperature of 665 °C was measured, whereas the concentrations of temperature-sensitive gas species, such as HF, HCl, H₂ and CO, were up to three orders of magnitude higher than those characterizing the Poás fumarolic fluids before 2007. The chemical evolution experienced by the fumarolic fluid was accompanied by an abrupt decrease of the lake volume. In December 2009-January 2010, the volcanic activity culminated in repeated (up to 8) phreatic events.

1.3-P-06

Compositional Changes of Magmatic-Hydrothermal Fluids Related to Anomalous Temperatures at Copahue Crater Lake (Argentina).

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Copahue volcano (37°45'S-71°10.2'W, 2977 m.a.s.l.) is an active andesitic stratovolcano within the Caviahue Caldera (CC), located in the Southern Andean Volcanic Zone (SAVZ, 33.3°-46°S) between Argentina-Chile. The most recent eruptions (phreatic and phreato-magmatic) occurred in 1992, 1995 and 2000. A hot acidic lake (pH 0.3-0.8 and temperatures 30-50 °C) is hosted in the Copahue active crater, and two acidic hot springs (pH 1.5 and temperatures up to 81 °C), which merge to form the Agrio river, seep out from the eastern summit flank. Several thermal fluid discharges, with outlet temperatures up to 135° C, are located inside the caldera, suggesting the presence of well-developed magmatic-hydrothermal system. The composition of thermal fluid is characterized by relatively high concentrations of acidic gas species, such as CO₂, H₂S, HCl and HF (up to 874000, 9023, 21 and 3 µmol/mol respectively) and

N₂ (up to 13268 µmol/mol), as typically found in volcanic emissions of arc environments. Between July and August 2004, a progressive decrease in water temperature of the crater lake was measured, and 80% of its surface frozen. Lake water salinity was at the minimum value (15570 mg/L) recorded since 2003 until present. In the same period, a significant increase of SO₄, Cl, Mg, Al and K concentrations in Agrio river water, was recorded. This event may suggest the occurrence of an input of SO₄-, Cl-rich hot fluids from the hydrothermal-magmatic system, causing the release of high amounts of strong rock former elements (RFE) from rocks, and consequent deposition of mineral phases. The partial sealing of the ascending conduits of thermal fluids discharging into the crater lake could be responsible of the temperature and salinity decreases observed in the crater lake.

1.3-P-07

Deflation of Copahue Volcanic System, Deformation Source Models from Inversion of Satellite Radar Interferometry Data Using a Genetic Algorithm.

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Copahue volcano (37° 45.35'S, 71° 11' W, 2997 m.a.s.l.) is one of the most active volcanoes in Argentina. It is an active andesitic to basaltic-andesitic stratovolcano, nested on the western rim of the Caviahue caldera, straddling the border between Argentina and Chile. The volcano summit has nine craters aligned in N60°E direction; the easternmost crater is presently active, and its filled with an acid-water lake of about 200 m in diameter. Historical eruptions have been reported on 1992, 1995 and 2000. The last eruptive cycle involved ash and gas emissions and it is considered to be Copahue's most vigorous activity in the past century. We have performed an interferometric analysis of Synthetic Aperture Radar images (InSAR) of the area, using a total data set of 18 ascending ENVISAT ASAR radar images (IS2, polarization-VV) from December-2002 to November-2007, 43 differential interferograms were constructed and combined by using Small Baseline Subsets algorithm. A mean velocity of 1.8 cm/yr was calculated, assuming the deformation rate constant during the time period of the interferograms. The deflation is mostly located on the northeastern flank of the volcano. We evaluate the geometry of the magma chamber from inversion of interferometric data. The signal was modelled assuming a uniform elastic isotropic half-space with Poisson's ratio 0.25 and rigidity modulus of 30-GPa. We used an inversion procedure employing a genetic algorithm to identify best fit source parameters. We tested two models, a point pressure source, known as Mogi source (Mogi, 1958), and an ellipsoidal source (Yang *et al.*, 1988). Model results indicate a deformation source located at a mean depth of 4 Km, with a mean volume change of 0.0015 Km³/yr, interpreted as decompression due to a perturbation of the magmatic-hydrothermal system. References: Mogi, K. 1958 BERI 36, 99-134. Yang, X.M., Davis, P.M., Dieterich, J.H., 1988. JGR, 93,

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1.3-P-08

Filtering the Noise from Satellite Measurements of Radiant Flux over Active Volcanoes

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Thermal remote sensing is a valuable tool for monitoring active volcanoes. One can detect thermal anomalies originating from a volcano by comparing signals in mid and thermal infrared spectra. Once a thermal anomaly is detected, it has to be characterized in order to evaluate the activity status of volcano. The radiant flux is a suitable parameter for volcano characterization. Atmosphere, satellite viewing angle and sensor characteristics have a significant influence on the thermal anomaly characterization. Some of the influences are easy to correct using standard remote sensing preprocessing techniques, however, some noise still remains in data. In addition, satellites in polar orbits have long revisit times and thus they might fail to detect short volcanic events. It would therefore be desirable to use data from different satellites in order to reduce uncertainties and improve temporal resolution. If one tries to simultaneously use data from different instruments, the measurements are often not comparable. Kalman filter allows the combination of measurements from different sources that have different levels of accuracy. Here we applied the Kalman filter to reduce noise and increase the temporal resolution of volcano radiant flux measurements from simultaneous MODIS and AVHRR measurements. As the evolution of the volcanic activity is difficult to predict we did not apply a physical model for the system state transition; we used a stochastic based model. A main challenge was to define the process noise covariance matrix and the relation between process and noise measurement. We finally decided to weight the process noise with the pixel area and cloud coverage over the volcano. We applied this technique to an eruption of Etna in 2002 and found good agreement with data of better resolution (DLR micro satellite BIRD).

1.3-P-09

Long Time Series Of Fumarolic Compositions At Volcanoes: The Key To Understand The Activity Of Quiescent Volcanoes

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Long time series of fumarolic chemical and isotopic compositions at Campi Flegrei, Vulcano, Panarea, Nisyros and Mammoth volcanoes highlight the occurrence of mixing processes among magmatic and hydrothermal fluids. At Campi Flegrei temperatures of about 360°C of the hydrothermal system are inferred by chemical and isotopic geoindicators. These high temperatures are representative of a deep zone where magmatic gases mix with hydrothermal liquids forming the

gas plume feeding the fumaroles. Similar mixing processes between magmatic fluids and a hydrothermal component of marine origin have been recognized at Vulcano high temperature fumaroles. In both the system a typical 'andesitic' water type composition and high CO₂ contents characterizes the magmatic component. Our hypothesis is that pulsing injections of these CO₂-rich magmatic fluids at the bottom of the hydrothermal systems trigger the bradyseismic crises, periodically affecting Campi Flegrei, and the periodical volcanic unrest periods of Vulcano. At Campi Flegrei a strong increase of the fraction of the magmatic component marked the bradyseismic crisis (seismicity and ground uplift) of 1982-84 and four minor episodes occurred in 1989, 1994 and 2000 and 2006. Increases of the magmatic component in the fumaroles of Vulcano were recorded in 1979-1981, 1985, 1988, 1996, 2004 and 2005 concurrently with anomalous seismic activity. Physical-numerical simulations of the injection of hot, CO₂ rich fluids at the base of a hydrothermal system, assess the physical feasibility the process. Ground deformations, gravitational anomalies and seismic crisis can be well explained by the complex fluid dynamic processes caused by magma degassing episodes. Sporadic data on the fumaroles of other volcanoes, for example Panarea, Nisyros (Greece), Mammoth (California), suggest that magma degassing episodes frequently occur in dormant volcanoes causing volcanic unrest processes not necessarily linked to magma movement but rather to pulsating degassing processes from deep pressurized, possibly stationary, magma bodies.

1.3-P-10

Deformation Monitoring at Volcan de Colima, Mexico and Its Implications to the Risk of Communities Around the Volcanic Edifice During the Recent Activity Phase (1998-2010)

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The Volcan de Colima is one of the most active volcanoes in Mexico. It is an andesitic stratovolcano located within the N-S trending Colima Rift Zone in the western front of the Mexican Volcanic Belt. The eruptions of the last 500 years involved a wide spectrum of eruptions styles, considering major block lava emissions, phreatic explosions, and large and moderate explosive events were each time is related the destruction and construction of lava dome in the active crater. More than 500,000 persons are settled around the volcano edifice within a distance of 50 km that can be impacted by a moderate eruptions of this active volcano.

The recent activity of the Volcan de Colima Mexico is monitoring by different physical sensors to detect the increase of activity. The deformation parameter is surveyed by a tiltmeter network composed of 5 plate sensors installed since 1999. The signal is digitized every 1.5 minutes and transmitted by telemetry to the Colima Volcano Observatory, where these sampled signals are processed. The recent activity of Volcan de Colima began with the extrusion of lava flow on November 1998

and continues to actual days. During the recent phases of activity we observed the behaviour of the deformation parameter and its implication to the risk of the communities located around the volcanic edifice.

1.3-P-11

One Decade of OP-FTIR Monitoring of Mount Etna Gas Plume Emissions: Lessons and Implications

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Solar occultation OP-FTIR measurements of Mt. Etna volcanic plume emissions have been carried out on average 1-2 times per week since March 2000 by geochemists from INGV-Catania, providing the largest such data set ever obtained, on a very active basaltic volcano. These measurements allowed simultaneous retrieval of the bulk plume content of SO₂, HCl and HF – three species with highly contrasted solubility behaviour in Etnean magma. Important temporal variations in SO₂/HCl, HCl/HF and SO₂/HF ratios and in the HCl and HF fluxes (obtained from routine UV monitoring of SO₂ flux) provide important constraints on the processes of magma feeding and degassing. Between and during eruptions we observed large systematic variations in the volcanic plume composition released from the summit craters, with SO₂/HCl varying between 1 and 8, SO₂/HF between 3 and 60 and HCl/HF between 2 and 6. SO₂ fluxes varied from 500 tonnes per day (t/d) to 25,000 t/d. These remarkable variations in gas emissions contain critical information on the state of the volcano. We will show that heightened SO₂/HCl ratios observed prior to Mt. Etna's eruptions are consistent with inefficient magma circulation that partially inhibits ascent of magma to the surface and enhances the probability of eruptions. Cumulative plots of the mass of degassed SO₂, HCl and HF allow detailed examinations of such deviations from steady-state magma supply. We also frequently observe recovery from such deviations, suggesting that the magma supply system is efficient over a wide range of pressures, from depths of 3-5km where SO₂ begins to exsolve, up to the near surface, where HF is lost from the magma. The combination of these unique, decade-long observations of SO₂, HCl and HF allow us to define a well-constrained model for the magma and gas dynamics that provide the fundamental control on volcanic activity at Mt. Etna.

1.3-P-12

Imaging of the Magma Supplying System of Unzen Volcano

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Unzen Volcano is an active volcano grown in the Unzen graben at the western end of the central Kyushu rift valley, Southwest Japan. The last eruption of Unzen Volcano occurred in 1990 – 1995, and 0.2 km³ of magma

effused forming a lava dome complex near the summit of the volcano. The various geophysical observations were carried out at the volcano during and after the eruption. In particular, Kyushu University has reinforced the seismic observation in order to reveal the magma supplying system of the volcano. In this study, we present high-resolution 3D tomographic images of the crust beneath Unzen Volcano using local earthquakes (tectonic or volcano-tectonic earthquakes) occurring in the Kyushu district. We adopted the Double-Difference (DD) tomography method of Zhang and Thurber (2003), and used arrival time data of 29,847 P-waves and 15,364 S-waves from 1,414 earthquakes observed at 106 seismic stations. Pairs of earthquakes within 15 km of each other are used to define travel time differences, yielding 27,786 for the P-wave data and 15,364 for the S-wave data. The result shows that the volcanic edifice shallower than 2km is characterized by a high velocity region compared with the surroundings. This is consistent with the result of seismic refraction experiment in 1995 (Shimizu et al., 1997), and can be explained by solidified magma bodies intruded in the past volcanic activities. In the Unzen graben deeper than 5km, a low velocity zone is dipping westward at approximately 45 degrees. The hypocenters of volcano-tectonic earthquakes activated before the lava dome emergence are located along the upper edge the dipping low velocity zone. In addition, the pressure sources inferred from geodetic measurements (Kohno et al., 2008) are located in the low velocity zone. These results confirm that the path of magma ascent is inclined beneath Unzen Volcano.

1.3-P-13

Continuous Monitoring Of Soil Radon Activity And Soil Temperature Near The Summit Of Mt. Etna (Sicily, Italy) During 2007-2009: Correlations With Stress Field And Volcanic Activity.

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During the period 2007-2009, the volcanic activity of Mt. Etna (Italy) was characterized by a series of paroxysmal events in 2007 that preceded a long-lasting (419 days) flank eruption. Four months after the end of that eruption, the opening of a new summit degassing vent marked the beginning of a new phase of activity, so far characterized only by degassing phenomena. Soil radon activity and soil temperature were monitored every 15 minutes at a low-temperature fumarole near the summit craters of Etna starting from late May 2007. The temporal pattern of these parameters showed in general their significant cross-correlation, thus pointing to a common gas transport mechanism. Magmatic/hydrothermal fluids in the sub-surface ground are convectively transported towards the surface along a major fault that runs from Etna's summit towards SSE and partly marks the boundary of an eastward sliding sector of the volcano that is involved into phenomena of flank collapse. Both of the monitored parameters indicate the occurrence of three long-term cycles of soil degassing during the period investigated, each one characterized by high average values of temperature and radon. The first cycle started in June 2007 and lasted until early

April 2008, thus accompanying the recharge of the volcano. The second cycle lasted from late April 2008 to mid-May 2009, thus preceding and accompanying the first phase of the 13 May 2008 – 5 July 2009 flank eruption. The third cycle started in mid-July 2009 and it's still ongoing. It marked a new recharge of the volcano that culminated in the opening of the new summit degassing vent in early November 2009. Therefore, continuous monitoring of soil radon and soil temperature near the summit of Mt. Etna has proven helpful in determining states of volcanic unrest related to recharge and/or pre-eruptive magma ascent.

1.3-P-14

Carbon Dioxide Diffuse Emission from the Soil at Vesuvio and Campi Flegrei (Pozzuoli): Ten Years of Observations

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Carbon dioxide flux from the soil is regularly monitored in selected areas of Vesuvio and Solfatara (Campi Flegrei, Pozzuoli) with the main aim of investigating if the surface phenomena could provide information about the processes occurring at depth. Surveyed areas include 15 fixed points around the rim of Vesuvio and 71 fixed points in the floor of Solfatara crater, where soil CO₂ flux is measured since 1998, at least once a month. In addition, two automatic permanent stations, located at Vesuvio and Solfatara, continually measure the CO₂ flux and some environmental parameters that can potentially influence the CO₂ diffuse degassing.

We analysed, with statistical procedures, the feature of the acquired signals, evaluating the spatial and temporal variations of the CO₂ degassing process.

Series acquired by continuous stations are characterized by an annual periodicity that is related to the typical periodicities of some meteorological parameters (e.g., air temperature, air humidity, etc.). Such a kind of signal permits to define the "reference" level of the CO₂ degassing process that diffusely affects the flanks and the base of the volcanoes.

Conversely, series of CO₂ flux data arising from periodic measurements over the arrays of Vesuvio and Solfatara, are less dependent on external factors such as meteorological parameters, local soil properties (porosity, hydraulic conductivity) and topographic effects (high or low ground). Therefore we argue that the long-term trend of this signal contains the "best" possible representation of the endogenous signal related to the upflow of deep hydrothermal fluids. At Vesuvio and Solfatara, the variations of these series have shown some correspondence with other physical changes of the volcanic systems.

1.3-P-15

Volcano webcams allow strain monitoring

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A photo sequence taken by photographer Gary Rosenquist during the 1980 Mount St Helens eruption allowed investigation of the first seconds of the flank collapse and lateral blast at high detail. The same photo set I now used, digitized and analyzed by modern processing methods. Herein I present first results of a digital image correlation technique applied to study textured image objects. The images, i.e. textured objects, are converted into the frequency domain using a fast Fourier transform. Correlation functions calculated in the frequency domain allow transformation parameters to be estimated. To achieve sub-pixel accuracy I employ correlation algorithms based on B-Splines gray value interpolation. The image correlation technique finally provides the displacement field for the first seconds of the Mount St Helens collapse. The results hence show localizations of shear zones, development of fault planes and a more complex evolution of the structural architecture of the 1980 St Helens lateral slide than thought previously. The analysis shows the high potential of optical images in structural and dynamic analysis, and provides strong arguments for systematic web cam installations at active volcanoes worldwide.

1.3-P-16

Seismic Events and Anisotropy beneath Mount Ontake, Japan, before a Small Phreatic Eruption in 2007

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We present recent seismological studies on Mt. Ontake volcano related to its small phreatic eruption in late March of 2007. Hashida and Nakamichi (2010) determined that volcano-tectonic earthquakes beneath the summit of Mt. Ontake had focal depths of 0.5 to 2.0 km below sea level and these focal depths did not change with time. Although reverse-faulting focal mechanisms with a NE–SW compressional axis were dominant, the polarities of P-wave first motions were dilatational for stations close to the summit; therefore, it is possible that focal mechanisms might contain non-double-couple components. Nakamichi et al. (2009) conducted a moment tensor inversion to characterize a very-long-period (VLP) event on 25 January 2007, locating its source at 600 m above sea level beneath the summit and explaining it by volumetric changes in an inclined crack at the source. Minifie et al. (2010) used S-wave splitting measurements to estimate spatial and temporal changes of seismic anisotropy associated with the 2007 eruption. Fast S-waves of local shallow earthquakes had average polarization azimuths of N78°E, which differs from the WNW–ESE orientation of regional principal stress by 35° and is nearly perpendicular to the strike of the VLP crack source. The polarization azimuths showed no significant change before or after the eruption, perhaps because the eruption was too small to influence the anisotropy. An alternative explanation is that the measuring period was too short to allow detection of temporal changes. References: Nakamichi et

al., 2009, JVGR; Hashida and Nakamichi, 2010, JPGU; Minifie et al., 2010, JPGU.

1.3-P-17

Estimation of Thickness of Volcanic Ash Falls using In-SAR Analysis

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It is important to estimate volume of volcanic ash falls around active volcano in order to speculate activities of the volcano. We successfully find out the thickness of volcanic ash fall and erosion of ash surface using In-SAR analysis. Anatahan volcano is one of active volcanoes in the northern Mariana island arc. Science 2007 we execute In-SAR analysis of ALOS/PALSAR data. As the result of our GPS survey, we found there was no obvious uplifting crustal deformation detected after the eruption started. However, the result of the In-SAR analysis shows much larger surface uplift and subsidence than movement estimated from GPS during same period. Anatahan volcano is very active during the period of December 2007- March 2008, and many phreatomagmatic eruptions were continued. The ash deposit has a thickness of more than 2 m around the active creator. The interferogram acquired in the same period shows incoherent area in around the creator and spreading toward SW direction from the creator. The NE wind is predominant in Anatanan during winter season. The thick ash fall deposit had changed ground surface totally enough to make the interferogram incoherent. Also, if ash mounded as volcanic base surge deposit, moving laterally across uneven surface, depressed ground would be filled by ash, and it makes the incoherent area in the interferogram. While the thin ash fall accumulated parallel to old ground surface, and acts like surface uplift in the interferogram. We visited uplifted sites in the interferogram, and measured thicknesses of ash fall from the old surface. The thickness up to 20cm corresponded to value of uplift in the interferogram very well. In other word, ash fall of more than 20 cm thick may change surface geometry so much that we could not get thickness of the ash fall using the In-SAR analysis.

1.3-P-18

New Insights into Composition of Volcanic Products at Mt. Etna, Italy, from Geochemical Pattern Classification

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Geochemical analyses of volcanic products erupted by Mt. Etna, Italy, have been carried out by INGV-CT (formerly CNR-IIV) staff since three decades. The need to realize a near-real time monitoring of the basic compo-

sitional features of a magma compelled since the 1990s an organization of personnel engaged for sampling and analyzing the collected rocks in laboratories. Geochemical monitoring has been outstandingly improved with the application of sophisticated, but quick, analytical techniques which take into account both oxides as well as trace elements of lavas. The geochemical monitoring offers up-to-date information on processes and dynamics of magma, and allows documenting the evolution of different eruptive styles throughout an eruptive event. Accordingly, changes in chemical parameters have become a key information for the Italian Civil Defence to highlight any hazardous evolution of volcanic activity at Etna, and promptly warn potential endangered populations. Compared to traditional classification methods, where compositional patterns are defined by selecting oxides and/or elements in binary and ternary petrologic systems, we can handle a statistics with many components, in our specific case thirteen (SiO₂, K₂O, CaO/Al₂O₃, Mg, Th, La, Nb, Nd, Sr, Tb, Cr, Ni, Rb/Nb). The statistical treatment of geochemical patterns exploits Kohonen Maps and Fuzzy Clustering, which are applied to samples collected at Etna between 1995 and 2005. We present a comprehensive picture of the evolution of these products in time and space with a convenient visualization of the results. The application of multivariate classification allows us to identify a signature in the compositional characteristics of magma erupted from the four summit craters and/or flank eruptive vents, even in the time spans in which volcanic activity was concurrent. Dubious compositional changes are also considered in the light of earthquakes and volcanic tremor characteristics, which offer independent evidence of the significance of the results.

1.3-P-19

Magma Dynamic during the 2007 Stromboli Effusive Eruption as revealed from High Precision Location of Seismic Events

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In a volcanic environment, high precision in earthquake locations constitutes one of the most important elements for accurate seismic investigation and to understand the relation between the migration of hypocenters and the magma dynamic. Stromboli is considered one of the most active volcanoes in the world. A new effusive eruption began on late February, 2007 and was characterised by intense seismic activity on the whole period. The accurate seismic signals analysis showed the presence of families of events with similar waveform signatures (i.e. multiplets) located beneath the crater region. Since traditional location techniques do not allow obtaining reliable hypocenters, our analysis focused on high precision locations of the seismicity, in order to better define the source geometry of the events. Hypocenters, therefore, have been relocated considering two steps: the former, based on a robust probabilistic approach, is used to found the absolute position of the

clusters; the latter exploits a master-event concept, for the relative location of the events. Finally, the shape of the clusters and the temporal migration of the foci were correlated with the eruptive phases. The results show that the occurrence of a cluster of events is related to the opening and closure of a vent opened in the Sciara del Fuoco slope and, in particular, to the intrusion of a dike injected by the swallow central feeding system in a radial direction. Another cluster lies in a narrow vertical volume positioned under the crater area. This suggests a source region depicting the shallower central feeding system and a trigger due to the build-up pressure on the central conduit caused by the collapse and obstruction of the summit crater area. Overall, the results highlight that the high precision locations method is an efficient and quick tool to obtain a better understanding of the magmatic processes occurring during an ongoing eruption.

1.3-P-20

Improved Monitoring of New Zealand's Volcanoes

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GeoNet is a project funded by New Zealand's Earthquake Commission and run by GNS Science. The project aims to provide high quality monitoring and research data for geological hazards across the country. Since GeoNet's inception in 2001, New Zealand's volcano monitoring capability has improved significantly. Prior to GeoNet, monitoring of New Zealand's volcanoes consisted mostly of analogue seismic networks, with limited geodetic and geochemical surveillance. Under GeoNet the seismic networks have been completely rebuilt using modern digital recording and telemetry. The extensive use of deep borehole seismic instruments in the Auckland Volcanic Field has allowed the network to cope with the increased seismic noise from the expansion of Auckland City and enhance the ability to detect small magnitude earthquakes. An extensive 39 station continuous GPS network has been built around the Ruapehu, Taupo and Okataina volcanoes providing daily high precision positioning. Geochemical monitoring has been greatly improved. Near real time SO₂ measurements from automated DOAS systems operate at White Island and regular flights analyse a range of volcanic gases from Ruapehu, White Island and Ngauruhoe. New analytical equipment has been commissioned allowing a range of trace elements and isotopes to be analysed from a variety of media.

Since building these networks data from them has captured detailed monitoring and research information from two small eruptions at Ruapehu (2006 and 2007), and periods of unrest at Ngauruhoe (2006-2010) and Taupo Caldera (2008). Plans for future capability expansion include a network of borehole tilt meters at Ruapehu to try and detect very small signals that may be precursors to small scale, yet hazardous, phreatic eruptions. Future emphasis will be placed on developing real-time gas and fluid geochemical techniques with the aim of improving the understanding of the interaction of hydrothermal and magmatic systems that occur at many of New Zealand's volcanoes.

1.3-P-21

Volcano Observation Using an Unmanned Autonomous Helicopter (2): seismic observation near the active vent of Sakurajima, Japan

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Observations in the vicinity of summit area of active volcanoes are important in eruption prediction and volcanic hazards mitigation. It is, however, challenging to install observation sensors near active vents because of the danger of sudden eruptions. We have been developing an observation system based on an unmanned autonomous helicopter (UAV) for risk-free volcanic observations. Our UAV is designed to be combined with various types of observation techniques, such as aeromagnetic survey, taking infrared and visible images from onboard cameras, sampling volcanic ash in the vicinity of active vents, and installing seismometers. We have developed an earthquake observation module (EOM), which is exclusively designed for UAV installation. It is very compact, solar-powered, and equipped with GPS timing, a communication device using cellular-phone network, and triaxial accelerometers. Sakurajima is one of the most active volcanoes in Japan. Since 2006, explosive eruptions have been continuing at the reopened Showa crater at the eastern flank. Entering the area within 2 km from the active craters is prohibited, and thus there were no observation stations in the area. From November 2nd to 12th, 2009, we could install EOMs in the summit area within 2 km from the active craters by using UAV. Although the state of communication was not perfect since the installation points were outside of the service area of the cellular-phone network, we succeeded in retrieving the seismic waveform data accompanying eruptions at Showa crater. Except for contamination by the mechanical resonance of the module around 35 Hz, the recorded waveforms of the explosive eruptions are as good as the best permanent stations in Sakurajima. Preliminary results of the analyses show that the source location distribution of the explosion earthquakes at Showa crater is improved by the inclusion of the near source stations installed by using UAV.

1.3-P-22

Volcano Observation Using an Unmanned Autonomous Helicopter (1) : an Experiment of Seismometer Installation and Low-Altitude Remote Sensing at Sakurajima

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Summit areas of active volcanoes are a key place for observing state of activity. These, however, are often left as a blank area in monitoring, because of the risk of eruptions, which potentially strike equipments installed or volcanologists who are installing equipment or surveying activity status. If it is possible to approach to these areas without any risk, we can obtain important information, which can be utilized for advancement of prediction of eruptions or disaster mitigation. As one of the methods to actualize this, we have worked on developing a system based on an unmanned autonomous helicopter(UAV), which enable us to install various kinds of monitoring instruments to summit areas, as well as to collect information from a low-altitude over active regions.

In our system, we adopted the UAV, model RMAX-G1, developed and manufactured by Yamaha-Motor Co., Ltd, which consists of the main body of a helicopter (length: 363 cm, weight: 84 kg and payload: ~10 kg) and a base station. Using the system based on this vehicle, high resolution aeromagnetic measurement was carried out at Izu-Oshima, which revealed detailed shallow level structure inside the caldera (Kaneko et al. in press).

For the operation of installation, we have newly developed "installation system", "fixing apparatus" and "observation module". The installation system is attached under the body of helicopter and hauls down the observation module to the ground. The observation module consists of a seismometer, batteries, a logging device and a telecommunication system, which is mounted on "fixing apparatus", assembled with aluminum tripod. In November 2009, installation experiments were conducted at Sakurajima using the developed UAV system, together with aeromagnetic measurement and capturing images (still, video and infrared). We succeeded in installing observation modules at three points around the summit and collecting seismic data via the telecommunication system for more than a month.

1.3-P-23

Monitoring Of Volcanic Activity Of Kusatsu-Shirane Volcano Using Water Chemistry Of Its Crater Lakes

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The Kusatsu-Shirane volcano, located in the central part of Honshu, Japan, is one of the most famous active volcanos in Japan. It has three crater lakes named Yugama, Mizugama and Karagama on its summit. Yugama, the largest and deepest one among the three, is well known as an active crater lake filled with strongly

acidic water (around pH 1). Contrary to this, only a few researchers have paid their attention to the other two lakes, because these lake waters show high pH and low salinity compared to the Yugama water. In these years, an expansion of fumarolic areas and an increase in fumarole temperatures are observed around the Mizugama crater, which probably suggests increased volcanic activity. Meanwhile, the color of the Mizugama lake water has often changed from opaque brown, which used to be the normal color, to greenish color and vice versa since 2005. This phenomenon is probably connected with the change in the Fe(II)/Fe(III) ratio in the lake water. We have monitored water chemistry of the all three crater lakes for more than 40 years. Our observations reveal that water chemistries of Mizugama and Karagama as well as that of Yugama have fluctuated reflecting the volcanic activity at least since 1960s. The fluctuation of water chemistry of Mizugama is distinctive in that the potassium content increased in and after the periods of high volcanic activity, although the mechanism of the potassium supply is still unknown. The water color and chemistry of Mizugama thus may be good indicators of volcanic activity of the volcano; the latter may be a more sensitive indicator of the volcanic activity due to its low salinity compared to the Yugama water.

1.3-P-24

Aerosol Particles from Fumaroles of El Chichón Volcano, Chiapas, Mexico

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Quiescent volcanoes are emitting constantly aerosol particles into the troposphere by fumarole activity. Although the impact of these particles on the environment may be considerably, only scarce information is available (e.g.: Pfeffer et al., 2006). The aim of this study is to characterize chemically and morphologically fumarolic aerosol particles from El Chichón volcano (Chiapas, Mexico; 1150 m.a.s.l.). Aerosol particles were collected actively onto Nuclepore filters and TEM grids. The sampling devices, an active PM10 and a corrosion resistant electrostatic sampler, were used inside the crater (close to fumaroles) and on the crater rim (CR). The samples were analyzed by computer controlled SEM (CCSEM) and TEM, both equipped with EDX. With CCSEM it was possible to analyze over 2000 individual particles with sizes between 0.4 μm and 10 μm per sample. Inside the crater, the particle number concentration (PNC) was >3000 particles/liter. The PNC at the CR was half as much. For both locations, the dominant "fumarolic" particle species were sulfur/sulfuric acid particles and Na-, K-, Na-K- resp. Ca-sulfates. Total sulfur containing particle flux is estimated to 0.1kgs⁻¹. Minor alkali chlorides were also detected. Many particles sampled inside the crater are composite particles. Some of them contain pseudo-hexagonal Na-K-sulfate crystals and Na-sulfate needles. Other particles are composites containing following elements: P, S, K, Na, K, (Mg), (Al), (Zn), (Pb). The phosphorus points to a non magmatic source. At the CR most of the composite particles and the P containing particles are no longer present and the samples are dominated by sulfur/sulfuric acid particles. More data about fumarolic aerosols are crucial for a better under-

standing of formation processes and their impact on the environment. References: Pfeffer et al., 2006, JVGR.

1.3-P-25

Periodic release of gas at dome building volcanoes: A simple model approach

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Here we present a numerical model inspired by Doppler radar observations recorded between Jan. 8-13, 2007 during a multidisciplinary experiment at Santiaguito volcano, Guatemala. During the observational period 157 eruptions were observed by Doppler radar. 75% of the explosive degassing events comprise more than one degassing pulse with a typical recurrence period of 3s. The occurrence of pulses during one event has been suggested from thermal imaging of the plume (Sahetapy-Engel et al., 2009), but it was so far unknown and first resolved using a Doppler radar that these pulses occur almost periodically and originate rather from the dome's surface than from turbulent jet motion. Based on the model by Johnson et al. (2008), we assume that below an impermeable plug a gas/foam layer develops through continuous degassing of uprising magma thereby increasing the pressure inside the system. Our zero order approximation to this model is to assume a simple gas pocket below the plug, i.e. we describe this as a damped spring (gas pocket)-mass (impermeable plug)-oscillator. Because of its size (200m diameter, 20-80m height) the plug exhibits a high momentum once it is accelerated by the overpressure. Damping is caused by a) wall friction and b) gas escape. In our simple model the resonance frequency of the spring-mass system mainly depends on the initial gas volume. Pressure, plug mass, friction and dimension of degassing pathways only affect the amplitude and its damping. For a reasonable choice of parameters, we can find oscillation frequencies of 2-5 seconds. References: J.B. Johnson, J.M. Lees, A. Gerst, D. Sahagian, and N. Varley, 2008. Long-period earthquakes and co-eruptive dome inflation seen with particle image velocimetry. *Nature*, 456:377-381, doi: 10.1038/nature07429 S.T. Sahetapy-Engel, and A.J.L Harris, 2009. Thermal-image-derived dynamics of vertical ash plumes at Santiaguito volcano, Guatemala. *Bull. Volcanol.*, doi: 10.1007/s00445-009-0284-8

1.3-P-26

Single Particle Analysis of Volcanic Aerosols from Stromboli, Italy

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Volcanic aerosols contain both primary and secondary particles. The former consist of the finest ash fraction, whereas the latter are formed by condensation of gaseous emissions. Previous investigations on the mineralogy of the aerosols and the condensation processes are usually limited to a small number of particles (e.g.:

Pfeffer et al., 2006). Automated single particle analysis allows to gather information on a large number of particles and to get a more representative picture of the ongoing processes. We sampled actively the PM10 aerosol fraction at four different locations on Stromboli, Eolian Islands, Italy, in April 2009. The samplers (PM10 impactor, 240 l/h pumping capacity, PC filters) were located close to the crater rim (Pizzo), in Stromboli village, on the Forgia Vecchia beach and along the northern shoulder of the Sciarra del Fuoco. Automated single-particle analysis using SEM/EDX was performed on the PC filters. The primary particles in all samples consist of glass, often enriched in silica, few spherules and individual crystals. The secondary sulphate aerosols at Pizzo are dominated by (>85% number concentration) submicronic K and Na bearing sulfates, whereas only few sulphuric acid droplets were found. The sulfate fraction in the samples collected at the three other locations, however, consist of sulphuric acid and Mg or Ca bearing phases. Na and K-bearing sulfates make up less than 25% of the particles. The change in sulfate mineralogy from the top to the lower parts of the volcano is either due to the increased mixing between volcano and sea aerosols, or may reflect a change in the chemistry (ph, fO₂) of the volcanic gas plume itself. The low concentration of sea salt particles in the latter speaks in favor of an evolution in plume chemistry. References: Pfeffer et al., 2006, JVGR.

1.3-P-27

Continuous In-situ Measurements Of Gases At Pisciarelli - Phelgrean Field: A new experimental Approach

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In late 2009, a new continuous gas monitoring research initiative started at a fumarole field located about 1 km south-est from Solfatara volcano named "Pisciarelli". The primary goal of the experiments was to prove that monitoring is possible with the set-up described below, and to compare the new data obtained at Pisciarelli with those of the complete literature record obtained by discrete gas monitoring at the investigated site. At Pisciarelli, a continuous gas flow was adjusted with a diaphragm pump, and the gas piped through a 200 m Teflon® tube away from the emission point. The temperature was measured periodically in the fumarole with a K-type thermocouple (inserted 30 cm into the fumaroles monitored). The released gas phase primary consists of water gas, which was trapped in a refrigerator and then further cooled into a second refrigerator. The remaining, almost water-free gas phase was continuously analysed with a quadrupole mass spectrometer for the following components: H₂, H₂S, CH₄, N₂, O₂, Ar, He, and CO₂. The gas line was also connected to a tuneable diode laser spectrometer for CO₂ concentration measurements.

Little surprising, the dry gas is dominated by CO₂ (>97 vol%), followed by H₂S, H₂, CH₄, and He. Due to the experimental set-up, the gas phase generally shows a varying contribution of atmospheric gases (O₂, N₂, Ar). For which the data were correct as air-free. During the time of investigation (about 7 months) clear differences in the gas compositions of the investigate fumaroles were observed within the analytical uncertainties of the experiment, confirming the possibility to use this continuous gas monitoring set up for long term monitoring. This is in good agreement with the available gas composition in literature and also with two episodes of small size emission of gases occurred during the monitoring time.

1.3-P-28

Enhancement of the “Bromine Explosion” Through Reactive Nitrogen Chemistry in a Volcanic plume (Kīlauea volcano, Hawai‘i)

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Since the first detection of bromine monoxide in volcanic plumes considerable interest has arisen in the atmospheric synthesis and impact of volcanic reactive halogens. We report here new measurements of BrO in the volcanic plume emitted from Kīlauea volcano – the first time reactive halogens have been observed in emissions from a hotspot volcano. Observations were carried out by ground-based Differential Optical Absorption Spectroscopy in 2007 and 2008 at Pu‘u‘Ō‘ō crater, and at the 2008 magmatic vent that opened within Halema‘uma‘u crater. While BrO was not detected in emissions from Pu‘u‘Ō‘ō, it was present in the Halema‘uma‘u plume (average of 3×10^{15} molecules cm⁻²) where its abundance was strongly correlated with SO₂ abundance. Anticorrelation between NO₂ and SO₂ (and BrO) abundances in the Halema‘uma‘u plume strongly suggest an active role of NO_x in reactive halogen chemistry. The calculated SO₂/BrO molar ratio of ~1600 is comparable to observations at other volcanoes, although the BrO mixing ratio is roughly double that observed elsewhere. The detection of BrO from the 2008 Halema‘uma‘u vent might reflect the overall high gas flux. Kīlauea has been characterized by persistent eruptive activity for many decades and thus our estimated emission of ~480 Mg yr⁻¹ of reactive bromine may represent an important source to the tropical Pacific troposphere.

1.3-P-29

Atmospheric Sounding at Etna Volcano Using Weather Balloons

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A SR2K2 Upper-Air sounding system is used at Mt. Etna, in Sicily, to retrieve atmospheric fields (wind speed, temperature, pressure, humidity) during the ascent of the sounding balloon to the upper atmosphere. The system is composed by a SR2K2-P ground station, GPS and radio data-link antennas, a ground check with built-in GPS repeater, and the sounding balloon bearing the weather instrument case. Two different types of launches have been planned: i) ordinary launches and ii) contingency launches. For these two typologies of launches, we identified several places outside built-up areas on the base of a previously study taking into account the main wind directions around the volcano. Ordinary launches have the objective to investigate the atmospheric field around Etna volcano and are carried out in a rest period at 12:00 UTC. These data are compared with 12:00 UTC soundings in Trapani, about 220 km W from Etna, and data obtained by weather forecasting models used to forecast volcanic plumes dispersal at INGV in Catania. The place is selected to direct the sounding balloon towards Etna summit craters. Contingency launches are instead carried out during explosive activities and have the objective to investigate properties of atmospheric field around volcanic plumes. In this work, we present the results of an ordinary launch carried out on 1 October 2009. The sounding balloon crossed the Etna summit measuring atmospheric field up to about 30 km (a.s.l.). This study will allow improving the reliability of the volcanic plume forecasting through a more accurate knowledge of the atmospheric dynamics as well as a better understanding of volcanic plume characteristics.

1.3-P-30

Degassing Pathways through the Shallow Magmatic-Hydrothermal System of Poás Volcano (Costa Rica)

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We report results from a multidisciplinary campaign carried out at Poás crater-lake (Costa Rica) on 17-18 March 2009. Thermal imagery of fumaroles on the north side of the pyroclastic cone within the crater and the lake surface revealed mean apparent temperatures of 25-40°C (maximum of 80°C), and 30-35°C (maximum of 48°C), respectively. Mean radiative heat output of the lake, uncorrected for downwelling flux, was estimated as ~230 MW. The mean SO₂ flux emitted by the crater measured by walking-traverses was 76 tonnes day⁻¹,

with approximately equal contributions from both the cone and the lake fumarole plumes. Gas measurements by active open-path FTIR spectroscopy indicated molar ratios of $H_2O/SO_2 = 151$ and $CO_2/SO_2 = 1.56$. HCl and HF were not detected in measured spectra but based on the detection limits of these species, we calculated $SO_2/HCl > 40$, and $SO_2/HF > 200$. Particles were sampled from the plume by air filtration. The filters were analysed using ion chromatography, which revealed an abundance of K^+ and SO_4^{2-} , with smaller amounts of Ca^{2+} , Mg^{2+} and Cl^- . We discuss here the implications of the results for degassing pathways through the shallow magmatic-hydrothermal system.

1.3-P-31

Seismic Activities prior to the Opening of a New Fumarole in November 2008 at Azuma Volcano, Japan

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Azuma volcano, Japan, is one of exceptional volcanoes where we can easily go to within 500 m of the craters by car. For preventing disaster, it is important to discriminate the precursors of eruptions including small phreatic ones. Opening of a new fumarole observed on November 11, 2008 is interpreted as a very small phreatic eruption. Vigorous emission of gases suddenly started and spread pyroclastics around the fumarole. Examination of seismograms has revealed two kinds of seismic activities prior to the opening of the fumarole. One is continuous tremor with small amplitude which preceded the fumarolic activity by one and a half hour and lasted seven minutes. Its spectrum has a rather broad peak which seems to suggest that the tremor was excited by some flow of fluid. The other precursor is a swarm activity which started at the beginning of August 2008, about three months before the fumarole opening. Similar earthquake swarms have repeatedly taken place every 1-3 years since 1998. The present swarm is distinguished from others by the activity of the earthquakes having simple spectrum with a few sharp peaks. The feature of the spectrum implies that resonators are involved in their generating mechanism. The activity of these events reached the peak at the end of September 2008, about one and a half month before the new fumarole was formed. It is noteworthy that the peak frequencies of the simple spectrum events vary widely from 1 to 20 Hz in this active period, in contrast with the peak frequencies in the previous swarm which had a narrow range of 1-5 Hz. We interpret these observations as that pressurized geothermal fluid filled cracks of different sizes and the cracks played as resonators with different eigen frequencies in the preparation stage for the opening of a new fumarole.

1.3-P-32

Magma Ascent Process of the 1998 Failed Eruption at Iwate Volcano, Japan, as Inferred from Temporal Changes of Seismic Activity and Strain

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Significant volcanic activity including earthquake swarms and volcano inflation was observed at Iwate volcano, Japan, from the beginning of 1998. New fumarolic area with 1 km² appeared on the ridge in the western part of the volcano in the spring of 1999, blighting wild plants around it, but magmatic eruptions did not occur at all. To understand the reasons why the eruption did not occur, we reexamine the spatio-temporal distributions of volcanic pressure sources determined by previously reported studies (Miura et al., 2000; Sato and Hamaguchi, 2006) in which GPS, strain and tilt data from dense geodetic stations are analyzed. The magma supply rates measured from their results are almost constant or even decreased with time. On the other hand, the occurrence rates of the volcanic earthquakes increase with time. This contrast observed in their temporal changes is interpreted by stress accumulation in the volcanic edifice caused by constant magma supply and no effusion of magma to the surface. By applying the theoretical expectation of ground deformations due to magma ascent (Nishimura, 2006), we further show that slightly accelerated strain data can be explained better by the magma ascending with a constant velocity than by that with increasing one. That is, in course of ascending, the magma seems not to get new additional buoyancy caused from gas bubble growth. This interpretation is supported by the observed results that the magma stayed at 2 km depth and horizontally migrated. These results obtained for the relation between magma supply rate and seismicity and the magma ascent process may explain the failed magmatic eruption at Iwate volcano in 1998.

References: Miura et al., EPS, 2000; Nishimura, GRL, 2006; Sato and Hamaguchi, JVGR, 2006.

1.3-P-33

GPS Monitoring at Vesuvio, Campi Flegrei Caldera and Ischia Island (Southern Italy)

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The Neapolitan volcanic area is located in the southern part of the Campanian plain and includes three active volcanoes (Vesuvius, Campi Flegrei Caldera and Ischia Island). This area shows different dynamical behaviours. Campi Flegrei caldera represents one well known and peculiar example of ground deformations (bradyseism), with periods of intense uplift during the 1969-72 and 1982-84, followed by subsidence phase with some episodic mini-uplifts superimposed. Contrary, Vesuvius is a substantially stable volcano, with small and localized subsidence mainly in the crater zone. Ischia Island has been characterized by subsidence in the S and NW sectors of the island. The presence of these three volcanoes in a dense populated area, makes ground deformation detection a crucial point in the risk mitigation. Ground deformation is an important volcanic

precursor, because linked to magma overpressure and migration, thus, continuous monitoring and modelling is one of the main instruments to attempt for a short time forecast of eruptive activity. Since several years, the INGV – Osservatorio Vesuviano installed a permanent GPS network (NeVoCGPS), constituted of 27 stations, in the Neapolitan volcanic area with a configuration that guarantees a continuous and fast 3D information about the dynamics of the area. All the GPS stations are managed by remote control, the data are daily downloaded automatically. After an automatic quality control procedure, the data processing is performed by the *Bernese Processing Engine* (BPE) of the Bernese GPS software v. 5.0. In this work, the entire chain of data acquisition and processing is described and some results obtained in last years are presented.

1.3-P-34

Micron-sized silicate spherules emitted during quiescent degassing from the 2008-2009 Halema'uma'u eruption of Kilauea Volcano.

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Analyses of particle filters (using scanning electron microscopy), along with Sun photometric observations, show that quiescent degassing from the 2008-2009 Halema'uma'u eruption of Kilauea emitted ~2 Mg d⁻¹ of micron-sized silicate spherules. The size distribution of these spherules was approximately lognormal with a modal diameter of ~2 μm, which is larger than silicate particles reported in other quiescent volcanic plumes. We show, for the first time, that the emission of spherules is a time-variable process, characterised by long periods of steady emission interspersed with short periods of transition. These results suggest that tangible relationships exist between the emission of spherules and dynamic processes occurring at the magma surface. In addition, compositional analyses of individual spherules (using energy dispersive X-ray spectroscopy) showed a range of compositions from magmatic to nearly-pure SiO₂. On the basis of results showing proportional decreases in Mg/Si, Na/Si, Ca/Si and Al/Si weight ratios, we propose that the variability is best explained by the deposition of SiO vapour onto ejected melt droplets at high temperatures. This process would be a terrestrial analogue to the formation of chondrules in the early Solar system.

1.3-P-35

Relationships Between the Active Structural Lineaments of The Campi Flegrei Area (Southern Italy) From Morphometric Analysis and Recent Ground Deformation

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The Campi Flegrei volcanic district formed within an extensional tectonic regime that was active in the region since the Plio-Quaternary times (Rosi & Sbrana, 1987). The tectonic elements outcropping in the area are mainly correlated with a circular geometry of deformation, and could also have been inherited by the regional NW-SE and NE-SW normal faults; likely, such faults acted as preferential magma rise conduits feeding the active Campanian volcanoes. In this paper we apply a methodology for identifying the structural lineaments from morphometrical data analysis (Nappi et al. 2007) derived by processing of a very high resolution DTM. The criteria of lineament extraction is based on the identification of linear topographic surface features, such as valleys, ridges, breaks in slope, boundaries of elevated areas aligned in a rectilinear or slightly curvilinear shape and that distinctly differ from the patterns of adjacent features (Jordan et al., 2005). We have identified significant structural lineaments extracting the linear continuity of the morphostructural features observed on the DEM. Their spatial and statistical coherence has been examined and the comparison with the structural lineaments already known from literature has been carried out. The results of the analysis have been correlated to the spatial distribution of the recent seismicity (crises of 1982-1984 and 2004-2006) as well as with the local ground deformation measured through high precision levelling surveys over the last 20 years, together with the tiltmetric data continuously recorded over the last 10 years. The aim of this analysis is understanding the relationships between the recent dynamics of the area and its active structural lineaments. References: Rosi & Sbrana 1987, CNR; Nappi et al. 2007, Mem. Soc. Geogr. It.; Mitasova & Hofierka 1993, Matem. Geol.

1.3-P-36

The Campi Flegrei (Campania, Southern Italy) 2000-2006 Ground Deformation Episode Analyzed In The Light Of The Local Seismotectonic Background.

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The Campi Flegrei is an active volcanic area characterized by many different eruptive episodes. A peculiar behaviour of Campi Flegrei since historical times has been the bradyseism, characterized by alternating intense ground uplift and slow subsidence episodes, with intense seismic activity. The major bradyseismic crises occurred in 1969-1972 (maximum ground uplift of about 177 cm), accompanied by seismic crises consisting of 4000 earthquakes of moderate energy (maximum

magnitude $M_D=2.5$), and in 1982-1984 (about 179 cm), characterized by 15000 earthquakes located in the central area of maximum deformation, near the harbour of Pozzuoli (Orsi et al., 1999). Minor crises were observed recently in 1989, 1994, 2000 and the last from June 2004 to October 2006, with slight ground deformation and low seismicity located in the eastern side of the Solfatara crater. The goal of our paper is to reconstruct the deformation pattern in the Campi Flegrei in 2000-2006, respect to the previous periods, particularly as regards its eastern sector, through the analysis of the altimetric and the tiltmetric measurements. In detail the uplift recorded by the tilt stations during the 2006 show asymmetrical deformation pattern with a higher tilt value observed near the Solfatara sector (Ricco et al., 2007). This deformation has been correlated to the hypocentral locations of the local seismic events over the same period, and also to the morphostructural lineaments derived from high resolution DTM (Digital Terrain Model). The results show a recent remarkable change of the deformation pattern in the eastern sector of the Campi Flegrei, which has been correlated with NNW-SSE active structural discontinuity on the eastern border of the Solfatara crater. References: Orsi et al., 1999, J. Volc. Geoth. Res.; Ricco et al., 2007, Ann. Geoph.

1.3-P-37

Volcanic and Tectonic Controls Revealed from GPS Observations in S. Miguel Island, Azores

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The Azores archipelago is located across the Mid-Atlantic Ridge, where three tectonic plates meet such as African (Nubian), North American and Eurasian plates. The archipelago has many active volcanic systems. Among them, the Monte Escuro-Congro area, located in the NE flank of Fogo (Água de Pau) volcano in the central part of S. Miguel Island has been recognized as one of the most active seismo-volcanic fields in the Azores. This area has been repeatedly suffered from significant earthquake swarms, e.g. in 1989 and in 2005 for last few decades, thus has provided good research opportunities for understanding the relations between seismic swarms and potential eruptions. The 2005 event was successfully observed with GPS network operated by CVARG (Center of Volcanology and Geological Risks Assessment, University of Azores). Previous seismological and geodetic researches have given strong suggestions for magmatic intrusions without resulting in any eruption episodes in the area. The smaller earthquakes have still existed after 2005 episode in the Monte Escuro-Congro area and its vicinity. In this study, the recent GPS data sets including 9 permanent GPS stations (7 operated by CVARG and 2 by regional government) have been processed using Bernese software v5.0 to evaluate ongoing volcanic and tectonic activities in the island. Preliminary results indicate the stress relaxation after 2005 episode and resumed deformation activities on the east part of Fogo volcano. The west part of Fogo volcano seems quiet both in deformation and seismic activities. This contrast suggests the existence of a local tectonic

boundary which can make magma movement upward more feasible and cause occasional swarm episodes (likely as "failed eruptions") in Monte Escuro-Congro area. Implementation of the permanent GNSS network has played an important role for seismo-volcanic risks assessment in the Azores.

1.3-P-38

Prior Processes of Outburst of Explosive Eruption: A case study for Sakurajima Volcano, Japan

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Showa crater of Sakurajima volcano have been re-active since June 2006, after 58 years quiescence. From our multi-parametric observations, typical prior processes of eruption have been revealed as follows. At a few hours before the eruption onset, magma starts to migrate and storage in the depths of a few hundreds meters. It is clearly recognized in record of strain change as an inflation process. Since a few tens minutes before the eruption, SO_2 gas emission rate is gradually decreasing which indicates that a sealing process at the crater bottom toward the eruption progresses. In the time of around 10-20 minutes before the eruption, inflating rate of the volcano starts to increase due to a construction of a plug above the conduit thus a formation of a gas pocket beneath the crater. They are also observed as the weakening then disappearing of volcanic glow in night-time events. At a few minutes before the eruption, small tremor starts to emerge and then its amplitude becomes larger with strain changes of inflation turning to be deflating. This is considered as the gas release through fractures newly constructed within the plug for a gas pocket. Seismic signals also shows that expansion process starts to occur at only one second before the eruption. It is probably the time when effect of the depressurization process reaches to the depth of magma head and sudden expansion of magma with degassing starts. About a half of a second later, such expanding magma rises and pushes the gas pocket up, which also detected in seismograms. It leads to swelling of crater ground for radiating weak infrasound preceding phase. After the failure of the plug due to its deformation, the accumulated gasses and expanding magma itself ejects together from the crater as a start of the eruption surface phenomena.

1.3-P-39

Estimation of ground movement caused by the 2000 Eruption of Usu Volcano, from the Geomorphic Image Analysis of DEMs

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It is not easy to measure the small-scale ground deformation caused by the eruption, earthquake or landslide efficiently in the large area. In this study, the method of

extracting the vector of ground displacement was developed by applying the technique of the image matching analysis to the visual image of the geomorphic quantity. We used the PIV method for the image matching analysis. A remarkable advantage of this technique is as follows: neither mapping for the measurement nor selection of specific characteristic for tracking is needed. Moreover, the ground displacement can be calculated from many points at random. In the image matching analysis, the displacement of about 1/10 size of a pixel is usually calculated by sub-pixel interpolation.

As a case study, this technique was applied to the measurement of the ground deformation at the 2000 Eruption of Usu volcano, northern Japan. In this eruption, numerous amount of cracks were observed at the northern and western part of the Usu volcano. Comparing aerial photographs taken before and after the eruption, it revealed that total uplift due to intrusion of the cryptodome was 60-75m (Suto et al., 2002; Koarai et al., 2002). We made a slope gradation map from 10m DEM before (30 Mar, 2000) and after the eruption (22 Jun, 2000) for image matching. As a result, the small displacement in a large-scale mass movement was able to be estimated. And it became clear that the center of the movement in the horizontal direction was located in the northwestern foot of the Mt. Nishiyama, and the deformation which spread radially from there was also detected. We think this method is effective for the measurement of the tracking of transitional deformation of volcanic edifice etc.

1.3-P-40

Kvert Project In 2006-2009

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The Kamchatkan Volcanic Eruption Response Team (KVERT) is a collaborative Project of scientists from the Institute of Volcanology and Seismology, the Kamchatka Branch of Geophysical Surveys, and the Alaska Volcano Observatory (IVS, KB GS and AVO). The purpose of KVERT Project is to reduce the risk of costly, damaging, and possibly deadly encounters of aircraft with volcanic ash clouds. To reduce this risk KVERT collects all possible volcanic information and issues eruption alerts to aviation and other emergency officials. KVERT receives seismic monitoring data from KB GS. Satellite data are provided from AVO and IVS. KVERT obtains visual volcanic information from volcanologist's field trips, web-cameras that monitor Klyuchevskoy (established in 2000), Sheveluch (2002), Bezymianny (2003) and Koryaksky (2009) volcanoes, and pilots. KVERT Project staff work closely with staff of AMC (Airport Meteorological Center) at Yelizovo Airport and the Tokyo Volcanic Ash Advisory Center (VAAC), the Anchorage VAAC, and the Washington VAAC to release timely eruption warnings. During the period of 2006-2009, many eruptions of Kamchatkan and Northern Kurile vol-

canoes were potentially dangerous for aviation: seven significant events have occurred at Bezymianny (2006 (2), 2007 (3), 2008 (1), 2009 (1)), three at Klyuchevskoy (2007, 2008, 2009), one of Koryaksky (2008-2009) and two at Chikurachki (2007, 2008). Eruptions of Karymsky and Sheveluch volcanoes have continued throughout the period 2006-2009.

1.3-P-41

Continuous GPS Observation in Canary Islands for Volcano Monitoring

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In response to the seismic-volcanic activity occurred around Teide volcano in Tenerife, Canary Islands from April 2004, a continuous GPS array was established in Tenerife, La Palma, and El Hierro Islands. The network consists of 10 permanent sites, of which 8 stations are located on Tenerife Island. Precise estimate of daily coordinates for each site shows that no significant crustal deformation has occurred even during the most active stage of the seismic crisis in the middle of 2004. GPS daily coordinates are quite stable after the event until now. Although we have not detected any sign of magma intrusion at depth beneath Mt. Teide, geodetic monitoring is an indispensable part of volcano monitoring. We are now trying to add quasi-real-time capability for the GPS network by making almost all the sites online. We also conducted a numerical test to examine the detectability of the present GPS network for a hypothetical magma intrusion beneath Teide volcano in Tenerife. Calculation results demonstrate that we will be able to detect deformation signals associated with a magma intrusion of $1 \times 10^7 \text{m}^3$ which is common to moderate size eruption or magma intrusion events.

1.3-P-42

UV Camera Measurement at a Dormant Volcano

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The UV camera is now becoming a new important tool in the armory of volcano geochemists for high rate SO_2 flux measurements. The high spatial resolution of the camera is particularly useful for exploring multiple-source SO_2 gas emissions, as the large composite fumarolic systems topping most quiescent volcanoes. We report here on the first SO_2 flux measurements from individual fumaroles of the fumarolic field of La Fossa crater (Volcano island, Aeolian island), which we performed using a UV camera in two field campaigns on November 12,

2009 and February 4, 2010. Making advantage of the high temporal and spatial resolution of the UV camera, we derived ~0.5 Hz SO₂ flux time-series for the main fumarolic areas, deriving fluxes from individual fumaroles ranging from 1.4 to 5.2 tons/day; and a total cumulative flux from the whole system of ~ 13 tons/day. The data of each campaign were implemented by determining, for each fumarolic vent, the molar SO₂/H₂S and CO₂/SO₂ ratios (which we derived using a portable multi-gas analyzer). Using the SO₂ flux data in tandem with the molar ratios, we also calculated the flux of volcanic species CO₂ (355 tons/day) and H₂S (5.6 tons/day) from Vulcano island.

1.3-P-43

Development and Maneuvers of "Mobile Observatory for Volcanic Explosion (MOVE)" –part 2–

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To observe volcanic explosion from near field with safe we have developed unmanned survey vehicle "Mobile Observatory of Volcanic Explosion (MOVE)" (Taniguchi et al., COV 5, 2007). On the maneuver at Izu-Oshima volcano in 2006 we succeeded in operating MOVE from 2km distant on the way of round trip between the flank of the volcano and the crater rim. However the operation was still unstable due to obstruction of wireless communication by topographic obstacles between operation site and MOVE. Hardness of setting up the operation site by several operators and support staffs was also a serious problem. To reduce these difficulties we have developed a car that equipments for operation are built in. The adoption of this operation car reduced the energy and time to set up the operation site drastically, and enables us to operate even in a bad weather. It also makes us easy to move to a new place to prevent a bad wireless communication by topographic obstacles. After completion of this car we made maneuvers on Aso volcano and Izu-Oshima volcano in 2009. In Aso volcano we tried to run MOVE from the edge of expected safe area at eruption to the vicinity of crater along 1.5km long sightseeing road, but could not clear a 100m shade zone near designation even though the operation car moved within safe area. In Izu-Oshima volcano, to the contrary, we tried the same route as in 2006 and could clear the zone where wireless communication was poor in 2006 maneuver by moving the operation car. As long as we use 2.4GHz radio wave to transfer visible image disconnection is inevitable at shade. To apply MOVE on eruption it is important to survey the route in advance to keep the wireless communication.

1.3-P-44

Monitoring Volcanic Eruptions Using Trace Metals In Tree-Rings: Preliminary Results From Mt. Etna

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Active volcanoes can influence surrounding vegetation both through passive degassing during quiescent periods and through eruptive degassing, by introducing into the atmosphere several metals as gases and particles. The chemical composition of tree-rings has been generally used to investigate the effects of anthropogenic gas emissions and dendrochemical methods have successfully recorded variations in the pollution levels. The use of tree-rings analysis in active volcanic areas has shown that vascular plants could be used as archives of volcanogenic metals deposition. Tree cores of *Pinus Nigra* and *Populus tremula* were collected in sites located both on the downwind (Citelli and Mt. Fontane sites) and on the upwind (Mt. Intraleo site) sectors of Mt. Etna in June 2008. Individual and composited tree-rings were analyzed by inductively-coupled-plasma mass-spectrometry for the determination of several trace elements (As, Cd, Li, Mn, Mo, Ni, Se, Sr, Pb, V). Tree cores were dated dendrochronologically before analysis, and their ages date back to 1915. The preliminary results show that some elements have significant differences in concentration between the two tree species analyzed, and in general metals are more concentrated in the samples from the downwind sites, hence more exposed to crater gas emissions. Furthermore, the temporal patterns of metal contents show some evident peaks likely related to some of the major flank eruptions of the volcano, particularly those occurred after 1945. This method can be used in many active volcanoes to reconstruct their past degassing rate and recognize possible eruptive cycles, thus helping forecast their future behaviour.

1.3-P-45

A Biomonitoring Study Using Endemic Plants for the Evaluation of Volcanogenic Deposition on Mt. Etna (Italy).

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A biomonitoring survey using leaves of tree (*Betulla aethnensis*, *Pinus nigra* and *Populus tremula*) and two endemic species (*Senecio aethnensis* and *Rumex aethnensis*) above treeline level, was performed on Mt. Etna, in order to evaluate the dispersion and the impact of volcanic emissions. Samples of leaves were collected in summer 2008 from 30 sites in the upper part of the volcano (800-3000 m a.s.l.). Acid digestion of samples was carried out with a microwave oven, and 44 elements were analyzed by using plasma spectrometry (ICP-MS and ICP-OES). The highest concentrations of all investigated elements were found in the samples collected closest to the degassing craters, and in the downwind sector, confirming that the eastern flank of Mt. Etna is the most impacted by volcanic emissions. Leaves col-

lected along two radial transects from the active vents on the eastern flank, highlight that the levels of metals decrease one or two orders of magnitude with the distance from the source. This variability is higher for volatile elements (As, Bi, Cd, Cs, Pb, Sb, Tl) than for more refractory elements (Al, Ba, Sc, Si, Sr, Th, U). The different species of plants show significant differences in the bioaccumulation of most of the analyzed elements, in particular lanthanides, which are systematically enriched in *Rumex* leaves. The high concentrations of many toxic elements in the two endemic species allow us to consider these plants as highly tolerant species to the volcanic emissions, and suitable for biomonitoring researches.

1.3-P-46

Monitoring the Popocatepetl Ash: 2008 and 2009

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Popocatepetl Volcano in central Mexico has been erupting since December, 1994 with a series of small ash emissions which clear the summit domes. Ash monitoring has continued since then. Activity in 2008-2010 has declined and there has been no ash in 2010, so far. Samples were collected on January 5, 8, 9, 11, 12, 14, 28, 29, 30 and February 8, 13, 14 and 21, 2008 and October 9, 29 and November 23 2009. Most of the ash is composed principally of andesitic lithics from the dome (60-80%), plagioclase and pyroxene crystals (8-30%) and small amounts of glass, but the February 13, 2009 ash had much more scoraceous particles (10%) and some olivine crystals. Previous eruptions have been associated with small incoming magma batches with similar characteristics.

Dry samples were sieved from 16.0mm to 0.063mm and finer particles were analyzed by laser diffraction (0.062mm a 0.00050mm). Textural analyses shows that most of the ash has bimodal size distribution, with peaks at phi 3 and 5 (125 and 32 microns), nonetheless, fine ash makes up at least 5% and up to 33% of each sample.

1.3-P-47

The Role Played By The Environmental Factors On Diffuse Soil Degassing At Stromboli Volcano

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Geochemical surveys and continuous measurements of several gas species in volcanic areas are useful to identify changes in volcanic activity as well as in deep magmatic processes. Diffuse soil degassing in volcanic areas releases high amount of gases and its monitor-

ing can be helpful for the mitigation of risk and volcano surveillance.

At Stromboli, previous surveys permitted us to recognize the zones surrounding the crater where diffuse degassing is active. Here we present the first results of the in-soil [²²²Rn] and CO₂ flux continuous monitoring started in April 2007 in one of these zones. Measurements of the CO₂ flux and in-soil ²²²Rn concentration have been acquired simultaneously with the main environmental parameters (soil and air temperature, atmospheric pressure, soil humidity, wind direction and velocity). A multivariate statistical analysis has been applied on the entire acquired dataset, in order to outline the role of each environmental parameter in controlling the variation of in-soil degassing. Results show the key role played by the environmental factors in the process of soil gas transfer from depth to the surface. A good correlation has been found between ²²²Rn and CO₂ flux, confirming the role of the latter as carrier of other gas species.

Our results stress the importance of the collection of environmental parameters in the geochemical monitoring aimed at the identification of the processes modulating soil diffuse degassing in volcanic areas. Furthermore, the simultaneous acquisition of several gas species can provide valuable information on the state of the volcano activity and its capability to release gas from its fracture network.

1.3-P-48

Gas, Particle and Thermal Emissions from Villarrica Volcano, Chile

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We report results from a multidisciplinary field campaign to Villarrica volcano, Chile in March 2009. A range of direct sampling and ground-based remote sensing techniques were employed to enhance assessments of the atmospheric and environmental impact of the volcano, and also extend the time series of measurements that have been made during recent years. An FTIR spectrometer and electrochemical sensors deployed on the crater rim, combined with operation of an UV spectrometer from a light aircraft, yielded measurements of the plume's gas composition (H₂O, CO₂, SO₂, HCl, HF, H₂S) and flux. Our results are similar to previous analyses, performed between 2000 and 2004, and suggest stability of the shallow magmatic system. Base treated filter packs were also deployed on the crater rim to trap the trace gas species HBr and HI. We estimate fluxes of these species to be 0.8 and 0.1 g s⁻¹, respectively. Analysis of the particulate matter, collected directly from the plume using a portable cascade impactor, revealed an abundance of micron-sized spherical particles. SEM-

EDS elemental mapping showed that these particles are rich in Si, Mg and Al. Non-spherical, S-rich particles were also observed. Sun photometry of the plume (~300 m downwind of the summit) indicated bimodal aerosol size distributions with maxima at <0.1 and ~1 mm. These results are consistent with prior analyses reported by Mather et al., 2004 pointing to continuity of the degassing and atmospheric processes that influence particulate, as well as gas, emissions. Magma was not visible from the crater rim during our campaign but thermal imaging data revealed a hot (~350°C) narrow pit within the summit crater. The radiant heat flux from this source was ~0.7 MW.

References:

Mather, T.A., Tsanev, V.I., Pyle, D.M., McGonigle, A.J.S., Oppenheimer, C. and Allen, A.G., 2004. Characterization and evolution of tropospheric plumes from Lascar and Villarrica volcanoes, Chile. *Journal of Geophysical Research*, Vol. 109, D21303, doi:10.1029/2004JD004934.

1.3-P-49

Multidisciplinary Monitoring and Investigations at Stromboli (Aeolian Islands, Italy)

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At the beginning of the 2007 eruption, two automatic stations hourly measuring CO₂ soil flux and environmental parameters were installed on the main CO₂ diffuse degassing flank structures of Stromboli. Anomalous increases of CO₂ release from these structures could represent a geochemical precursor for high energy explosions from the craters, onset of effusive eruptions

and even opening of flank eruptive fissures that might threaten the village of Stromboli. On May 2008 a new monitoring station measuring self-potential and soil temperature every 5 minutes was installed in the crater area. Other multidisciplinary studies using electric resistivity tomography, self-potential, CO₂ flux, soil temperature, ground penetrating radar, and thermal imaging have been used to investigate the inner structure of Stromboli volcano and its hydrothermal circulation. The measurements were performed on key areas and volcanic features strongly influencing hydrothermal fluid circulation at the scale of the volcanic edifice have been identified. Results indicate a wide extension of hydrothermal circulations also in peripheral zones of the volcano and allow proposing a new hydrothermal fluid circulation pattern inside this active volcanic edifice.

1.3-P-50

SO₂ Loss Rates Reveal More Accurate Emission Rates from the Soufrière Hills Volcano, Montserrat

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The monitoring of volcanic gases is key to the understanding of volcanic activity and therefore very important, especially for volcano observatories. Sulfur dioxide (SO₂) emissions have played center stage in many studies focused on volcanic gas monitoring, due to the fact that it can aid in the prediction of volcanic eruptions as well as the detection of a decline in activity. SO₂ absorbs ultraviolet (UV) light, which makes it possible to use remote sensing techniques for its detection (Stoiber et al., 1983). Using two mini UV-spectrometers, four days of measurements (March 26 and April 12, 13 and 22, 2004) were conducted at Soufrière Hills Volcano (SHV), Montserrat, to collect SO₂ data of ash-free plumes near the vent and at several distances downwind (Rodríguez et al., 2008). These were processed to determine fluxes (Rodríguez et al., 2008; Alonso, 2008; this research), with the objective of calculating SO₂ loss rates (Rodríguez et al., 2008; this research) and correcting the 2004 daily SO₂ emission rates determined and reported by the Montserrat Volcano Observatory (MVO). Using the exponential relationship between flux and plume age in the loss rate equation: $\varphi_{t_1} = \varphi_{t_2} e^{(k \cdot (t_2 - t_1))}$, we were able to determine SO₂ loss rates for the SHV plume. The average loss rates ($3.8 \times 10^{-4} \text{ s}^{-1}$) were then used to correct the at-source emission rates for the year 2004. A ~48% difference was found between the total SO₂ emissions for 2004, calculated by comparing the corrected emission rates with the emission rates reported by the MVO. Differences in the daily emissions ranged between 10% and 100%, depending on plume conditions. Based on the corrected daily emission rates of SO₂ we were able to estimate the contribution of the SHV to the global SO₂ and S budgets in 2004. These were ~321 and ~161 kilotons, respectively.

1.3-P-51

Preliminary Results from Shear Wave Splitting Analysis in Canary Islands

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The Canarian archipelago consists of seven large volcanic islands that form a chain of approximately 500 km extends through the eastern Atlantic, between latitudes 27°N and 30°N, with its eastern border at only 100 Km from the Northwest Africa coast. The Canary Islands have developed into a complex geodynamic system, characterized by Jurassic oceanic lithosphere formed during the early stages of the opening of the Atlantic occurred between 180-150 Ma. Thus, this region have had a volcanic history very long and complex, characterized by distinct periods of volcanic activity. This implies that each island has had different development and making it difficult to establish a common geodynamic model.

We study the geodynamic situation of the region to provide seismic constraints on the lithospheric structure beneath them. For this purpose we study seismic anisotropy, since seismic anisotropy can constrain deformation in the mantle, and thus flow. We measure shear wave splitting of teleseismic events covering the period 2004-2008, analyzing SKS and SKKS phases recorded from seven permanent broad-band seismic stations (CFUE, CRAJ, EBAJ, EFAM, EGOM, EHIG and EOSO) deployed in each island. The data are available through Instituto Geografico Nacional of Madrid (IGN).

Even if for some stations we have a small number of events available, but also a high noise level present on oceanic island stations, we determine the anisotropic parameters stacking of individual measurements. In our preliminary observation, we detect a different trend for fast anisotropy directions for La Palma and Fuerteventura islands respect to the other islands, perhaps caused by variable upper mantle deformation beneath the seven islands.

1.3-P-52

Volcanic Seismology Studies at Copahue Volcano-Argentina

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Seismic activity registered from seismic field survey carried out at Copahue volcano, Southern Andes, Argentina, using a small-aperture, dense seismic arrays.

Copahue volcano (37°45'S; 71°10.2'W, 2965 m) is located in the border Argentina-Chile, in the extreme southwest of the Caviahue caldera (Caviahue-Copahue complex- southern Andean Volcanic Zone). It has numerous historical eruptions, where his last and most important activity took place in July 2000. Caviahue-Copahue complex is characterized mainly by emissions

andesitic and basaltic andesitic and it is located in the transition zone between two major fault systems, Liqueñe Ofqui fault zone and Copahue-Antiñir thrust system.

Volcano seismology studies are important to understand different aspects of the volcanic system. An analysis of the data recorded between November 2003 and January 2010 from the different seismic arrays has been able to identify high-frequency events such as volcano-tectonic earthquakes (VT) and long period events (tremor). Local VT events were identified (difference in arrival times of phase waves between P and S less than 10 sec.) generally, these events display clear P and S wave arrivals, high-frequencies spectral content, between 1 and 16 Hz and they are related to brittle fractures. They have been located in two areas, one near Caviahue village (about 9 km east of the volcano) possibly related to an existing horst-graben system inside the caldera. These events are characterized by having VT epicentral distances less than 32 km and 15 km depth according to the seismic array located near to Caviahue village; and another one, in the area of the Barco lake (southwest of the volcano-Chilean territory).

Long period events expose spectral energies usually concentrated at frequencies of 1 and 2 Hz and array solutions show a predominant slowness vector pointing to geothermal fields located about 6 km north of the array site.

1.3-P-53

Evaluation of New Features for Automatic Recognition of Volcano-Seismic Events.

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Monitoring of precursory seismicity in volcanoes is the most reliable and widely used technique in volcano monitoring. Since a visual inspection by human operators is a tedious task in a non-stop monitoring process, different classification or recognition procedures have been proposed to automatically identify and classify the different types of volcano-seismic events. Feature extraction (that is, the representation of the signal by means of feature vectors) is a crucial step in automatic classification. Seismic signal is usually segmented into short frames and each frame is represented by a vector containing appropriate features to perform classification. The components of the feature vector should be designed in order to allow discrimination among the different classes (or types of events), and the design of the feature vector strongly affects the recognizer performance. Mel Frequency Cepstral Coefficients (MFCCs) have been successfully used as feature vector for continuous recognition of volcano-seismic events. In this work we propose new features that capture peculiarities of the events in the frequency or time domain. We evaluate the capability of different features (new features,

MFCCs, combination of both groups, etc.) to improve the performance of automatic recognition systems. A GMM-based classifier has been implemented in order to assess the efficiency of the proposed features. Results using hundreds of events recorded from stations situated at Colima (Mexico) and Arenal (Costa Rica) volcanoes show that the proposed features improve the recognition accuracy and therefore they may be relevant in continuous automatic classification of volcano-seismic event.

1.3-P-54

Comparison of Volcano-Seismic Signals from Different Volcanoes: Characterization of Different Sources of Events and Strategies for the Evaluation of Automatic Recognizers of Volcano-Seismic Events.

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Automatic recognition of volcano-seismic events based on Hidden Markov Models has provided good results for some volcanoes (such as Colima Volcano). Such a success can not be directly extrapolated to other volcanoes (for example, Arenal Volcano). These different behaviours of the recognizers have motivated the comparison of the seismic signals from different volcanoes and the characterization of them as sources of events, in order to investigate the motivation of the differences in recognition accuracy. The careful inspection of Arenal database highlights several difficulties that can explain such disappointing results: higher number of events per time unit; high proximity among events which sometimes appear even overlapped in time; there are certain events labelled as ‘garbage’ meaning by this label that the human operator can not reliably identify the type of event; labelling results from different human supervisors do not always agree. On the contrary, the good results achieved for Colima database seem to be connected with certain characteristics of the volcano: most of the events are, in practical, isolated events. This empirical fact lead us to revise the strategies used to recognize and evaluate recognizers, and to check whether the methods are adequate for event sources similar to Colima, but not for event sources similar to Arenal. In such new challenging scenario we propose a different recognition evaluation strategy for volcanoes similar to Arenal. Instead of evaluating the HMM recognition results in terms of events, we propose a frame-based evaluation of the recognition results. Evaluation of the recognition in terms of events for volcanoes like Arenal was masked by the effects of a high number of insertions that do not represent a real recognition problem when inspecting the actual recognition process occurred. The proposed evaluation procedure provides a recognition result more representative of the ability of the recognizer to operate correctly.

1.3-P-55

Insufficient Amount of Training Data in Automatic Recognition of Volcano-Seismic Events: Strategies for Dealing with this Problem.

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Several strategies for automatic recognition of volcano-seismic events have been proposed during the last years. Usually, existing technology applied in other contexts has been adapted to the recognition of volcano-seismic events: that is the case of Hidden Markov Models (widely applied for automatic speech recognition). One of the problems of automatic recognition of volcano-seismic events is the size of the training database, since it strongly determines the degree of complexity tolerated by the recognition system. As the recognizer complexity increases, the accuracy improves, but a limit is imposed by the quality and size of the training database, because the examples included in the training database must be representative (according to the system complexity) of the global behaviour of the events. When the size of the training database is not large enough (for a given complexity of the recognizer), the system becomes ‘over-trained’, that is, the recognizers adapts very well to a few examples, and recognition results decrease as the recognizer complexity increases. Even though the availability of volcano-seismic signals is increasing during the last years, the segmentation and labelling of databases currently requires the supervision of a human operator and the size of the available labelled training databases is, in practice, limited. In this work we study the trade-off between the training database volume and the complexity of the automatic recognition system. Strategies to improve such size limitation and to achieve robustness of the recognizer against it are proposed. Following this philosophy, a very attractive simplification of the system which increases the system tolerance to small training data sets is presented: the decoupling of the temporal modelling and the feature extraction and vector modelling of the volcano-seismic signal. Different recognition systems implementing such decoupling are compared to analyze their performance in conditions of limited training database size.

1.3-P-56

Automatic and Semi-Automatic Tools for Segmentation and Labelling of Large Databases of Volcano-Seismic Signals.

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As research on volcanic systems evolves, the availability of volcano-seismic events databases simultaneously increases. The number of campaigns, the amount of data recorded in them and the information retrieved from such data are continuously increasing. The study of volcanic signals requires the careful inspection, identification and labelling of the different events contained in the recorded databases. Manual segmentation of large databases represents a big bottleneck for the advances in research, due to the amount of time required by the human operator to perform it. Additionally, the difficulty to establish objective criteria to be applied by human operators to identify and segment the events must be considered. Finally, an emerging obstacle is constituted by the peculiarities of each particular volcanic system: different volcanoes (and even the different stages of their eruptive cycles) originate different types of events. This makes difficult the consolidation of common criteria for the definition and labelling of volcano-seismic events. This work proposes two strategies for dealing with the segmentation and labelling of large volcano-seismic databases. The first approach is based on a simple classifier that provides a tentative segmentation to the user, together with different representations of the signal (its amplitude, its spectrogram, its energy along time, etc). Such information is used by the human operator who performs then a quick supervised segmentation. The second proposed strategy consists of an event recognizer based on Hidden Markov Models trained with known events manually labelled. Such recognizer is used to produce an automatic segmentation of the events within the database under labelling. Results are provided for both segmentation strategies together with a comparative analysis of their respective performances.

1.3-P-57

Initial Results of Seismic Attenuation for P-Waves on Tenerife Island (Canary Islands, Spain)

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In the present work we show the initial results of seismic attenuation study on Tenerife Island (Canary Islands, Spain). Seismic attenuation studies help us to know how the intensity of the seismic energy decreases with the distance from the source, and its relationship with the structure of the medium. Directly related to this studies the quality factor allows us to understand the degree and distribution of heterogeneities in the region under study. Data used correspond to an active seismic experiment (TOM-TEIDEVS) carried out on the island in 2007. Initially, we have chosen 9 of the 200 available seismic land stations, to obtain a spatial image of the attenuation values. The 9 selected stations cover homogeneously the island. The analyzed signals have a high signal-noise ratio. The seismograms are modeled using the diffusion model and assuming the dominance of P-waves in the initial seismogram and in coda. The parameters that we are going to study are: b (attenuation coefficient), d (dispersion factor) and Q (quality factor) as a combination of intrinsic and scattering

attenuation. The average values for these parameters on Tenerife Island are: $\bar{b}=0.10 \pm 0.08s^{-1}$ and $\bar{Q}\approx 377$, in the frequency range of 4.5-7.5 Hz. These values at the used frequency ranges are low in comparison to other analyzed regions, and reflect the complex structure of the volcanic area of Tenerife. The high value of the error indicates a high dispersion of the data. It shows different regions with different structural features and thus, different values of seismic attenuation and quality factor. For this reason we have proceed to regionalize the obtained values and derived Q_i and Q_s values for different areas of the island. Results show a direct relationship between high attenuation and velocity anomalies derived from tomography studies and also with the geology of the island.

1.3-P-58

Statistical Analysis of Along Continuous Time Series of Volcanic Explosions of Volcán de Colima, México.

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We analyzed four years of continuous data (2003-2006) using the daily explosions of Volcán de Colima, the series is interrupted only by the lava effusion. At the time between explosions is called inter-time. An analysis of distribution functions shows that for small time scales is not consistent with a Poisson distribution. The shape of the distribution varies randomly, using a moving window of a month of data with a step of 5 days. Applying an analysis of R/S that allows us to estimate the Hurst exponent, which gives us information about the correlation between inter-time blocks. Proving that when we have values of $H < 0.5$ is released more energy by the explosions, and when values are $H > 0.5$ corresponds to periods extrusion and dome formation. We examine the relationship between energy and the duration of the explosion, using the period with more energy in the explosions occurs. Finding that there is a logarithmic linear relationship in the explosions with duration over 150 seconds. We use a trend analysis of the entire database, seeing changes in the behavior of the series related to changes in volcanic activity. When most energetic explosions occur, the U_L results are below 1, indicating that there are more inter-time between the explosions. We can see the same behavior even prior to lava effusion. Finally, we investigated whether atmospheric factors influencing the duration and time between explosions, finding that none of them has no effect on the dynamical system of the volcano.

1.3-P-59

Seismic Characterization of Seismicity Recorded by Seismic Array at Volcán de Colima, México.

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The main objective of the present study was to investigate the wavefield properties of the seismic signals generated by the Volcán de Colima (México). We have analyzed these properties to understand and classified the volcanic. Our study is focused using array techniques on distinguish waves that come from both the subduction zone and the volcanic area. An initial classification was made based on the results of spectral analysis of the seismic signal, where it was found that the volcanic signal is in a frequency range of 0.5 – 3 Hz. The seismicity was recorded by a short aperture seismic array over two periods: October 2005 and April 2006. After analysis we found local, regional, and distant tectonic earthquakes, as well as, volcanic explosions, LP events, volcano-tectonic, tremor, screw type events, etc. We can distinguish two types of explosions, Vulcanian and purely phreatic. Both types of explosions share the same characteristics, i.e. a long-period signal (not related to any type of emission) before the arrival of high frequency phases, and later a high frequency signal that was directly related to ash or gas emission. By comparing the results of both of these analyses, we were able to identify the dominant wave types that comprise the wavefield and infer in time and space a possible primary source mechanism that triggered the volcanic explosions. The depth of the source was identified at a depth ranging between 2.6 km and 3.3 km below the crater, associated with the range of measured apparent velocities relative to the first onset of the long-period signal. The volcano-tectonic earthquakes were located at 0-5 km depth around the volcanic edifice.

1.3-P-60

Monitoring Of Active Volcanoes in Colombia: 25 Years of Continuous Learning.

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The tragic eruption of Nevado del Ruiz Volcano (NRV), in November 13, 1985 was the onset of formal volcano monitoring program in Colombia. With few seismic stations (5), a couple of electronic tiltmeters, a COSPEC, and some periodic measurements of deformation and geochemistry sampling, INGEOMINAS (Colombia Geological Survey) started the volcano monitoring program in Colombia. Initially the monitoring was focused only in NRV, done by the Volcanological and Seismological Observatory of Manizales. Later, volcanoes such as Nevado del Tolima Volcano (NTV), and Cerro Machín Volcano

(CMV), and Cerro Bravo Volcano (CBV) were included in the monitoring program too. In May 1989, Galeras Volcano (GV) erupted, and a new volcanological observatory was created (Volcanological and Seismological Observatory of Pasto). In 1990, Nevado del Huila Volcano (NHV) and Puracé Volcano (PV), were included in the monitoring program, and a other volcanological observatory was created (Volcanological and Seismological Observatory of Popayán). From only 5 portable seismic stations at the beginning of the monitoring program in 1985, to more than 120 telemetric stations of different types (seismology, deformation, geochemistry, geophysics, and do on), and more than 100 non-telemetric stations, up to date (2010), the Colombian governments with help of World Bank, have invested a remarkable budget to achieve this goal. At his moment, 12 active volcanoes are monitored continuously, and two of them are in eruption process (NHV and GV). In this 25 years, more than 20 eruptions have occurred in different active volcanoes in Colombia. Excepting NRV eruption on November 1985, only few people have been killed by those eruptions (about 10 people). This has been possible, thanks to the on time alerting by the volcanological observatories. The continuous monitoring program has allow to obtain models of behavior of the most active volcanoes, which have been used to alert people with few days to several weeks before an impending eruption. On the other hand, hazard maps of the most active volcanoes in Colombia have been elaborated, as well as modeling of dispersion of volcanic products. The involving of people in the culture of prevention, have permitted to advance in the education programs, as well as in the conscientiousness of the danger of volcanoes.

1.3-P-61

Gas Monitoring and Detection of Microseismicity in the Volcanic System of Campo de Calatrava, European Intracontinental Volcanism (Spain)

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8. In the Campo de Calatrava for 8 million years to the middle Holocene has developed an eruptive activity organized in cycles or stages (Ancochea, 1983, Poblete, 1993) separated by long periods of calm. At present there is a residual activity was characterized by diffuse emission of magmatic gas between predominantly CO₂ whose origin could be an important degassing of a deep magmatic body, and its arrival to the surface be related to the fracture system affecting the Paleozoic basement (Calvo *et al.*, 2010). In August 2007, and within the project VOLATMCO₂, researchers of ITER (Canary Islands), conducted a first evaluation of the diffuse emission of gases, which continued in 2008. The results highlighted the need to carry out continuous monitoring of gases that would evaluate in more detail its origin and value of emissions. To do so, within the scope of the research project entitled: Evaluation of the emission of CO₂ in the volcanic system of the Campo de Calatrava. The gas vent of La Sima, in May 2009 we proceeded with the installation, in the area that have been detected

major gaseous emissions – vents of La Sima- of a geochemistry station in continuous mode for the detection of CO₂ and H₂S. The increase in the emission of CO₂ and radon, coincident with the detection of earthquakes located in areas close to the volcanic region, has led to the signing of a cooperation agreement between the University of Castilla-La Mancha (UCLM) and the National Geographic Institute (IGN) by which it is proceeding with the installation of a seismic network to detect in the area a possible microseismicity. This will enable progress in the understanding of the current behavior of the volcanic system of the Campo de Calatrava, and its relationship to other systems belonging to the European intracontinental volcanism.

1.3-P-62

Diffuse CO₂ Emissions from Taal Volcano Main Crater, 2008-2009 Surveys

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Measurements for diffuse CO₂ emissions done in 2008 and 2009 in Taal Main Crater Lake and soil give the estimate of total output from the lake and show areas with high CO₂ flux. CO₂ fluxes were measured by accumulation chamber method on March-April 2008 and February 2009. Taal Main Crater Lake is a 1.3 km wide lake inside the largest crater (Main Crater) at the center of Taal Volcano Island. Volcano Island is composed of around 47 cones and craters that largely follow north-east-southwest and northwest-southeast trends and reflect the dominant structures in the area. In 2008, areas with high CO₂ flux anomalies, with highest value 1,831 g·m⁻²·d⁻¹, were found on the northern part of the lake. In 2009, the same high anomaly area was observed but with additional areas on the south and east of the lake following a northeast trend near the shore. Projection of this trend in anomalies to the southwest of the island connects it with northeast trending fissures in the area. Highest flux value on the lake from the 2009 survey was 2,457 g·m⁻²·d⁻¹ near the southwest shore. Total CO₂ output for the Main Crater Lake at the time of the measurements also increased from 506 ± 15 t·d⁻¹ in 2008 to 947 ± 22 t·d⁻¹ in 2009. Subsequent measurements should see if this is within seasonal variation or a significant change in the volcano's activity. Measurements of soil CO₂ degassing in the northeast thermal area in the Main Crater show a decrease in areas with high anomalies from 2008 to 2009. High thermal anomalies on the lake were found near the northeast and southwest shores, reflecting thermal areas within the Main Crater.

1.3-P-63

Protocols For UV Camera Volcanic SO₂ Measurements

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Ultraviolet camera technology offers considerable promise for enabling 1 Hz timescale acquisitions of volcanic degassing phenomena, so providing two orders of magnitude improvements on sampling frequencies from conventionally applied scanning spectrometer systems. This could, for instance enable unprecedented insights into rapid processes, such as Strombolian explosions, and scope for non aliased corroboration with volcano geophysical data. The uptake of this technology has involved disparate methodological approaches, hitherto. As a means of expediting the further proliferation of such systems, we here study these diverse protocols, with the aim of suggesting those we consider optimal. In particular we cover: choice and set up of hardware, calibration for vignetting and for absolute concentrations using quartz SO₂ cells, the retrieval algorithm and whether one or two filters, or indeed cameras, are necessary. This work also involves direct intercomparisons with narrowband observations obtained with a scanning spectrometer system, employing a differential optical absorption spectroscopic evaluation routine, as a means of methodological validation.

1.3-P-64

SO₂ emission from Mayon volcano measured simultaneously with COSPEC, FLYSPEC and mini-DOAS

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An accurate estimation of SO₂ emission rates is an important issue to elucidate the activity of volcanoes, moreover the monitoring of its temporal evolution might help to predict a possible eruption and thus, save the loss of human's lives in cities nearby volcanoes. COSPEC is being used during the last decades for remote monitoring SO₂ fluxes from active volcanoes. In the last years new instruments have been developed and improved, in order to be more portable, cheaper and lighter. Two of them are miniDOAS and FLYSPEC. These two instruments consist of a small spectrometer with a lens for collecting scattered UV light, and are controlled/powered via USB with a laptop. Between the 19th and 24th of February 2010, a comparison study among these three instruments has been performed at Mayon volcano (Philippines). The instruments were mounted aboard a road vehicle and a helicopter. The SO₂ flux obtained during this campaign, as an average of more than 100 measurements, has been of 646 tons/day. Availability of helicopter was just one day, allowing us to measure simultaneously with a miniDOAS and a FLYSPEC. Differences were found to be less than 5%. A complete comparison between these three instruments was performed aboard a road vehicle, by means of both moving and stationary measurements. For the intercomparison we used different calibration cells and

also direct measurements of the volcano plume, from the sunrise to the sunset. Results show differences between COSPEC, miniDOAS and FLYSPEC. Nevertheless, results suggest their suitability for studying the emission rate of SO₂ in the volcanic plume.

1.3-P-65

Carbon Dioxide Emission from Deception Volcano Bay, Antarctica

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Deception Island is a volcanic island located at 62°59'S and 60°41'W in the South Shetland archipelago. It constitutes a back-arc stratovolcano with a basal diameter of ~ 30 Km, rising ~ 1400 m from the seafloor to the maximum height of 540 m above sea level. The island has a horse-shoe shape with a large flooded caldera with a diameter of about 6x10 km and a maximum depth of 190m. This caldera also known as Deception Bay is open to the sea through a narrow channel of 500m at Neptune Bellows. Deception Island has suffered historical eruptions since the late 18th century, and well-known eruptions occurred in 1967, 1969 and 1970. To provide a complementary geochemical approach to the volcanic monitoring program at Deception, we have studied the diffuse CO₂ emissions from the surface environment of Deception bay. To do so, in-situ measurements of CO₂ efflux were performed by means of a modification of the accumulation chamber method consisting on a floating device. A total of 244 water CO₂ efflux measurements were performed in Deception bay in November and December, 2009. Water CO₂ efflux values ranged from non-detectable up to 120 g m⁻² d⁻¹. To quantify the total CO₂ emission from Deception Bay, a CO₂ efflux map was constructed using sequential Gaussian simulations (sGs). Most of the studied area showed background levels of water CO₂ efflux (~4 g m⁻² d⁻¹), while peak levels (>20 g m⁻² d⁻¹) were mainly identified inside the Fumarole Bay, Telefon Bay and Pendulum Cove areas, showing a close spatial correlation with the location of the seismic swarms produced by the volcanic activity of Deception. The total CO₂ emission from Deception Bay was estimated about 191 td⁻¹ ± 9 td⁻¹. This study demonstrates the importance of performing CO₂ emission surveys at the bay of Deception as an important tool to monitor the volcanic activity at this volcano of Antarctica.

1.3-P-66

Dynamics of Diffuse Carbon Dioxide Emission from Cumbre Vieja Volcano, La Palma, Canary Islands

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La Palma island (730 km²) is one of the youngest and the most active volcanic island of the Canary archipelago. Volcanic activity has concentrated on the southern part of the island in the last 1 Ma forming Cumbre Vieja volcano (220 km²). The most recent eruption in the Canary Islands occurred at Cumbre Vieja (Teneguía volcano, 1971), and other five eruptions have taken place at Cumbre Vieja in the last 500 years. Since fumarolic activity is absent at Cumbre Vieja, surface CO₂ diffuse degassing is a powerful tool to evaluate the volcanic activity. Changes in the total CO₂ diffuse and the location of its anomalous values could be related to changes in the volcanic activity. As part of the volcanic surveillance program of Cumbre Vieja, soil CO₂ efflux measurements were performed by means of a portable NDIR sensor according to the accumulation chamber method in approximately 600 sampling sites in the period 1997-2009. The total CO₂ output released to atmosphere in a diffuse way has been estimated in the range 657-2,309 t/d in the studied period. Highest CO₂ efflux values were measured in and around Teneguía volcano. The differences observed on the CO₂ outputs for the 11 surveys seem to be related to short-term meteorological variations. As part of the volcanic surveillance program of the island and to improve the knowledge of CO₂ diffuse emission dynamics in Cumbre Vieja, two automatic geochemical stations were installed at the interception centre of the main volcanic rifts (LPA02) and at the southernmost part (LPA04). Significant differences in the CO₂ efflux measured values have been observed: LPA02 has showed mainly biogenic CO₂ diffuse emission values (~3 g m⁻² d⁻¹) and LPA04 has showed more important deep contribution, with an average value of 35.4 g m⁻² d⁻¹.

1.3-P-67

Diffuse CO₂ Emission from Timanfaya Volcano, Lanzarote, Canary Islands, Spain

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Lanzarote, the easternmost island of the Canaries, is located 125 km far from the African coast, and together with Fuerteventura are the oldest islands of the Canaries. It has suffered two historical eruptions in the last 500 years: Timanfaya (1730-1736) and Tinguatón (1824), both characterized for the formation of multiple aligned cones, which covered 25% of the total surface of the island. At present, Lanzarote doesn't show any visible gas emanation, in spite of the presence of an important thermal anomaly located inside Timanfaya's National Park, with a temperature close to 100°C at few centimeters depth. For this reason, the study of CO₂ diffuse emission becomes an important tool for the volcanic surveillance program in Lanzarote. In this work we present four soil CO₂ emission surveys performed at Timanfaya volcanic field since 2006 by means of the of the accumulation chamber method covering an area of about 252 km². Interpolation maps constructed by

means of Sequential Gaussian Simulation allowed us to identify zones with anomalous CO₂ emission rates and to estimate the total CO₂ output. Diffuse CO₂ emission values have ranged between non detectable values to 34 g m⁻² d⁻¹, and most of the study area have shown relatively low values, around the detection limit of the instrument (~0,5 g m⁻² d⁻¹). Total CO₂ outputs of the study area have been estimated in the range 97-243 t d⁻¹ during the study period. As part of the volcanic surveillance program of Lanzarote and to improve the knowledge of CO₂ diffuse emission dynamics in Timanfaya, an automatic geochemical station will be deployed near future to monitoring of the CO₂ emission in a continuous mode.

1.3-P-68

Diffuse and Visible Emission of CO₂ from Etna Volcano, Italy

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This work reports the first estimation of total CO₂ emission to the atmosphere (visible and non-visible) from Etna volcano, Sicily, by means of direct methods. Until present, only direct measurements of the CO₂ emitted by the volcanic plume of Etna had been performed, and not data of direct soil CO₂ efflux from surface environment of this volcano were available. To estimate the total CO₂ emission, 4075 soil CO₂ efflux measurements were performed by means of the accumulation chamber method in October-November 2008. Most of the study area showed background levels of soil CO₂ efflux (0.53 g·m⁻²·d⁻¹), while peak values (>1725 g·m⁻²·d⁻¹) were mainly identified inside the summit craters and at Torre del Filosofo area. Other zones with relatively high CO₂ efflux values were identified at Paternó, Zafferana Etnea and Trecastagni-Viagrande. The total output of CO₂ diffuse emission from the study area (973 km²) was computed in 20320 t·d⁻¹, where 1671 t·d⁻¹, about 8.3% of CO₂ diffuse emission, was emitted by an area of 87 km² which includes the summit craters and Torre del Filosofo. To evaluate the visible/diffuse CO₂ emission ratio, plume CO₂ emission rate was estimated by multiplying SO₂ emission rate times observed CO₂/SO₂ plume ratio following the methodology described by Shinohara (2005). Total CO₂ visible emission was estimated about 31.5 kt·d⁻¹, value is in the range reported for Etna volcano (0.9-67.5 kt·d⁻¹; Aiuppa et al., 2006). The total output of CO₂ diffuse emission represents 39% of the total CO₂ emission from Etna volcano to the atmosphere. These results agree with the observations of Allard et al. (1991), who reported that diffuse and visible CO₂ emissions were in the same order of magnitude. This study demonstrates the importance of measuring diffuse CO₂ emissions from active volcanoes like Mt. Etna in order to have a better approach on the global estimate of CO₂ emission to the atmosphere from subaerial volcanoes.

1.3-P-69

Monitoring Carbon Dioxide Emission from Pinatubo Crater Lake, Philippines

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Mount Pinatubo is part of a chain of composite volcanoes along the Luzon arc on the west coast of the island. The arc of volcanoes is due to the subduction of the Manila trench to the west. The 1991 eruption, one of the world's largest of the 20th century, ejected massive amounts of tephra and produced voluminous pyroclastic flows, forming a small, 2.5-km-wide summit caldera whose floor is now covered by a lake. Caldera formation lowered the height of the summit from 1745 to 1486 m. The main objective of this study is to perform periodical surveys of diffuse CO₂ emission at the surface environment of the lake-filled Pinatubo caldera complementary to the volcanic monitoring program that PHIVOLCS is carrying out at Pinatubo. The measurements of CO₂ efflux were performed by means of a portable Non Dispersive Infrared spectrophotometer (NDIR) model LICOR Li-800, following the accumulation chamber method coupled with a floating device. Later, interpolated maps were constructed by means of Sequential Gaussian Simulation (SGS). Surveys were performed in 2008 and 2009. Diffuse CO₂ emission values ranged between non detectable values to 2465 g m⁻² d⁻¹ and 1423 g m⁻² d⁻¹ in 2008 and 2009 surveys, respectively. However, the 2009 survey showed a higher average CO₂ efflux value, 459 g m⁻² d⁻¹ with respect to 2008 survey, 366 g m⁻² d⁻¹. During 2008 survey, higher CO₂ efflux values were localized at the NE and NO zones, whereas in 2009 survey, the mean anomaly was localized mainly at the SW zone. Interpolated maps of CO₂ efflux allowed us to estimate the total CO₂ emission rate from lake-filled Pinatubo caldera lake in 711± 17 t d⁻¹ and 928 ± 19 t d⁻¹ for 2008 and 2009 surveys, respectively, showing an increasing on the CO₂ emission rate from 2008 to 2009.

1.3-P-70

Dynamics of Diffuse CO₂ Emissions at the NW Rift Zone, Tenerife, Canary Islands

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We report the results of 30 soil CO₂ efflux surveys by the accumulation chamber method at the North West Rift (NWR) Zone of Tenerife Island. The surveys were carried out from 2000 to 2006 to evaluate the temporal and spatial variations of CO₂ efflux and their relationships with the volcanic-seismic activity at Tenerife. Conditional sequential Gaussian simulations were applied to estimate the total CO₂ output from the studied area at the NWR Zone. Total CO₂ emission rates ranged between

52 and 867 t d⁻¹. Temporal variations in the total CO₂ output do not seem to be masked by external variations, showing a temporal correlation with the onsets of seismic activity. These geochemical observations support unrest of the volcanic system, as is also suggested by anomalous seismic activity recorded in the area during April 22-29, 2004, by the National Spanish Seismic Network operated by the National Geographical Institute of Spain. Spatial distribution of soil CO₂ efflux values also showed changes in magnitude and amplitude, and the higher CO₂ efflux values were commonly located along an elongated area trending WNW-ESE. Subsurface magma movement is proposed as a cause for the observed changes in the total output of diffuse CO₂ emission, as well as for the spatial distribution of soil CO₂ efflux. Geophysical observations such as seismicity patterns also support this hypothesis. Since the observed surface geochemical anomalies are spatially well correlated with major structural features of the study area, a magma driven fracture in the NWR Zone of Tenerife during April-May 2004 could explain the volcanic unrest at Tenerife. The increasing trend of total CO₂ output suggests increasing pressurization of the volcanic-hydrothermal system; a mechanism capable triggering dyke intrusion in the near future along the NWR Zone of Tenerife.

1.3-P-71

An Increasing Trend of the Diffuse CO₂ Emission from Teide Volcano (Tenerife, Canary Islands): A Preliminary Geochemical Signature of Volcanic Activity Changes at Tenerife?

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We report the results of 11 soil CO₂ efflux surveys at the summit cone of Teide volcano (SCT), Tenerife. The surveys were undertaken from 1997 to 2009 to determine the scale of total CO₂ emissions at the SCT and to evaluate the temporal variations of CO₂ efflux and their relationships with the volcanic-seismic activity. Our results reveal significant fluctuations, which do not seem to be masked by external variations, standing out from the rest the ones measured in 2001, and the increasing trend observed from 2007 to 2009, both having similar shapes, intensities, and emission rates. The significant pulse observed in total CO₂ emission in 2001 provided the first geochemical observation supporting unrest of the volcanic system, as it was addressed later by anomalous seismic activity recorded in Tenerife Island during April 22-29, 2004 (IGN). The new increasing trend observed from 2007, might be precursor of new anomalous volcanic-seismic activity in the next future, suggesting that subsurface magma movement is the cause for the observed changes in the total output of diffuse CO₂ emission at SCT.

1.3-P-72

Soil CO₂ Efflux Monitoring at Izu-Oshima Volcano, Japan

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Izu-Oshima is a 15x9 km active volcanic island located around 100 km SSW of Tokyo. The centre of the island is occupied by a caldera complex with a diameter of 3 km. A large post-caldera cone known as Mt. Mihara is located at the southwestern quadrant of the caldera. Izu-Oshima has erupted 74 times, consisting mainly in fissure eruptions, both inside and outside of the caldera. The last eruption of Izu-Oshima occurred in 1986. In March 2007, a quantitative study of the diffuse CO₂ degassing at Izu-Oshima was carried out to quantify the total diffuse CO₂ emission from both the entire island (91 Km²) and the central caldera, and to identify those structures controlling the degassing process. The survey of diffuse CO₂ emission was carried out following the accumulation chamber method. The location of the CO₂ anomalies showed a close relationship with the structural characteristics of the volcano, with most of the gas discharged from the rim of the summit crater and the fissures of the 1986 eruption out of the caldera. As part of the volcanic surveillance program of the island and to improve the knowledge of CO₂ and H₂S diffuse emission dynamics in Izu-Oshima, an automatic geochemical station was installed in March 25, 2008 inside summit crater of Mt. Mihara. Soil CO₂ and H₂S efflux and several meteorological and soil physical variables have been measured in an hourly basis until present. Soil CO₂ efflux ranged from non detectable values up to 94.5 g m⁻² d⁻¹, whereas soil H₂S has been not always detected reaching efflux values up to 14 mg m⁻² d⁻¹. Soil CO₂ efflux time series has shown a stable behaviour with variations due to external variables (environmental parameters).

1.3-P-73

Dynamics of diffuse CO₂ emission and eruptive cycle at Cerro Negro volcano, Nicaragua

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Cerro Negro is a basaltic cinder cone belonging to the active Central American Volcanic Belt, which includes a 1,100 Km long chain of 41 active volcanoes from Guatemala to Panama. Cerro Negro first erupted in 1850 and has experienced 21 eruptive eruptions with inter eruptive average periods between 7 and 9 years. With the objective to monitor the diffuse emission of CO₂ and

evaluate the relationship with the eruptive cycle, ten soil CO₂ emission surveys has been performed in Cerro Negro by means of the accumulation chamber method since the last eruption in 1999, covering an area of 0,6 km². Soil CO₂ efflux distribution maps were constructed following a Sequential Gaussian Simulation in order to distinguish areas with anomalous CO₂ emission rates and to compute the total CO₂ emission from the studied area. Cerro Negro showed high CO₂ efflux values at the south of 1995 eruption crater and adding at the north of 1992 crater also in the 1999 survey. Total diffuse CO₂ output estimated in 1999 was 1.860 t d⁻¹, three months after the occurrence of the last eruption. However in the inter-eruptive phase, total diffuse CO₂ output decreased progressively to background values of 10 t d⁻¹ in March 2008, except a small increment in 2004, to 256 t d⁻¹, associated with an anomalous seismic activity. During the last two surveys, an increasing on the total CO₂ emission has been observed, from December 2008 to March 2009, with total diffuse CO₂ output estimates of 12 t d⁻¹ and 38 t d⁻¹, respectively. These temporal variations show a close relationship between diffuse CO₂ emission and the eruptive cycle at Cerro Negro. This relationship indicates that monitoring CO₂ emission is a important geochemical tool for the volcanic surveillance at Cerro Negro.

1.3-P-74

Open Path-Tunable Diode Laser Measurement For Determination Of Gases In Volcanic Application

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Measurement systems, based on TDLs and working in the near IR, can be used for the determination of volcanic gases by their optical absorption. In this paper the basic principle and applications of TDL-measurement systems are described, which work in the so-called open-path configuration. They have the advantage, that volcanic gases can be detected on measurement paths from about 10 m up to 1000 m without grab sampling. Further advantages are: High sensitivity, high specificity with negligible interference to other gases, fast measurement response (about 1s), portable measurement systems with low power consumption. In this paper various volcanic applications for the TDL-measurements of CO₂ and H₂S are described. Examples are:

Investigations of the CO₂ and H₂S emissions of the Volcano Teide (Tenerife) and Fogo (Cape Verde Islands) concerning single fumaroles, crater, and cone slopes.

Measurements of diffuse degassing of CO₂ and H₂S and optical fence measurements in the Quaternary Volcanic Province of Central Italy at Cava dei Selci, Solfatara, Caldara di Manziara, Vejano and Mola di Oriolo.

Measurements of diffuse degassing of CO₂ and H₂S on Volcano (crater, open mud pool).

Measurement of the CO₂/H₂S ratio at Fumarole Bay, Deception Island (Antarctica).

1.3-P-75

Tilt and GPS Data Patterns During Tungurahua's Eruptive Process, 2006-2010

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Tiltmeter data has been fundamental to help ascertain magma movements prior to important eruptions of Tungurahua. The VEI 3 and 2 pyroclastic flow-forming eruptions of 2006 were preceded by accelerated inflationary trends several weeks prior to these eruptions. Similarly another strong inflationary period in late 2007 led to a VEI 2 eruption in early February, 2008. Installation of 3 continuous telemetered GPS_i has permitted cross checking with tilt data to corroborate results. Subtle inflationary trends registered by both systems suggested that the early 2010 reactivation of Tungurahua would involve relatively smaller volumes of magma compared to what had been expelled during previous periods. Modeling of pressure changes and volumes of the source using both tilt and GPS data, results in magma volumes that are coherent with the approximate volume of ash fall during January and February, 2010 (2.8 million M3).

1.3-P-76

Development of a New Metodology for the Surveillance and Monitoring of Atmospheric Pollutants Sources.

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The new technology developed for monitoring natural and anthropogenic emission sources is based on the integration of the different areas of knowledge involved in the surveillance of atmospheric pollutants: Instrumental Technology, Software Engineering, Meteorology and Air Pollution Dynamics. The CEAM Foundation have integrate all these areas of knowledge in a coupled system capable of measuring and tracking the temporal evolution of three-dimensional dispersive conditions of pollutants on very complex terrain under a wide range of meteorological conditions.

The availability of measurements aloft obtained by means of a remote sensor (COSPEC, Millán et al. 1978) enabled us to make a direct comparison between the experimental dispersion parameters and the simulated ones (Palau et al. 2006). This represents a clear advantage over the information provided by the fixed ground-level monitoring stations for atmospheric pollutant control. Ground-level pollutant concentrations on complex terrain present high spatial and temporal variability that is difficult to simulate and compare directly with fixed ground-level measurements and new ways of interpretation and assessment of air quality on complex terrain must be looked for.

The new technology developed has been success-

fully applied to different air pollution scenarios (or case studies) as, for example, the Etna Volcano (DORSIVA experimental campaign) and the NO₂-plume around Valencia city. The integration of the improved remote sensing experimental data with validated numerical systems can give a complementary view for the interpretation of meso-meteorological processes and for the monitoring and surveillance of air pollutants on complex-terrain regions.

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Palau, J.L.; Pérez-Landa, G.; Meliá, J.; Segarra, D.; Millán, M.M. (2006) A study of dispersion in complex terrain under winter conditions using high-resolution mesoscale and Lagrangian particle models. *Atmospheric Chemistry and Physics*, 6, 1105- 1134.

1.3-P-77

150 Years of Seismological Monitoring of Mount Vesuvius (Italy).

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Mt. Vesuvius (southern Italy) is one of the volcanoes with the greatest risk in the World because of its highly explosive eruptive style and its proximity to densely populated areas. The urbanization around Mt. Vesuvius began in ancient times and the impact of eruptions on human activities has been very hard. This is testified by the ruins of Pompeii, which are covered by the products of the plinian eruption that took place in 79 AD (Sigurdsson et al., 1985), and more recently by the chronicles of the eruptions that occurred from 1631 to 1944. For these reasons, Mt. Vesuvius was also one of the first volcanoes to be equipped with monitoring instruments. Pioneering instrumental observations began just before the second half of the 1800s, when the Vesuvius Observatory was founded, in 1841 (Imbò, 1949). At that time, Vesuvius was very active, and its effusive and explosive eruptions often caused damage to the surrounding areas. At the same time, it was a famous tourist attraction and drew travelers from all over the world (Gasparini and Musella, 1991). Since the middle of the nineteenth century, at least 12 eruptions have occurred that have been superimposed on persistent intra-crater activity characterized by Strombolian explosions and by the formation of small lava lakes. The last eruption occurred on 18 March, 1944, and marked a change in the status of Mt. Vesuvius, as it entered a closed conduit phase, which persists today. Following this last eruption, a change occurred in the 1960s, as documented by an increase in the occurrence rate of earthquakes. Since 1972, the monitoring of Mt. Vesuvius has become more systematic and has improved over time, so that there is a remarkable dataset relating to the current phase of quiescence.

1.3-P-78

Temporal Evolution of Diffuse CO₂ Emission from the Summit Crater of Fogo Volcano, Cape Verde

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Fogo is the most prominent and active stratovolcano of the Cape Verde archipelago and has a high probability of hosting a future eruption. In 1999, a volcanic monitoring program started, focusing mainly on the diffuse CO₂ emissions from Fogo's summit crater. Since then, soil gas surveys have been undertaken at the summit crater of Fogo to evaluate the temporal and spatial variations of CO₂ efflux and their relationships with the volcanic activity. Soil CO₂ efflux and soil temperature have been measured at 35-65 sites homogeneously distributed covering an area of about 0.12 km² inside the summit crater of Fogo. Soil CO₂ efflux measurements are performed following the accumulation chamber method. Based on the Sequential Gaussian Simulation (sGs) algorithms, CO₂ efflux distribution maps are construed to evaluate the spatial evolution of the diffuse soil CO₂ emission and to estimate the total CO₂ output from the summit crater. The 1999 survey was performed just 4 years after the last eruption at Fogo (April 1995), with an estimated total CO₂ emission rate of 918 ± 409 t·d⁻¹. A drastic decrease in the CO₂ emission rate was observed in the following survey performed in 2007, eight years after the first one, with a total CO₂ emission of 56 ± 15 t·d⁻¹. This value and the estimated for 2008 and 2009 (39 ± 9 and 258 ± 74 t·d⁻¹, respectively) are much lower than the observed in 1999. This observed decreasing trend on diffuse CO₂ emission from the summit crater of Fogo seems to be related to its eruptive cycle. Following the evolutionary model of gas release from volcanoes described by Notsu et al., 2006, Fogo seems to be at present within a post-eruptive phase. Evolution in the magma degasification processes from deep sources can explain the observed temporal change in the diffuse CO₂ emission. Monitoring this geochemical parameter will be tremendously beneficial for Fogo volcanic surveillance program.

1.3-P-79

Strengthening the Seismic-Volcanic Surveillance Program of Teide-Pico Viejo Dormant Volcano through Geochemical Characterization of Las Cañadas Aquifer.

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Teide-Pico Viejo Volcanic Complex located at the central and most elevated area of Tenerife Island (2,037 km²) is actually a relatively young volcano. At least a sub-plinian eruption (VEI ~ 4) have occurred in the last 2,000 years (Ablay et al, 1995) and since Chahorra eruption (VEI ~ 3) on 1798 DC, the last volcanic eruption at Teide-Pico Viejo, it has been dormant, displaying only weak and low temperature fumaroles at the summit cone. Nevertheless, any new unrest at Tenerife Island (~ 1 million inhabitants and ~ 3-4 million tourists visiting each year) may produce issues for the safety of this dense population. The geochemical survey of groundwaters is one approach that can provide useful information to strengthen the geochemical seismic-volcanic surveillance program of a dormant volcano such as Teide-Pico Viejo Volcanic Complex (Federico et al., 2004). In this work, we report the results of the geochemical characterization of dissolved gases (N₂, O₂, Ar, CO₂, CH₄, CO, H₂, He, ²²²Rn) in 96 groundwaters sampled at Las Cañadas aquifer (around the Teide-Pico Viejo volcano) between May and October, 2006. There are several aims for this work: (1) to determine the background level of magmatic gas input in the aquifer during quiescent periods, (2) to better define the origin of dissolved gases in Las Cañadas aquifer, specially CO₂, and (3) to delineate high permeable pathway of upward migration of volcanic-hydrothermal gases. Dissolved gases in most groundwater analyzed are variable mixtures of CO₂-rich fluids from the volcanic-hydrothermal system (as represent the Teide fumaroles) with dissolved air. Spatial distribution maps show anomalous concentration of ²²²Rn, CH₄, H₂ and CO₂ dissolved in groundwater at the westernmost area of Las Cañadas aquifer, which is in good spatial correlation with geophysical and geochemical anomalies related to 2004-2005 seismic-volcanic unrest at Tenerife Island (e.g. Pérez et al., 2007). References: Ablay et al., 1995, BV; Federico et al., 2004, JVGR; Pérez et al., 2007, PAGEOPH.

1.3-P-80

TDL, UV-DOAS, COSPEC and miniDOAS measurements of the degassing from the summit crater of Teide volcano, Tenerife, Canary Islands

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Recent analysis of Teide fumaroles gas revealed the presence of SO₂ content in the volcanic-hydrothermal discharges from the summit crater while his geochemical observation was not reported in the past. For to investigate SO₂ emission rates from the summit crater of Teide volcano, COSPEC and miniDOAS measurements were performed in a stationary mode on June, 2005 but the obtained results indicated that SO₂ emission rates from the summit crater of Teide volcano were lower than the detection limit. TDL and UV-DOAS were used at

Teide volcano in September, 2005 and August, 2006 for remote measurements of chemical composition of the crater atmosphere. Parallel to these measurements a CO₂ diffuse flux emission campaign was performed inside the crater containing 140 points and also samples were taken of fumaroles. The concentrations obtained by remote sensing systems were used to calculate the CO₂/H₂S and CO₂/SO₂ ratios in the crater atmosphere of Teide volcano. These molar ratios calculated were 1200 for CO₂/H₂S and 150E+03 for CO₂/SO₂ during September, 2005 and 920 and 42E+03 in the same order for August, 2006. During this study, a maximum total output emission, diffuse and visible, of SO₂ was estimated in 1.87 Kg·day⁻¹ for the Teide's summit crater. These geochemical observations about the low rates of emission of SO₂, not support at present the reawakening of Teide volcano as others scientists have described.

Session 1.4

1.4-O-01

Modelling Of The Long-range Transport Of Volcanic SO₂ And Ash Plumes Utilising Space-based Measurements

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Volcanic eruptions are among the main natural hazards, which influence nature, human beings and climate and may affect air traffic. Within the project Exupéry (development of a fast response system for volcanic unrest) SO₂ total columns are retrieved with the GOME-2 instrument on MetOp satellite in near-real time and with a global coverage in about one day. SO₂ is a good indicator for volcanic unrest and activity and is often used as a marker for volcanic ash transport. By means of a backward trajectory ensemble matching technique relevant parameters (emission location, time and height) are estimated. Using these parameters as a first guess for the source-receptor relationship, the Lagrangian particle dispersion model FLEXPART is initialised and the long-range transport of volcanic SO₂ for several days can then be derived. For an investigation of modelled removal processes case studies with an inert SO₂ tracer as well as for different SO₂ deposition rates are carried out. The results have been compared to space-based observations from IASI and AIRS, to ground-based measurements as well as to the results of an Eulerian chemical transport model using the same source term is shown. Because the satellite-based observation of ash particles is complicated and ambiguous, SO₂ is often used as an indicator of volcanic ash dispersion for early warning purposes. In order to investigate this approach the results of a comparison between SO₂ transport and ash observations from MODIS and IASI are shown for recent eruptions, such as the eruption of Kasatochi volcano in Alaska in August 2008. The retrieval of a first ash indicator from IASI is based on a principle compo-

ment analysis (PCA). For the derivation of the ash cloud out of MODIS the Brightness Temperature Differences (BTD) between 11 μ m and 12 μ m bands are used.

1.4-O-02

High Resolution Radar Monitoring of Soufriere Hills Volcano, Montserrat with TerraSAR-X

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Since July 2008 we have used the Spotlight mode of the TerraSAR-X radar to image the Soufriere Hills Volcano on Montserrat at high temporal and spatial resolutions (11 days, ~ 2m). The activity of the volcano during this period included the explosion of 28 July 2008 and minor extrusion in August 2008, vigorous lava dome growth and explosions during December 2008-January 2009 and dome growth and partial dome collapse during October 2009 to February 2010. Change differences in the amplitude images allowed the extent of new pyroclastic flow deposits to be mapped. Typically the valley-floor block-and-ash deposits would have a "rougher" signal and the flanking surge deposits a "smoother" signal. Some of the valleys during this period were infilled by deposits up to 100 m deep. In places radar shadowing could be used to calculate the depths of infill. Explosion/collapse craters on the lava dome could also be identified, but the rapidly changing topography precluded correction of radar distortion and accurate mapping. Topographic mapping using InSAR was also possible on the lower slopes not affected by new deposits during the measurement interval and during periods when there was no volcanic activity.

1.4-O-03

Analysis of Teide Volcano Deformation Using Persistent Scatterers Interferometry With Ascending-Descending ENVISAT ASAR Images.

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Teide is an active stratovolcano located in the centre of Tenerife Island (Canary Islands) where a scientific debate is currently open about the significance of some geological and topographic structures in terms of volcano deformation and potential gravitational instability. In addition, a recent study using the advance Differential Interferometry of SAR images (DInSAR) technique of Small Baseline Subset (SBAS) has shown that the whole

central Tenerife is characterized by a rather continuous subsidence, interpreted as a result of the gravitational sinking of the dense core of the island. However, the detailed evolution of deformation in the summit area of the volcano has not still been analysed in detail integrating geodetic and geological data. For this reason in this work we use the Stable Point Network technique (SPN), the Altamira Information's Persistent Scatterers Interferometry (PSI) technique, to process both ascending and descending 63 Envisat ASAR images of the volcano obtained since 2003 to 2009. We have gathered the results into a GIS together with relevant information for their interpretation, such as geology or detailed aerial orthophotos and DEMs, and environmental information such as snow extent in winter scenes which strongly influence the coherence of SAR image dataset. Based on the obtained results, we present a complete map of the absolute actual deformation of the Teide volcano integrating the PSI observations with field geological data and discuss the implications in terms of volcano deformation and instability.

1.4-O-04

Probing Volcanic Clouds With The A-Train

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Volcanic eruptions and degassing inject gases and particles into the Earth's atmosphere, creating hazardous conditions for aircraft, degrading air quality and visibility, and leading to potential climate effects. Due to the transient nature of volcanic clouds and the difficulty of in-situ measurements, their complex physico-chemical environment remains poorly understood. Yet, such knowledge is critical for assessments of volcanic cloud hazards, prediction of climate and air quality impacts, and validation of plume models. NASA's A-Train polar-orbiting satellite constellation, including the Aura, CALIPSO, CloudSat and Aqua spacecraft, offers near-coincident, multi-spectral passive and active measurements that are providing unprecedented insight into the structure and composition of volcanic clouds and plumes. A-Train data include total column sulfur dioxide (SO₂) from Aura/OMI, Aqua/AIRS and Aqua/MODIS; stratospheric SO₂ and hydrogen chloride (HCl) columns from Aura/MLS; stratospheric and tropospheric SO₂ profiles from Aura/MLS and Aura/TES; profiles of aerosol optical depth and depolarization from the CALIPSO lidar; and hydrometeor profiles and microphysical properties from the CloudSat radar. The advent of space-borne lidar and radar observations from CALIPSO and CloudSat is an important advance for studies of explosive volcanism. Lidar data provide vertical profiles through aerosol-laden volcanic clouds, revealing internal structure and providing direct measurements of plume-top altitude, a key parameter when assessing eruption mass flux. Radar data provide information on coarser particles and hydrometeors in fresh volcanic plumes. Such measurements offer improved parameterization and validation for models of eruption dynamics and plume dispersion. Major explosive eruptions of Chaitén (Chile), Okmok (Aleutian Islands), Kasatochi (Aleutian Islands), Redoubt

(Alaska), and Sarychev Peak (Kurile Islands) in 2008-2009 have provided numerous opportunities to explore the potential of A-Train data for volcanological studies. This presentation will focus on the use of A-Train data to capture the first few hours of eruption plume development following explosive eruptions.

1.4-O-05

SBAS-DInSAR Investigation of the Displacement Field at Nyamuragira and Nyiragongo Volcanoes in Congo.

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Nyamuragira and Nyiragongo are neighbouring volcanoes in the Democratic Republic of the Congo (DRC), and are amongst the most active and dangerous in the world. They are located within the Western branch of the East African Rift, and are the western-most active volcanoes of the Virunga Mountains. The volcanism of the area is characterized by effusion of basic magmas, which are mostly erupted by flank fissures and cinder cones, and less frequently by the summit calderas.

In order to follow the temporal evolution of the deformation affecting the investigated area, the Small Baseline Subset (SBAS) algorithm has successfully been applied. The obtained time series measure the projection of the occurred ground deformation along the radar line-of-sight (LOS), and are obtained by processing a sequence of small baseline differential interferograms. The results have been obtained by processing a set of 43 SAR images acquired by the ASAR sensor on-board the ENVISAT satellite (swath IS2) on descending orbits (Track: 35, Frame: 3637) from January 2003 to November 2009. Following the identification of a proper set of small perpendicular (250 m) and temporal (800 days) baseline DInSAR interferograms, 117 differential interferograms has been selected and subsequently combined to generate deformation time series.

The resulting mean deformation velocity map and a number of displacement time series, associated with some particularly relevant points, are presented and discussed.

This study confirms the effectiveness of such techniques in the comprehension of volcano deformation dynamics, especially for areas where no (or limited) alternative measurements are possible and/or available

1.4-O-06

Strombolian Activity Analysis Using Multi and Hyperspectral Remote Sensing Data

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In the framework of the 'V2-Paroxysm' project funded by the Italian Civil Protection (DPC-INGV 2007-2009) satellite data time series on Stromboli volcano have been acquired and processed. Stromboli is located in the Aeolian Islands (Italy) and represents one of the most active volcanic islands on Earth. The typical activity is characterized by regular explosions emitting small volumes of lava spatter and pyroclasts up to 50–100 m above the craters every 15–20 min. Strombolian typical explosions are occasionally interrupted by major explosions, paroxysmal events, effusive activity and landslides. Data acquired from medium spatial resolution sensor ASTER on board of Terra satellite, and Hyperion on board of EO-1 satellite, have been treated in order to characterize the volcanic emissions in the atmosphere in terms of particles and gas composition. In particular, already developed remote sensing techniques have been used to derive both maps of aerosol optical depth, and SO₂ and CO₂ concentration.

Moreover, since 2006 Stromboli volcano has been regularly monitored using low spatial resolution and high frequency AVHRR data acquired in real-time from NOAA satellite, the procedure and results will be presented. The data set collected during the latest 5 years has been used to analyze evidences of changes in term of thermal anomalies that have been correlated with the anomalous events such as effusive activity and paroxysm.

1.4-P-01

Interplay of deformation sources at Hawaii Island investigated through InSAR time series and time-dependent modeling

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Volcanoes are known to closely interact with the tectonic environment. For instance they may be controlled by active regional-tectonic faults and erupt after earthquakes. Similarly, adjacent volcanoes interact with each other in time and space, as suggested for the Hawaiian volcanoes Kilauea and Mauna Loa. As shown herein by new satellite radar data, this interplay on Hawaii is even more complex than previously thought. It involves magma chamber pressure changes, dike intrusions, slow earthquakes and ground subsidence. The affected regions are the Mauna Loa and Kilauea volcano summits, their active rift zones, the island's unstable southeast flank and even the city of Hilo. Using data acquired by the European satellite ENVISAT, we present a five-year spatiotemporal InSAR analysis of the deformation signals recorded between 2003 and 2008. The data suggest that most of the deformation sources are acting in chorus. Magma intrusions at the Mauna Loa chamber and the intrusions into the Kilauea rift are correlated in time, and they also change with gravity-driven flank movement events. Some of the events occur silently underneath the Kilauea south flank, such as slow earthquakes that may largely affect all of the active magmatic systems and reverse their sign of correlation. This study of the interplay between multiple deformations shows that the sources are correlated, providing a better understanding of Hawaiian volcano activity. It may also lead to new methods for assessing the hazards that

arise during volcano-tectonic activities elsewhere.

1.4-P-02

Mt. Etna 2008-2009 Eruption: A Model From The Integration Of Satellite GPS And DInSAR Data.

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GPS and DInSAR data collected from 2007 to 2008 are analyzed in order to define the dynamics preceding and accompanying the onset of the 2008 Mt. Etna eruption. The first GPS survey was carried out in June 2007 on the entire Mt. Etna network. During the first months of 2008, before the eruption onset, three surveys on part of this network were carried out. Immediately after the beginning of the eruption, on May 13 2008, other GPS measurements were carried out on the north-eastern part of the network. The last survey was carried out in June 2008 on the entire network. Envisat interferograms cover similar time windows spanning from 2007 to 2008. Ground deformation patterns show a slight inflation of the volcano in the pre-eruptive long-term comparisons. The emplacement of the dyke has been imaged by three Envisat pairs, and by two GPS surveys. We apply the SISTEM (Simultaneous and Integrated Strain Tensor Estimation from geodetic and satellite deformation Measurements) method to integrate GPS and DInSAR data. The SISTEM method computes 3D displacements map on each point of the studied area and, provides the complete 3D strain and the rigid body rotation tensors. The results of the integration highlighted strong displacements localized on the summit area, quickly decreasing towards the middle flanks of the volcano. A preliminary analysis of DInSAR data, covering also a post-intrusion period, suggests the presence of a depressurizing source localized beneath the upper south-western area. This pattern seems to be confirmed by the displacements by GPS stations on the uppermost part of the volcano. In order to image the geometry of the feeding system of the volcano during the months preceding and accompanying the onset of the eruption, data inversions were also performed by a genetic Algorithm searching for an planar dislocation using the Okada model.

1.4-P-03

A Remotely Sensed System for Lava Flow Hazard Assessment.

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We developed a GIS-integrated system for lava flow hazard assessment. The alert system consists of three components: (i) detection of volcano hot spots, (ii) esti-

mation of time average discharge rates, and (iii) prediction of lava flow paths. The first two components are applied to near-real-time infrared satellite data acquired by MODIS and SEVIRI sensors. The last component uses satellite-derived estimates of lava eruption rates to drive numerical simulations of lava flow paths. We used MAGFLOW cellular automata model to chart the spread of lava flows as a function of time. We applied our system on Etna volcano during the entire time of effusive eruption began on 13 May 2008 and terminated on 6 July 2009. Daily MODIS data combined with field reports were most useful for recording a detailed time-series of the volcanic activity. As a further discussion, the advantage obtained by the use of SEVIRI data in increasing temporal coverage improving satellite monitoring of active volcanoes was analyzed. The use of MAGFLOW model for forecasting lava flow inundation provided a mean for assessing the hazard posed during the ongoing eruptive event.

1.4-P-04

The Regular Stratovolcano Shape based on SRTM DEM Morphometry: Implications to Eruptive Behaviour

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We studied the shape of the most regular-shaped stratovolcanoes of the world to mathematically define the form of the ideal stratovolcano. Based on the Shuttle Radar Topographic Mission (SRTM) 90 m-resolution DEM data, we selected the 20 most circular and symmetrical volcanoes, which all belong to subduction-related arcs surrounding the Pacific. The selection of the volcanoes benefits from the introduction of a new definition of circularity, which is more robust than previous definitions, being independent of the erosional dissection of the cone. Our study is based on the analysis of the radial elevation profiles of each volcano. The lower half section of the volcanoes is always well fitted by a logarithmic curve, while the upper half section is not, and falls into two groups: it is fitted either by a line ("C-type", conical upper part) or by a parabolic arc ("P-type", parabolic/concave upper part). Chemical composition of the two groups' eruptive products indicates higher SiO₂ and/or higher H₂O content for C-type volcanoes, which could imply a higher incidence of mildly explosive (e.g. Strombolian) eruptions. We propose that this higher explosivity is responsible for forming the constant uppermost slopes by the deposition of ballistic tephra and its subsequent stabilisation at a constant angle. In contrast, P-type volcanoes are characterized by a smaller SiO₂ and H₂O content, which can be responsible for a higher incidence of effusive events and/or a lower incidence of upper flank-forming (i.e. mild) explosive eruptions. Therefore, the concave upper flanks of these volcanoes may be shaped prevalently by lava flows. We suggest that such a distinction between stratovolcanoes provide insights into their dominant eruptive style as well

as their future eruptive behaviour: C-type volcanoes are expected to produce more frequent mildly explosive eruptions, and vice versa.

1.4-P-05

InSAR Displacements Associated with The November 2006 and January 2010 Nyamulagira Eruptions

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The basaltic shield volcano of Nyamulagira (Democratic Republic of Congo), located in the western branch of the East African rift, is Africa's most active volcano with an average of an eruption every other year. In November 2006, an unusual eruption took place on the South Eastern Flank of Nyamulagira from a fissure located halfway between Nyamulagira and Nyiragongo. A lava flow was reported extending southward toward the inhabited areas of Lake Kivu and the main supply road for Goma.

Because of the political situation and the bad weather condition at the time of the eruption, no field data indicate the precise location of the eruptive fissure. This eruption was covered by ENVISAT interferograms from four different view angles, three from ascending orbits and one from a descending orbit. The interferogram from the descending orbits had the most favorable spatial and temporal baselines and showed a signal over a 200 km² area East, North and South of the presumed eruptive fissure. The interferograms from ascending orbits showed displacements over 25 km² areas North and East of the fissures.

The interferograms were analyzed using a method that combines a 3D numerical modeling for elastic medium with a near neighborhood inversion algorithm.

Preliminary results show that two sources are needed to explain the measured displacements. One of the sources corresponds to a dike located between Nyamulagira and Nyiragongo, which is aligned with the axis linking the two volcanoes. The other source, which is responsible for displacements measured North of Nyamulagira, still needs to be determined. As displacements created by both sources are close in space and time, these two sources should be determined simultaneously. The preliminary modeling results for the 2010 eruption show that the same kind of processes occurred, even if the InSAR displacements are much less extended than in 2006.

1.4-P-06

Study of the Nyiragongo – Nyamulagira Area (Dem. Rep. of Congo) by Means of Multi-Temporal InSAR Approaches: Comparison of the Stamps (TU Delft) and SBAS (IREA) Methods.

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Nyamulagira and Nyiragongo are two active volcanoes located in the western branch of the East African Rift (Virunga Volcanic Province, North Kivu, Dem. Rep. of Congo). At these latitudes, the dense equatorial vegetation induces rapid decorrelation that hampers the use of conventional radar interferometry (InSAR) for ground deformation monitoring over most of the area, except on bare lava flows. One way (at least partly) to overcome the vegetation-induced decorrelation is to increase the number of SAR acquisitions. This increases the chances of producing interferograms with favorable small temporal and spatial baselines, and allows identification of pixels that remain coherent. After five years of such a systematic data acquisition, we have now at our disposal about fifty scenes in different track, swaths and modes of ENVISAT SAR data.

The poster presents the first results of multi-temporal InSAR methods applied in the Virunga Volcanic Province. Two methods are tested and compared: the small baseline (SBAS) method developed at IREA and the "StaMPS" method that combines a small baseline and persistent scatterer (PS) approach.

Both techniques show similar results (lava compaction of the Nyamulagira old lava flows and inside the crater as well as some co-eruptive deformations). The number of pixels selected with the small baseline approach of both methods is much larger than the number of pixels selected by the PS approach, although there are some pixels that are only selected with the latter technique.

Many coherent pixels were also detected outside the rift valley although no significant displacements could be identified away from the escarpments.

1.4-P-07

The Combined Use of Multispectral and Radar Satellite Images to Map the Lava Flow Field of Nyamulagira (North Kivu, D.R.C.).

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Nyamulagira (3058m a.s.l.) is an active shield volcano located at the western edge of the Virunga Volcanic Province (VVP), in the western branch of the East African Rift. It is also Africa's most active volcano with one eruption every 2-4 years. The Nyamulagira lava field covers ~1150 km² and is composed by long lava flows often reaching tens of kilometers. Despite this intense activity, Nyamulagira remains poorly studied and the only existing volcanological map was produced in the 1960's by Thonnard et al. (1965). The high frequency of eruptive events makes any lava flow map quickly obsolete. In this work, we mapped the Nyamulagira lava flows from 1938 to 2010 using optical images (Landsat, ASTER) as well as amplitude and coherence images derived from radar imagery (ENVISAT-ASAR, ERS, JERS). Integrated in a GIS database with additional data (e.g. eruptive fractures, topography, land use, etc.), we produced a flexible and easy-to-update map, which has already proven to be of a great help during the management of the latest Nyamulagira eruption (2nd-27th January 2010). Reference: Thonnard, R.L.G., Denaeyer, N.E., Antun, P., 1965. Carte volcanologique des Virunga (Afrique centrale), feuille n°1, 1:50,000. Centre National de Volcanologie (Belgium), Publication n°32.

1.4-P-08

MISR Observations of Etna Volcanic Plumes

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In the last ten years, Mt. Etna, located in eastern Sicily, has produced a great number of explosive eruptions. Volcanic plumes have risen to several km above sea level causing problems for aviation and for the surrounding communities. A reduction of risks may be accomplished using remote sensing techniques to evaluate important features of volcanic plumes. These techniques allow the retrieval of column heights and plume extents. Since 2000, the Multi-angle Imaging SpectroRadiometer (MISR) on board NASA's Terra spacecraft has been extensively used to study aerosol dispersal and to extract the three dimensional structure of plumes coming from anthropogenic or natural sources, including volcanoes. In the present work, MISR data from several explosive events occurring at Mt. Etna were analyzed using a program named MINX (MISR INTERactive eXplorer). MINX uses stereo matching techniques to evaluate the height of the volcanic aerosol with a precision of a few hundred meters. We analyzed about twenty volcanic plumes produced during the 2000, 2001, 2002-03 and 2006 Etna eruptions, evaluated the column heights, and constructed three-dimensional images when data allowed. These eruptions were in fact a good target for MISR thanks to the prolonged activity of Etna that continuously ejected volcanic aerosols for periods of several hours to months. Results obtained by this analysis are compared with observations collected during the moni-

toring activities of INGV in Catania. Finally, the potential of MISR to detect important characteristics of volcanic plumes as well as to correctly address tephra dispersal modeling is demonstrated.

1.4-P-09

Retrieval of Explosive Activity from MODIS Sensor at Stromboli Volcano

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Satellite remote sensing is a convenient way to monitor the changes of Stromboli thermal energy, such as MODIS (Moderate Resolution Imaging Spectroradiometer) which is a NASA's flagship sensor system with 36 spectral bands in the visible and infrared region of the spectrum (0.4–14.4 μm). Stromboli daily thermal radiation has been estimated through an accurate analysis of a wide dataset (more than 4700 night and day-time MODIS granules) acquired over Southern Tyrrhenian Sea during a period spanning between 1 January 2006 and 1 October 2008, time lapse characterized by low, middle and high Strombolian activity. MODIS images have been analyzed by using an automatic computer-based approach that allowed us to discriminate with accuracy the pixels contaminated by hot material. In particular, the observations made on Radiance Flux time series indicate that the typical and persistent activity of Stromboli has been characterized by an average of 0.08 W m⁻² sr⁻¹ mm⁻¹, with a maximum value of 0.8 W m⁻² sr⁻¹ mm⁻¹. Therefore, MODIS observations reveal the changes of thermal energy related to hot material emitted during the moderate and high Strombolian activity. In this view, we identified the periods characterized by higher emission of hot material before the onset of 2007 eruption and since January 2008 to the end of period investigated. Finally, we suggest that our investigation can be extended for remote volcanoes hard to monitor having similar activity and size of Stromboli.

1.4-P-10

Surface Deformation Analysis Via The SBAS-DInSAR Approach In Several Volcanic Areas: An Overview

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Differential Synthetic Aperture Radar Interferometry (DInSAR) is a remote sensing technique that allows us to produce spatially dense deformation maps with centimeter to millimeter accuracy. An effective way to detect and follow the temporal evolution of deformation is via the generation of time-series; to do this, the information available from each interferometric SAR data pair must be properly related to those included in the other ones, via the generation of an appropriate sequence of DInSAR interferograms. In this context, several approaches have been already proposed. Among these procedures, we consider the one referred to as Small Baseline Subset (SBAS) approach that implements an appropriate

combination of DInSAR interferograms generated from SAR images pairs characterized by a small spatial and temporal separation (baseline) between the acquisition orbits.

We remark that the SBAS algorithm allows us to exploit averaged (multilook) interferograms; this permits to reduce the amount of data to be processed, thus simplifying the analysis of extended areas (typically of about 100X100 km). In order to generate long-term time series the basic SBAS technique can be trivially extended by combining data acquired by different sensors, i.e., ERS and ENVISAT.

In this work we present several experiments relevant to different sites. The presented results are based on the exploitation of ERS and ENVISAT SAR images and are focused on Etna, Hawaii, Lazufre volcanic area (Chile) and Campi Flegrei caldera.

1.4-P-11

Interpreting SEVIRI Image Time-Series of Volcanic Eruptions

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Geostationary weather satellites provide images of the Earth at temporal rates on the order of tens of minutes, revealing the evolution of volcanic plumes and the thermal radiant output from eruptions in great temporal detail. These time series can be combined with detailed maps of the resulting volcanic products from high resolution satellite images, ground observations, and simple models of volcanic product emplacement to construct detailed histories of volcanic eruptions.

Here we present studies of recent eruptions in Africa and Europe using time series of SEVIRI images. The SEVIRI instrument is mounted aboard the geostationary satellites Meteosat 8 and Meteosat 9, imaging Africa, Europe and the Middle East every 15 minutes in 12 bands. We use SEVIRI measurements of the thermal radiance from lava flows and gas plumes to invert for lava effusion rates and sulphur dioxide content, which in turn allow us to place constraints on processes in magma chambers and conduits feeding the eruption. We discuss the potential of these techniques for understanding eruption dynamics.

1.4-P-12

Interferometric Process Using Terrasar-X High Definition Data: A Study At Colima Volcano, México.

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Interferometric radar (INSAR) is a useful tool to generate current digital elevation models (DEMs) in volcanic environments, where topography changes occur rapidly due to recurrent volcanic activity. Colima volcano is the most active volcano in Mexico, and hence modifications in its drainage system configuration are recurrent. However, vegetation, topography and high slope greatly affect the quality of these results. We used three pair of TerraSAR-X data from Colima Volcano: two pair Spotlight High Resolution (1m x 1.5 m) and one pair Spotlight

(1.7m x 3m). Different system parameters were used in order to compare and obtain best results. From interferometric process, in the three cases, the coregistration step yielded values greater than 80 % of variance in the summit area and main ravines; from coherence map we obtained high coherence (0.7 - 0.94) for the same area. So, the Interferogram and unwrapping phase process only were possible in areas linked to recent deposits or where de vegetation is not present. On the other hand, the incidence angle and high slope were the main factors in determining the generation of INSAR data due to slopes greater than 40° characterize the Colima volcano. TerraSAR-X data are a useful tool for the assessment of topographic variations in active volcanic areas, where the vegetation cover is limited.

Session 1.5

1.5-O-01

Active Monitoring of Dike Intrusion Events by Electromagnetic ACROSS

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In eastern Izu Peninsula, activities of earthquake swarms and submarine volcanisms have repeatedly been occurred since 1974 Off Izu Peninsula earthquake (M=6.9). Swarm activity has strongly increased from 1978 and submarine eruption had taken place in 1989, followed by intrusive events of dikes associated with swarm activities almost every year until 1998. These activities in the shallow crust have been keep quiet, except a short swarm activity including M5.2 and M5.3 events in Dec. 2009. The reason why this quiescence continued for more than 10 years has left unanswered. In addition, the working hypothesis of "fluid driven mechanism" (Sasai, et al., 2001) to explain the crustal deformation associated with dike intrusion should be tested. In this report, we will present some results of model calculation about a possibility of detection method of magmatic activity associated with dike intrusion events in eastern Izu Peninsula by active electromagnetic observation network. The ACROSS (Accurately Controlled Routinely Operated Signal System) is a controlled source system continuously transmitting very accurately controlled sinusoidal signal both for electromagnetic and seismic waves. By assuming to reuse two electrodes separated to 2.2km as a dipole source, the effects of dike intrusion are estimated with a simplified horizontally layered models of both amplitude and phase of electromagnetic waves for frequency range between 0.01 to 10 Hz. Preliminary results indicate that the difference of phases could be detectable for 0.1 to 1Hz when a dike intrusion took place as sill-like configuration at depth between 7.5 to 10 km that depth range were expected the occurrence of swarms associated with dike intrusion. As assumptions

made are too simple to verify the working hypothesis of "fluid driven" mechanism for crustal deformation, more detailed analyses by using data from appropriate observation system are obviously needed.

1.5-O-02

Magnetic Observations of Izu-Oshima Volcano, Central Japan, in Its 1950 and 1986 Eruptions

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Izu-Oshima volcano is a basaltic volcano island, about 120 km south from Tokyo. The latest eruption took place in 1986, which started with the summit eruption from the central cone within the main caldera and was followed by flank fissure eruption. The former eruption cycle before the 1986 activity started from 1950, and continued intermittently until 1974. At the initial stage of the 1950 activity, enormous changes in the geomagnetic dip were observed by Rikitake (1951). Magnetic changes had been observed in association with the moderate activities at the summit crater of the central cone during the 1950's (Yokoyama, 1969). Continuous magnetic and resistivity measurements had been intensively made before, during and after the 1986 eruption, which contributed to clarify the eruption mechanism of Izu-Oshima volcano. The long-term, medium-term and short-term precursory magnetic changes were ascribed to the thermal magnetic and the piezomagnetic effect (Sasai et al., 1990). The phase II activity (fissure eruptions) of the 1986 eruption was caused by a more differentiated andesite magma, which should have intruded into a shallow depth in the past (Aramaki and Fujii, 1988). No evidence exists for such an intrusive event. We suspect if the large dip changes observed in the 1950 activity could be an indication of such an event. Rikitake's (1951) data were reexamined to obtain a more reasonable source, and a triaxial ellipsoid model was presented with the aid of genetic algorithm (GA). This model suggests that there exists a large vacant space filled with highly magnetized coarse scoria, which may be closely related to the past activities of the volcano.

1.5-O-03

Electromagnetic and Geochemical methods applied to the investigation of Taal hydrothermal system (Philippines)

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On volcanoes which display hydrothermal/magmatic unrests, EM methods can be combined with geochemical (GC) methods. The integration of these methods allows us to image in detail hydrothermal systems, to find out possible scenarios of volcanic unrest, and to monitor the on-going activity with some knowledge on the sources of heat, gas and fluid transfers.

Since a large seismic activity accompanied by noticeable ground deformation and opening of fissures, Taal volcano in Philippines is submitted to sporadic, but

sometimes intense seismic crises. A strong and large scale hydrothermal system stands on the volcano and is periodically re-activated. Commonly applied since 2005, combined EM and GC methods give an accurate description of the hydrothermal activity and heat discharge. EM methods, as magnetic and self-potential, map the hydrothermal system and locate the source of thermal and fluid transfers at depth, while soil degassing and thermal imageries clearly point out the location of the most active areas where thermal discharges take place. GC methods also specify the origin of the gas and fluids escaping from faults, fumaroles, and geothermal areas. Between 2005 and 2009, no large change in the hydrothermal activity took place, in spite of sporadic seismic swarms and surface activities which could lead to sudden phreatic explosions. The heat discharge of the volcano is estimated and monitored with time, based on repeated surveys. Such combined EM and GC methods are now integrated in the monitoring of the slow unrest of the volcano.

1.5-O-04

Structural Boundaries and Fluid Flow of Central Tenerife Volcanic Complex Inferred from Self-Potential Mapping, Canary Islands (Spain)

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An extensive self-potential survey has been carried out in the central volcanic complex of Tenerife Island (Canary Islands, Spain) during five field-campaigns developed between September 2007 and April 2010. A total amount of about 160 km of profiles with 20 m spacing between measurements has been completed, including radial profiles extending from the summits of Teide, Pico Viejo and M. Blanca and circular profiles inside and around Las Cañadas Caldera and the northern slopes of Teide and Pico Viejo. One of the main results of this mapping are the electrical effects of well developed hydrothermal systems within the edifices of Teide, Pico Viejo and M. Blanca volcanoes, which sustain active fluid convective systems transporting positive electrical charges towards the topographic surface. A strong structural control of the surface manifestation of these hydrothermal systems is also deduced from the data. In the outer part of the mapped area, especially towards Las Cañadas Caldera floor and walls, the influence of the hydrothermal systems disappears and the self-potential signal seems to be controlled by the topography

and the thickness of the vadose zone of Las Cañadas aquifer. This is indicated by a general inverse correlation between self-potential and topographic altitude. Nevertheless, remnant hydrothermal activity at some points along the Caldera wall, especially around the Roques de García area, is also compatible with the data. Two other important anomalies are detected: a positive one towards the northwestern Santiago del Teide rift; and a negative one in the Caldera floor between M. Blanca and El Portillo, probably related to the head of the flank-collapse La Orotava valley. This study has been performed as part of the IGN Volcanic Monitoring activities, with the aim of improving the understanding of central Tenerife volcanic system. The results are being used as a base to install hydrothermal monitoring.

1.5-O-05

Magnetic Monitoring as Effective Early Warning of Volcanic Eruptions at Mt Etna (Italy)

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Large changes in the stress field accompanying loading and rupture of crustal rocks during volcanic activity are expected to generate associated local magnetic field changes. Stress redistribution induces variations in the magnetization of rocks producing a local piezomagnetic field, which is proportional related to deviatoric stress field. The geomagnetic time sequences, recorded by the magnetic monitoring network continuously operating at Etna volcano since 1998, have shown remarkable changes during the onset of the last volcanic crisis. In particular, during the onset of 2008 Etna activity, the near-real time magnetic data, in agreement with the northward propagation of seismic events and with the deformation pattern, allow to describe the most likely scenario occurred during the eruption. At around 9:00 GMT on 13th May magma was rapidly injected from the central conduit and laterally propagated along the northern flank for 2 km producing a NNW-SSE fracture field. On the basis of the historic activity, this scenario alerted the scientific community for the volcanic and seismic hazard related to the northern flank of the volcano. Intrusion stopped at 14:00 GMT before reaching the North-East Rift structures and no lava emission occurred. Successively, no significant variations in all the monitored geophysical parameters were detected and the hazard alert level in the northern flank, related to the opening and propagation of eruptive fissure, was lowered. To advance the reliability of model-based assessments of magnetic observations we developed an integrated elastic 3D model to compute geodetic, gravity and magnetic field changes caused by intrusive sources in volcanic areas. The integrated approach is probably the only procedure capable of giving a global response to the volcanological problem and to minimize interpretative ambiguities. The model based on Finite Element Method allows for considering a complex description of Etna volcano to evaluate the effect of to-

pography and medium heterogeneities.

1.5-O-06

Electromagnetic Radiation Generated by Lightning at Erupting Volcanoes.

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Lightning generates a broad band of electromagnetic radiation that is used to locate and map lightning in thunderstorms. Lightning is commonly seen and reported in volcanic eruptions. We have used our VHF (very high frequency radio waves) Lightning Mapping Array to study lightning in three recent eruptions. We made measurements during the 2006 Augustine eruption, the 2008 Chaiten eruption, and the 2009 Redoubt eruption. We found prolific lightning during the explosive eruptions. In thunderstorm studies different band of radio emissions reveal different aspects of the lightning. Emissions in the low and very low frequency bands are due to the largest features such as current impulses during a ground strike. VHF emissions are used to locate 1000s of impulses emitted as the lightning channels are formed. At Augustine we found a new type of lightning that occurred at the vent as the volcano erupted. These features make the radiation from lightning a good way to detect and monitor eruption

1.5-O-07

Observation and Monitoring of Central American Volcanoes Using a Thermal Camera

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The incorporation of new geophysical techniques to monitor and study the volcanic activity is one the biggest leaps that volcanology has made in recent years, and in particular, the appearance of the IR thermal imaging which has provided a new way to closely monitor both dormant and active volcanoes. Since 2005, ITER volcano research group has performed observation and monitoring of Central American volcanoes by means of IR thermal imaging. Surveys have been performed using a FLIR P65-model thermal camera at active volcanoes of Guatemala, Costa Rica, El Salvador and Nicaragua, in order to delimitate the extension of the areas showing thermal anomalies and to investigate the spatial and temporal evolution of the anomalies. Results of these performances have allowed us also to evaluate in Santa Ana volcano (El Salvador) the energy output from its crater lake and to estimate the H₂O gas flux utilizing continuously-recorded thermal images of the volcanic plume. This type of estimation will be also performed at other Central America volcanoes showing plumes like Masaya in Nicaragua and Poás in Costa Rica. These surveys strongly support the idea of establish a continuous thermal monitoring system at Central American volcanoes, as part of remote sensing discipline. The high accuracy, endurance and the easy-to-use device

are others of the positive factors to begin this type of volcanic surveillance. Furthermore, if we consider the accessibility to some of these volcanoes, and the importance of the thermal surveillance together with other geophysical methods, the idea of establishing a continuous thermal monitoring network should not be discarded as a long-term objective.

1.5-O-08

Thermal Monitoring Program for the Volcanic Surveillance in the Canary Islands, Spain

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Canary Islands is the only active volcanic territory of Spain. Volcanism is characterized by the existence of basaltic fissural eruptions and the large active central volcanic complex of Las Cañadas caldera in Tenerife. Only Lanzarote, El Hierro, La Palma and Tenerife Islands have experienced volcanic eruptions in the last 5000 years. As part of its volcanic surveillance program, the Institute of Technology and Renewable Energy has implemented a Thermal Monitoring Program (TMP) in the Canary Islands. This TMP split in two different modes: discrete and continuous. Discrete mode consists on thermal surveys carried out periodically covering all the volcanic systems of La Palma (Cumbre Vieja), El Hierro, Lanzarote (Timanfaya) and Tenerife (summit of Teide volcano, NE and NW rifts). Surveys are carried out by simply direct measurement of the soil temperature at 40cm depth. Temperature distribution maps are later constructed with Sequential Gaussian Simulation. Discrete mode is completed with (i) a weekly thermal monitoring of the water temperature in 19 horizontal galleries located at the base of Cañadas Caldera and (ii) a monthly thermal monitoring of Teide volcano fumaroles. Additionally, the discrete mode has been improved with the use of a handheld Thermal Camera (FLIR) for mapping the ground surface temperature of Teide volcano summit. Continuous network consists on the monitoring of eight geochemical stations located in Tenerife, two in La Palma and one in El Hierro. At each station, the temperature at 40cm depth is measured in an hourly basis.

1.5-P-01

First High Resolution Seismic Tomography, P Wave Velocity Structure Beneath Tenerife Island (Canary Islands, Spain).

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3D velocity structure distribution has been imaged for first time using high resolution traveltimes seismic tomography of the active volcano of Tenerife Island (Canary Islands, Spain). In this island is situated the stratovolcano Teide (3718 m high), that is part of the Cañadas-Teide-Pico Viejo volcanic complex. In January 2007, a seismic active experiment was carried out as part of the

TOM-TEIDEVS project. About 6850 air gun shots were fired on the sea and recorded on 150 independent land seismic stations. The images have been obtained using ATOM-3D code (Koulakov, 2009) and more than 63000 P wave traveltimes. The velocity models show a very heterogeneous upper crust. The tomographic images points out the no-existence of a magmatic chamber near to the surface and below Pico Teide. The ancient Las Cañadas caldera borders are clearly imaged featuring relatively high seismic velocity. Moreover, we have found a big low velocity anomaly in the northwest dorsal and in the southeast of the island. Several resolution and accuracy tests were carried out to quantify the reliability of the final velocity models. As main conclusions of our work we can remark: a) This is the first 3-D velocity image of the area; b) we have observed low velocity anomalies near to surface that could be associated to the presence of magma, water reservoirs and volcanic landslides; c) high velocity anomalies could be related to ancient volcanic episodes or basement structures; d) our results could help to resolve many questions relate to the evolution of the volcanic system, as the presence or not of big landslides, calderic explosions or others; e) this image is a very important tool to improve the knowledge of the volcanic hazard, and therefore volcanic risk.

1.5-P-02

Geophysical Methods Combination Using A Hierarchical Approach For The Detection And Monitoring Of CO₂ Degassing At The Near Surface

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One important edge stone for the risk assessment at volcanoes is the availability of methods for the detection and monitoring of potential CO₂ degassing. Thereby, it must be taken into account that the degassing can happens with high fluxes over small areas but also as diffuse emission over larger areas. For an efficient and comparatively fast as well as cost effective assessment of different types of potential CO₂ degassing, different methods and technologies from chemistry, hydrogeology, geophysics and biology should be combined. With the aim of detection, quantification and monitoring of CO₂ emanations, we use passive and active Fourier Transformation Infrared Spectroscopy (OP-FTIR) methods for large scale investigations and CO₂ accumulation chambers for point measurements. Both types of methods can be used for the spatial delineation of areas with different degassing rates as well as for the monitoring at selected sites. Furthermore, we apply geophysical methods as DC geoelectrics, electromagnetics and self potential measurements for the mapping and monitoring of potential CO₂ pathways in the subsurface. To be able to cover larger areas, the application of methods will be embedded in a hierarchical approach. The basic concept of the approach consists of mapping and monitoring areas of interest, characterized by different levels of investigation. Initially remote sensing techniques can be used to describe the investigated landscape/area and to localize and describe (in general) areas of interest, producing a regional characterization of zones

with different need of detailed information. At this point, surface surveying/ monitoring techniques will be used to characterize the CO₂ degassing behaviour at identified areas of concern. Finally, among the different areas of concern, critical sites for intensive mapping and monitoring may be identified, for more sophisticated instrumentation in order to allow a detailed monitoring thereby increasing the spatial and temporal resolution.

1.5-P-03

Aeromagnetic Data Reveal Dome Structure on Mount St Helens

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Aeromagnetic data can delineate compositional, structural, hydrologic and temperature variations of volcanic systems, all affecting hazard assessment. Aeromagnetic collected over Mount St Helens in July 2007, during the 2004-08 dome-building eruption display magnetic lows over most of the new domes with low amplitude (40 nT) highs over dacite spines. Previous work shows the volcano and the 1980-86 dome can be considered homogeneously magnetized in approximately the Earth's field direction with intensities ranging from 4.2-4.9 A/m, except in areas where material is above the Curie temperature of titanomagnetite (approximately 580°) where the magnetization is negligible. However, a model of the magnetic effect of uniformly magnetized terrain shows magnetic highs are expected over the new domes rather than the observed dominantly low signature. Given the uniformity of composition in the volcano, it is unlikely that the observed lows relate to compositional variations. Temperatures recorded with thermal infrared data were recorded as high as 730°, suggesting that a portion of the observed lows could relate to rocks that are non-magnetic because they are above the Curie temperature. However the most likely explanation for the observed lows is that they relate to talus with random magnetic orientations. Further comparison of the new aeromagnetic data with older data sets will help determine the effects of temperature on the magnetic data. These data sets increase understanding of the cycle of dome growth and decay.

1.5-P-04

Characterization of a Magmatic Diffuse CO₂ Degassing Structure by Combining Resistivity Tomography with Sedimentologic and Soil Gas Measurements: The Hartoušov Mofette Field (Western Eger Rift / Czech Republic)

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The mofette field of Hartoušov is located in the Cheb Basin, a shallow Neogene intracontinental basin in Cen-

tral Europe. The NE part of the Cheb Basin is one of the most seismically active regions of Central Europe with repeated swarm earthquakes. The numerous cold CO₂ emanations (>99 Vol.% CO₂) in the basin are supposed to be connected to the seismic activity and to stem from the upper mantle.

The mofette field has been investigated by combining resistivity tomography and self potential measurements with sedimentological studies and soil gas to evaluate the structural and sedimentological control of the mofette area.

The investigations reveal a positive correlation between areas of high CO₂ soil gas concentration and flux with geophysical anomalies (negative self potential, positive structures of low electrical resistivity) as well as with specific sediment properties (content of pyrite and organic material, occurrence of dispersed pebbles, uplifted clay layer). These features are thought to be directly or indirectly related to the magmatic caused CO₂ flow. Negative self potentials anomalies were interpreted as having been caused by a downward movement of the meteoric water balancing the upward fluid flux in permeable pathways.

The top of a pre-Quaternary clay-rich unit with a high content of smectite is highest at the location with the most intense CO₂ emanation. The clays form a domal feature, as confirmed by the 3-D geoelectric measurements by low electrical resistivities. The driving force behind the updoming of the clays might be the pressure of uprising fluids. Additionally, the more intense swelling of smectite due to higher rates of fluid flow at these locations might also contribute to this phenomenon. Isolated quartz pebbles dispersed in fine-grained sediments could have been transported upward by gas jets bonded to vents during periods or events of intense gas emanation.

1.5-P-06

DACM - "System in a Box" for Complex Sampling Procedures and Multi Parameter Analysis

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The actual situation on the measurement sites shows a large number of instruments from several manufacturers, each with its own communication path and data base format. In many cases adds the operator "self-made" equipment for sampling and to join the various equipment. The effort for this is mostly very high and often some technical compromises must be made which reduces the performance of the single instruments.

To overcome this situation we developed the DACM (Data Acquisition and Control Module) technology. Instruments based on this technology can be modified anytime by the user without special knowledge and the claiming of the manufacturer.

The DACM based offers a set of components which can be configured, parameterized and controlled with respect to the requirements on site. Typical components are Radon/Thoron modules (soil gas, water, air, exhalation), signal inputs for sensors like Co₂, Methane, So₂..., control outputs for instance for pumps, magnetic valves for exhalation measurements but also complex functional blocks like spectrometers, PID regulators etc.

A complex sampling schedule can be created within few minutes by a graphical software interface.

Because of the short half life, Thoron measurements require frequently additional equipment and sampling procedures depending on the place of measurement. Especially in geological applications occurs a large number of influences by other ambient parameters. Simultaneous measurement of these parameters is necessary to check cross correlations to achieve reliable results for Thoron.

Besides the components, the DACM contains the complete infrastructure for field applications like removable mass storage (MMC), communication interface (modem, GSM, wireless networking) and operator interface. The systems are trimmed to low power consumption for long operation periods using battery or green power. The unified structure of the acquired data simplifies the later analysis and assessment.

1.5-P-07

IR imaging of a Masaya Volcano Incandescence

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Infrared monitoring is increasingly being used because of its well-known advantages: artificial IR sources are not required (although sometimes are used), night monitoring is possible and diurnal measurements are less affected by sunlight (direct or scattered). In addition IR radiation coming from an object provides a great deal of information about the object properties, especially those related to its temperature. For these reasons IR techniques are widely applied to volcanic surveillance. Ground based IR monitoring adds some advantages such as higher spatial and temporal resolution. However, IR radiation emitted by an object can be affected by different physical phenomena along its trajectory towards the detector, which induces variations in the expected signal and causes errors and difficulties in the measurements interpretation. This interference with the media has to be considered in order to avoid errors. Nevertheless, the analysis of environment effects can be used to retrieve its properties. Commercial IR cameras are valuable tools to monitor lava and temperature anomalies in volcanic areas. Despite they usually work in the atmospheric windows (3 – 5 mm or 8 – 12 mm) they consider the effect of atmospheric gases (H₂O and CO₂). However, atmospheric corrections implemented in commercial cameras do not take into account volcanic gases such as SO₂, HCl, etc. In order to remove the effects of volcanic gases absorption special filters can be implemented in the IR cameras. In this work we suggest a filter to avoid the SO₂ interference in the lava temperature retrieved from an IR image. In addition an algorithm to retrieve the SO₂ total column is proposed. It is based on the combination of images acquired with and without the filter. The capability of this algorithm has been tested by means of Open-Path FTIR spectroscopy and applied to images of a incandescence in Masaya volcano, where FTIR spectra and IR images were measured simultaneously.

1.5-P-08

Study of GPS- TEC Related to Sichuan Earthquake (M=7.9) of 12 May, 2008 and Their Fractal Analysis

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Daily variation of vertical TEC data recorded at Bichpuri Agra station (Geographic Lat. 27.2 °N, Geographic Long. 78°E) employing a GPS receiver has been studied for a period of three months from 1 April to 30 June 2008 in relation to Sichuan earthquake (M=7.9) of 12 may 2008. A significant enhancement has been observed in TEC 22 days before this earthquake. This result is interpreted in terms of EXB drift mechanism, where E is electric field of seismic origin. Further, fractal analysis of TEC data has also been carried out using Burlega- Klein method and it is found that fractal dimension gradually increases long before the occurrence of this earthquake. These results are not influenced by magnetic storms and are attributed strongly to earthquake.

Session 1.6

1.6-O-01

A Sensitive Analysis on Mohr-Coulomb and Hoek-Brown Parameters Effective in Ground Response Curve

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Convergence-confinement is one of the most popular methods that is applied for analyzing the interaction of a circular opening in rock masses. It is assumed that circular tunnel excavated in a continuous, homogeneous, isotropic, initially elastic rock mass subjected to a hydrostatic stress P₀. Selecting appropriate failure criteria is very important in the analysis since it affects on plastic zone and on the resulted displacement and stress field around the opening. Some closed-form solutions have suggested for the ground reaction curve, although they are driven based on elastic-perfectly plastic or elastic-brittle-plastic models of rock mass behavior. Brown et al(1983) proposed a stepwise procedure based on Hoek-Brown criterion to solve stress and displacement around the circular opening for elastic-strain softening model of rock mass behavior. A similar stepwise procedure was extracted in this study for Mohr-Coulomb criterion. Finally a sensitive analysis was implemented for Mohr-Coulomb and Hoek-Brown criteria in respect to their parameters. By comparison of the relative displacement caused by changing strength parameters in Hoek-Brown and Mohr-Coulomb criteria, it can be concluded that Mohr-Coulomb criterion is more sensitive in respect of variation of strength parameters of rock mass than Hoek-Brown.

1.6-O-02
Basic properties of non welded basaltic lapilli and influence on their geotechnical behaviour

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In the Canary Islands there are hundreds of volcanic cones and extensive blankets of lapilli and civil works are very frequently undertaken in areas containing this material. Furthermore, basic lapilli (of basaltic, basanitic, or tephritic composition) are common in many volcanic regions of the world. They are small pyroclastic fragments (2 to 64 mm in diameter) emitted by Strombolian-type eruptions, very irregular in shape and with many open and closed voids. As a whole it is a light and quite loose granular material. The article covers two related aspects: (1) basic properties, such as texture, unit weight and geochemical composition; and (2) geotechnical parameters and behaviour under different situations: on slopes, under foundations and as granular layer for roads. We conclude that, resulting from their low density, high porosity and angular shape; lapilli particles have a quite different geomechanical response from other granular natural materials.

1.6-O-03
Big Telescopes Foundations In Volcanic Environments

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The development of the astrophysics science requires new technical and more sophisticated tools to complete the observation tasks successfully. During the last years, some teams are developing bigger telescopes with the latest technologies, allowing to obtain better results in the astronomical observations. In this way, the Spanish Government and some partners developed and built a telescope with the biggest primary mirror of the world called "GRAN TELESCOPIO CANARIAS" (GRANTECAN) in La Palma, Canary Islands, Spain, being considered the biggest telescope of the world. As the engineer of the Enclosure Group, responsible of the Civil Work and Auxiliary Installations of the GRANTECAN project, I will show in this paper a summary of the geotechnical studies, a brief description of some of the mandatory requirements for the telescope pier foundations, and the final design to accomplish the foundations and structure project requirements.

1.6-O-04
Cliff Stabilization Solutions at the South Coast of Madeira Island

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The necessity to protect important infrastructures constructed, along the south coast of Madeira Island, at the top and at the bottom of high cliffs, against the collapse of isolated rock blocks or of significant masses of soil and rock debris, has led to the development of complex geotechnical projects and to the execution of specific stabilization works. This paper describes, for some of those cliffs, the existing geological conditions and the main instabilization processes that affect them. Attending to the acquired experience from these works, some considerations are presented about the advantages and limitations of the stabilization solutions considered, especially in what concerns the required logistics for their execution.

1.6-O-05
Construction Experiences with Volcanic Unbound Aggregates in Road Pavements

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This experimental research discusses the performance of crushed granular materials resulting from volcanic rocks employed in the construction of subgrades and continuous grading unbound aggregate road base and subbase courses. Some frequent doubts related to their suitability for the aforementioned use, to their observance of the technical specifications of different countries, and to the methodology and criteria to control field compaction and bearing capacity are intended to be clarified. In attempting to validate the utilization of these volcanic granular materials in untreated road base courses and the requirements and tests for field compaction, the object of this work has been to study the influence of foundation conditions and construction procedures on the rate of compaction. For this purpose some experiences of several Atlantic islands (Azores, Canary Islands, Cape Verde and Iceland), or more distant as Hawaii, are compiled and additional recommendations are contributed for volcanic aggregates as those from Canaries or Azores. The experimental results reveal that it is possible to reach a good load-carrying capacity with these granular materials, and also that conventional tests can be used. Variability of geotechnical properties of granular aggregates resulting from volcanic rocks is generally more significant than with non-volcanic materials, thus manufacturing and reception control should be more intensive. However, laboratory test results have confirmed that it is possible to attain with them satisfactory adjustment to grading and allowable tolerances of different specifications in Europe, provided that an optimum regularity of the product can be assured with the production and stockpiling control. In this way, they can be employed in road structural courses even with

heavy traffic conditions. The in-situ study has allowed us to obtain the rate of compaction as a function of the Effective Modulus of the base course foundation.

1.6-O-07

Deformational behaviour of pyroclastic rocks beneath the upper reservoir of the hydro-wind plant at El Hierro.

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El Hierro Hydro-wind Plant is a singular project, as its aim is to make the island energy self-sufficient. It involves constructing two reservoirs – the higher of which began being constructed in September 2009. This article attempts to reflect the peculiarity of the behaviour of the materials at the bottom of this reservoir, which will have to support a significant hydrostatic load, and the difficulty of characterising these in laboratories and design offices in order to assign geotechnical parameters to them which will reflect their geotechnical performance in situ. The studies undertaken to achieve this characterisation are described and the expected settlement of the materials is analysed. Although this settlement could possibly take place without causing the failure of the basin impermeable membrane, it is worth limiting the differential settlement. With this aim, a ground treatment to limit the total settlement to 10-12 cm was considered necessary. The article describes in detail the preload proposed to minimize settlements. In order to complement the studies relating to the deformability of the upper layers of the ground and to check the validity of the preload, the project included the construction of a trial embankment, which is the best means for obtaining the ratio between the deformation modulus for virgin compression and that corresponding to recompression. Finally, the estimated settlements are compared with those obtained at the trial embankment, and the deformational behaviour of materials resulting from the alteration of pyroclasts is analyzed.

1.6-O-08

Design and Construction of the Machico-Caniçal Expressway Tunnels at Madeira Island

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The Machico-Caniçal Expressway, with 8 km long, is part of Madeira Island new development program, which connect Funchal city to Caniçal village through a continuous expressway along the islands south coast. This expressway crosses an extremely mountainous region, conditioned by the existence of two very heterogeneous geological volcanic complexes, generally covered by unstable debris deposits or by thick alluvial deposits, leading to the construction of a very much di-

versified group of civil engineering works. This paper presents the main aspects related with the design and construction of six double tunnels along the referred expressway. It will also be presented some safety aspects related to those tunnels.

1.6-O-09

Etna Flank Dynamics: a Sensitivity Analysis by Numerical Modelling

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Most active volcanoes show clear evidence of flank instability resulting from several interacting causes including gravity force, magma ascent along the feeding system, and local and/or regional tectonic activity. The complexity of such dynamics is still an open subject of research.

Mount Etna, the largest European stratovolcano, is located in a complex regional tectonic framework and is affected by several volcanotectonic elements, represented by both rift zones and faults, which influence the volcano dynamics. A deep-seated instability characterizes the eastern and south-eastern flank, with differential movements within the unstable mass.

This work investigates the dynamics of such flank deep instability by means of bi-dimensional numerical modelling, comparing finite element and finite difference methods (SIGMA/W and FLAC 5.0 codes), and by limit equilibrium analyses. The input dataset was supported by dedicated structural-mechanical field surveys, rock mass characterization at outcrop conditions, geotechnical tests, and extrapolation of average values representative for deep conditions.

The stress-strain analyses were performed along a WNW-ESE section, extending for 61 km and to a depth of 10 km. The meshing, adjusted to fit the topography and the main units, has an average resolution of 100 m. Five main geological and lithotechnical units were considered and characterized in terms of constitutive law and the associated strength and deformability properties: 1) volcanic edifice, 2) subnean clays, 3) Apennine-Maghrebian flysh, 4) Hyblean plateau, 5) intrusive complex. Sea water load and hydrogeological conditions were taken into account.

The complicated conceptual model was first simplified and progressively implemented with a sensitivity analysis to evaluate the effect of topography, geometry and rheological behaviour (Mohr-Coulomb, Hoek-Brown) of the structural units. The model was then implemented considering the presence of magma pressure along the feeding system. The results are expressed in terms of stress-strain field, displacement pattern, plasticity states and shear strain increments, or factor of safety.

1.6-O-10

General Method for Estimating the Active and Passive Earth Pressures on Retaining Walls Assuming Different Strength Criteria

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A new method for estimating the earth pressures on retaining walls has been developed. It is an extension of Coulomb's earth pressure theory for non cohesive materials that can follow a non-linear strength criterion. This was previously done by the authors (Serrano et al, 2007) for some basic assumptions that have now been extended. The method is valid for materials that may have either a linear or non-linear strength criterion (parabolic or Hoek-Brown), a non-horizontal surface and an earth-wall friction angle. The method considers the material dilatancy. Moreover, the failure surface does not need to be plane, as in previously developed methods, but its shape is obtained as a result of the calculus, by applying Euler's variational method that obtains the extremal force.

1.6-O-11

Geological and Geotechnical Conditions of Human Interventions in Natural Volcanic Caverns: the Outfitting of "Los Jameos del Agua" Auditorium, Lanzarote, Canary Islands, Spain

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The possibility of using volcanic caverns associated with lava tubes is analysed according to their geological and geomorphological configuration and their dimensions. Each particular risk is defined and studied by considering its threat. The different natural risks are grouped into four categories: Group I: Structural instability zones due to hanged strata or extremely low width levels at the top of the cave. Group II: Medium and large block instabilities. Group III: Small block instabilities. Group IV: Surface weathering and in-stabilities in rock particles (sand or gravel). In this paper this methodology is applied to the well-known auditorium of "Los Jameos del Agua", located in Lanzarote. This volcanic island forms part of the Canary archipelago. This volcanic tube is visited by more than 800,000 people per year. After an analysis of the different alternatives, the proposed technical solutions for each level of risk are de-scribed and the results of some calculations are shown.

1.6-O-12

Geological and Geotechnical Conditions of the Machico Caniçal Expressway at Madeira Island

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The Machico-Caniçal Expressway, with 8 km long, is part of Madeira Island new development program,

which connect Funchal city to Caniçal village through a continuous expressway along the islands south coast.

This expressway crosses an extremely mountainous region, conditioned by the existence of two very heterogeneous geological volcanic complexes generally covered by unstable debris deposits or by thick alluvial deposits, leading to the execution of a very much diversified group of civil engineering works.

This paper presents the most relevant geological and geotechnical aspects identified along this expressway, in particular in what special engineering structures (bridges and tunnels) and retaining walls are concerned.

1.6-O-13

Geomechanical Appraisal of the Deformation Potential of a Deep Tunnel in a Volcanic Rock Mass

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Ophiolitic complexes can be defined as an association of ultra basic volcanic rocks (ultramafic) and basic (mafic) constituents of the oceanic crust as a result of a phenomenon of abduction clash between continental plates. An intricate structure in which volcanic rocks are intruded in the direction of the schistosity of the metamorphic rocks is further complicated by large scale overthrusts which create tectonic melanges at the base of such mega structures, affecting it by secondary tectonic contacts and inverse faults. The whole entity is found in considerable tectonic disorder where packages of peridotites or pillow lavas of various sizes "float" inside a sheared shale-like mass. It is understandable that tunnelling in such a formation requires a good appraisal of the rock mass deformation potential as it will have a direct impact in the support behaviour, particularly in the deeper sections with more than 250 m overburden. This paper deals with the geomechanical characterisation of the heterogeneous rocks mass and the different models employed to simulate its behaviour during the tunnel excavation and support.

1.6-O-14

Geotechnical Characterisation of Volcanic Rocks and Soils of Madeira's Island

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This paper focuses on the description and the characterization of volcanic rocks and soils of Madeira Island, based on data from expertise judgment, field survey and laboratory tests. The objective has been the compilation of data from geotechnical designs for Madeira Island, in the last 20 years, in order to de-scribe the geological conditions and to evaluate the geotechnical parameters of the main volcanic formations such as: basalts, breccias and tuffs.

1.6-O-15

Geotechnical description of halloysite clays from La Palma Island (Spain)

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Barlovento dam situated in La Palma Island (Canary Island, Spain) suffered settlements, up to 2 m, in a particular area of its bedrock. The aim of this work is to analyze the cause that produced such settlements and make a geotechnical description of the halloysitic clays situated in the bedrock of the reservoir. A geotechnical survey campaign was carried out that consisted on five boreholes, thirteen dynamic penetration tests and laboratory tests. Geological data were collected from two reports issued by Servicio Geológico de Obras Públicas around 1970. With the data coming from the boreholes, two geological profiles were made. The mineralogical tests determined that the clay material detected in the boreholes was formed mainly by halloysite. This clay material was studied, from a geotechnical point of view, through tests of identification, state, strength, deformability and permeability. It is important to remark the great difficulty of this material, during the performance of the laboratory tests, as its geotechnical behaviour is clearly different of the materials with Soil Mechanics usually treats. Because of that, the identification tests (grain size and plasticity tests) were made with different procedures of the ones described in the technical Spanish standards. The laboratory and in situ testing made it possible to determine the compressibility of the halloysitic clay and to consider that the settlements were only due to the variable thickness of that compressible material.

1.6-O-16

Geotechnical Parameters of Basaltic Pyroclastics in La Palma Island, Based on Convergences Measured in a Tunnel

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The improvement works of the Highway C-830, section Tenagua - Los Sauces (La Palma, Canary Islands, Spain) includes the construction of the so called Tunnel 3, excavated over a length of 150 m, on basaltic pyroclastics of the Volcanic Series II, with a maximum depth of about 110 m. The pyroclastics are sediments of air projection, like slag, lapilli, bombs and ash. It is a coarse grain size soil, with low density and SPT values between 30 and 60. It's a loose material or slightly welded, but with important overlapping between particles. The 9 m internal width full-face tunnel was supported by a 13 cm shotcrete layer. This work presents a back-analysis of a tunnel section based on measured convergences values. The analysis used FLAC2D and shows the excavation and supporting of the tunnel along with other phases during construction. Some incidences that resulted in convergences increases have been considered in the calculation. With this analysis we aimed to obtain realistic values of the geotechnical parameters of pyroclastics. However, its accuracy depends on a great number of variables. Finally, modulus of deformation,

cohesion, friction and lateral earth pressure coefficient of pyroclastics (E , c_M , ϕ_M and K_0), were estimated. These estimated values are not the only possible solution given the available data, but they represent realistic values in the authors' opinion.

1.6-O-17

Geotechnical Properties of Volcanic Materials of the Mount Erciyes

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In the eastern part of Anatolia, there are several mountains originating in volcanic genesis. The mount Erciyes is most famous one of these series which include large amount of volcanic products being used as building materials. This mountain and the related volcanic products such as basalts, tuffs, pumice, perlite, andesine and other volcano sedimentary rocks covers an area of about 5000 km² which include the cities Kayseri, Kırşehir and Nevşehir. This region is known as Cappadocia.

The aim of this study comprises the research for determination of geotechnical parameters such as unit weight, porosity, seismic velocity, rebound hardness, heat conductivity and other rock mechanical parameters. After determination of these parameters several relationships between these parameters such as between heat conductivity and porosity, heat conductivity and uniaxial strength etc. will be investigated.

1.6-O-18

GÜİMAR AND LA OROTAVA LARGE LANDSLIDES: THE ROLE OF THE SUBMARINE FRAGMENTARY MATERIALS

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The Canary Islands have suffered in the last million years the largest known landslides, with estimated volumes exceeding one hundred cubic kilometers, being the most spectacular Güímar and La Orotava landslides in Tenerife, El Golfo in El Hierro and Cumbre Nueva in La Palma.

This paper presents the results of an investigation into the causes of the landslides of Güímar and La Orotava, the failure mechanisms and the properties of the affected materials, particularly the submarine fragmentary rocks (hyaloclastites) whose properties are especially significant for the stability of volcanic island flanks. The geological and geomechanical models and possible causes and mechanisms of these landslides are presented.

1.6-O-19

Innovate Aspects in the Execution of the Strengthening and Stabilizing of the Volcanic Cavern of "Los Jameos del Agua", Lanzarote, Canary Islands, Spain.

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The rehabilitation of the volcanic natural cave that constitute "Los Jameos del Agua" Auditorium, located in Lanzarote (Canary Islands), was a challenge in the development of new technologies, materials and even machinery, specifically designed for strengthening and conditioning this impressive natural area. As a consequence that this is the biggest natural Auditorium in Europe, and a specially protected space, both, the project and its execution have required to contemplate the double condition of securing more than 800,000 people who use it every year, while maintaining the original aesthetics.

The Auditorium, designed by the famous architect César Manrique, is the product of a geological volcanic pipe, which is currently in progressive degradation. Several instabilities observed in the natural terrain that forms the vault caused the preventive closure to the public of the Auditorium in 2003.

To strengthen the cave and avoid falls of large blocks of stone, it was decided to create a one meter thick vault, to act as a monolithic arch. For that purpose, a first generalized short bolting was carried out. After that stage, a long bolting was carried out to assure the contribution of the higher strata to the stability of the cave. The medium size stones fall risk was solved through individualized fine bolts. All bolts, made of fibreglass and polyester, were injected with specially designed epoxy resins. A chemical sealing product served for consolidating partially the surface of the cave, preventing the fall of small rocks. Finally, a mineralizing product applied widely was the procedure chosen for the general consolidation of the surface.

1.6-O-20

Isotropic Collapse Load as a Function of the Macroporosity of Volcanic Pyroclasts

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Two main types of "macroporosity" in pyroclastic volcanic rocks can be distinguished: "reticular" and "vacuolar". The first type is produced when the large pores are located between grain particles. The second type is produced when large pores are located inside a vitreous rock mass. However, a mixed type can be defined in most cases, when both kinds of void are present. At other times, the pyroclasts do not exhibit any kind of "macroporosity". An extensive study of how the type of porosity may affect the strength of the material is being carried out at CEDEX geotechnical laboratory. Samples with different types of "macroporosity" have been tested under isotropic loads. As a result of a theoretical study, an expression of the isotropic collapse load has been obtained, for any type of "macroporosity", and compared with test results.

1.6-O-21

Lightweight Aggregate and Lightweight Concrete and its Application in the Improvement of the Thermal Properties of Volcanic Lightweight Aggregate Concrete Blocks from Canary Islands

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Concrete blocks with volcanic aggregates currently produced in the Canary Islands (BHIC) have a high coefficient of thermal conductivity. The application of Spanish Building and Construction Regulations, known as CTE, leads to the need for multilayer construction systems in external building walls. These systems are less efficient from an economic and environmental point of view. This paper focus on the improvement of thermal properties of the BHIC, so that the external building walls can be executed in the islands using single-leaf masonry without having to add thermal insulation.

1.6-O-22

Low Stress and High Stress Phenomena when Excavating in Basalt Flows

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Contrasting geophysical, rock mechanics and rock engineering experiences caused by either exceedingly low or extremely high stress are described, from projects in the USA and Brazil. The Hanford nuclear waste disposal candidate was the 900 m deep Cohasset flow in the Colombia River basalts, but this was found some distance away at a more convenient shallow depth for preliminary but extensive characterization studies, at the so-called Hanford BWIP project. Some interesting joint deformation effects were caused by the low stress levels, with an in situ block test and some cross-hole seismic measurements, each affected in special ways by the anisotropic joint properties and by the low stress levels. The latter could be controlled in the block test, and included temperature effects which caused joint closure. An unexpected linear stress-deformation behaviour was measured in the block test due to the contribution of both shear and normal components of joint deformation. In this project, and in the following Brazilian project, some site characterization was performed by the author, looking both at joint properties and rock mass properties, and evaluating their potential and actual effect on deformability, stress level and tunnel damage. In the case of the Brazilian 1,450 Mw Ita Hydroelectric Project, contrasting Q-values in adjacent columnar and entablature flows were the focus of stress-fracturing predictions for various hydropower tunnels. It was found that the least jointed flows with high Q-values attracted extremely high stresses in the topographic ridge defining the project location across a loop in the river. Stress fracturing and extensive, many meters deep, 'dog-earing' occurred in the five large 150 m² diversion tunnels. In the higher-elevations of five pressure tunnel linings, cracking occurred when con-

tact grouting, specifically in the 3 o'clock and 9 o'clock positions, over total lengths of hundreds of meters. Extreme spillway erosion was also blamed on the effect of the high stresses.

1.6-O-23

Modeling of the Collapse of a Macroporous Material

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The macroporous materials are a mix of solid particles, joined together with bridges of materials that may be the same or different of the solid particles. For example, volcanic rocks like volcanic agglomerates. In this way, it is interesting to try to explain how the collapse of these materials takes place. With the great improvement of the numerical methods and the power of computers it has been possible to carry out a discrete analysis instead of a continuum one, like would have happened with the classical theories of continuum. This article shows the first steps taken in this path of modeling the collapse of macroporous materials in a discrete way.

1.6-O-24

NATURAL STONE FROM THE ARCHIPELAGO OF AZORES: RELATIONSHIP BETWEEN LITHOLOGY AND PHYSICAL-MECHANICAL BEHAVIOUR

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Since the early days of the settlement in the archipelago of Azores, in the 15th century, natural stone has been used in the construction of residences, religious monuments and public buildings, because of its local abundance.

The purpose of this study was the characterization of the main commercial types of natural stone of the archipelago of Azores, in terms of their mineralogical, chemical and technological properties. This characterization allowed to appraise their suitability for the different types of applications. In a preliminary stage, the study comprised seven varieties of natural stones exploited in various quarries and processing plants of São Miguel Island and Santa Maria Island — two of the nine islands that form the archipelago of Azores. Petrographic studies and chemical analysis were performed in all the selected varieties as well as the following physical-mechanical tests (carried out according to European Standards): uniaxial compressive strength, flexural strength under concentrated load, apparent density, water absorption at atmospheric pressure, open porosity (or apparent porosity), linear thermal expansion coefficient, abrasion resistance (with Capon machine) and rupture energy (commonly known as impact resistance).

Finally, relationships were established between the

main physical-mechanical properties of the natural stones under study, and their main lithological and textural characteristics.

1.6-O-25

Project and Technical Assistance to The Retaining Structures of Cabo Girão Tourist Resort

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The Tourist Resort Cabo Girão, located in Câmara de Lobos, at Madeira island, is constituted by a general building of common services, 9 buildings with 3 floors, 22 villas, paths and leisure spaces, including courts of tennis and swimming pools.

As a result of several restraints associated with the implantation of different construction areas such as the layout, topography and geological/geotechnical conditions it was necessary to conceive different types of retaining structures, namely gravity walls, cantilever concrete wall, nailed retaining wall and soil nailing slope stabilization. The total length of these almost forty retaining structures was about 3160m.

It will be presented the conception of the project in its different phases. An important interaction between the architecture and the geotechnical project was crucial, in order to improve the implantation of the constructions and the retaining structures to assure the economical viability of the resort.

The main activities developed in the project and during the technical assistance of the work will be described, including the necessary alterations during the execution of the retaining structures.

1.6-O-26

Recovery Gallery of Fuente Santa Spring, La Palma, Spain

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The most complex excavation confronted by the Canary administration in what refers to a hydraulic work was a 200-m long recovery gallery on the so-called Fuente Santa (Holly Fountain) spring, buried by the eruption of San Antonio Volcano in 1677. This problem was not related to the creep of the excavated material but rather a total lack of stability in a gallery that was intended to be driven through a pile of debris that had been collected in the course of a few days representing a 150-m high overburden. Finally, mention should be made that if with these works the Fuente Santa spring could be detected and unburied the reasons were not the actual technological advances required to achieve this purpose; the difference was that, as opposed to our ancestors, we could resort to four disciplines. The first one was History that with its accounts found at municipal, insular and national archives we could find what we should look after and where to do it; the second one was Engineering that provided us with the method of

excavation, with a gallery rather than a well, the election of which opened the way to be able to excavate through a pile of unstable and dangerous rocks along a 200-m stretch and at the same time provided us with a method capable of maneuvering and detecting the spring flow buried underground; Then came Geology that showed us how to tell apart the material spewed by the eruption from the original soils found at the site prior to burial of the spring; and last but not the least, Chemistry that through its cryptic language of cations and anions lead us progressively to the very source of Fuente Santa spring.

1.6-O-27

Retaining Structures in Machico-Caniçal Expressway at Madeira Island

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The Machico-Caniçal Expressway, with 8 km long, is part of Madeira Island new development program, which connect Funchal city to Caniçal village through a continuous expressway along the islands south coast.

This expressway crosses an extremely mountainous region, conditioned by the existence of two very heterogeneous geological volcanic complexes, generally covered by unstable debris deposits or by thick alluvial deposits, leading to the construction of a very much diversified group of civil engineering works.

The constraints related to the layout, the topography, the high urban occupancy and the very unfavourable geological/geotechnical conditions, specially the presence of debris deposits with significant thickness and very weak resistance characteristics, lead to the necessity to conceive different types of retaining structures,.

This paper presents the main aspects related with the design and construction of the referred structures, namely gravity walls, reinforced earth retaining walls with jetgrouting foundation, anchored walls and sheet pile walls and also soil nailing.

1.6-O-28

Road Tunnel Design and Construction at Madeira Island

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In the last two decades a new fundamental road network was undertaken at Madeira island. Due to the vigorous relief of the island, the great heterogeneity, the structural and lithological complexity of volcanic rock formations and to the land occupation, tunnels became dominant, in order to allow an acceptable level of comfortable accessibilities to the main villages of the island.

To achieve more adequate and economical solutions facing the topographic and geotechnical conditions, a large spectrum of innovative structural tunnel solutions were developed.

The objective of this paper is to give a global vision of the importance of this group of infrastructures, focusing in conception and design aspects, along with the description of the geotechnical conditions, primary and secondary lining and phased construction.

1.6-O-29

Rock Mass Classification Schemes In Volcanic Rocks

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Volcanic massifs, due to their origin, present certain characteristics that make their study through a classic geomechanical classification not always appropriate. The presence of discontinuities, the peculiar block shape and the presence of voids condition the behavior of lavatic massifs. Behavior of pyroclastic massifs depends mainly on their matrix rock, making the use of existing geomechanical classifications inadequate. This work represents a first step in the development of a geomechanical classification specific to volcanic massifs, accounting for all the properties that actually condition their behavior.

1.6-O-30

Shear Behaviour of Stromboli Volcaniclastic Saturated Materials and its Influence on Submarine Landslides

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On 30 December 2002 a submarine landslide generated high tsunami waves and destabilized the subaerial slope of the NW flank of the Stromboli volcanic island. The volcano flank is a large subaerial and subaqueous scar filled by loose volcaniclastic materials. Their susceptibility to undrained shear failure is investigated through stress- and displacement-controlled large-scale ring shear tests (LRST), conducted at DPRI-Kyoto University at different hydraulic boundary conditions. Results are presented in the form of stress paths and time-histories of shear resistance and pore pressures and are discussed with reference to the different testing conditions. Finally shear band formed in LRST are analyzed in terms of changes in porosity and grain size distribution in order to investigate the development of grain crushing at failure and at large displacement.

1.6-O-31

Socorridos Pumping Station and Water Storage Tunnel at Madeira Island

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The Socorridos pumping station and water storage tunnel are located at Madeira Island, Portugal, and are part of a system conceived to reuse the water flow from the Socorridos hydroelectric plant. This facility includes an underground cavern with 26m high, 12m wide and 44m length, and a tunnel 1250m long with a storage capacity of 40 000m³. The rock mass at the site is of volcanic origin with most of the excavation performed in a mass of volcanic breccia and basalts but with consolidated alluvia recent deposits located in the roof arch of the cavern. A description of the main characteristics of the project is presented and the results predicted by the design are compared with the results obtained from monitoring.

1.6-O-32

Stability of the Cone and the Foundation of Arenal Volcano in Costa Rica

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Arenal volcano is deforming the basement under ~20 x 103 kPa, and affects it for several kilometers below the surface and about 5 km around the volcano base. The total settlement below the present (1968-2009) lava field (0.75 km²; 0.6 km³) is 2 m or more, but it represents at the moment only 20% of the consolidation, so its deformation will be continuous for years. The volcano grew up on the top of weathered volcanic rocks (weak and plastic portion) conditions that are ideal for deforming the basement (subsidence, folding or faulting) and generate instability on the cone according to structural and volcanic models. The results of numerical models show that Arenal is at an incipient deformation stage by spreading of the basement. The overall effect generates stability at the interior of the volcano and its foundation. The twin edifice (cones C and D) can generate rock slides (cold or hot) as well as debris avalanches (0.03-0.75 km³).

1.6-O-33

The Origin and Geotechnical Properties of Volcanic Soils and their Role in Developing Flank and Sector Collapses

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Giant volcanic landslides are one of the most hazardous geological processes. Still, the mechanisms that trigger them remain unresolved. Recent studies suggest that the presence of weak volcanic materials is likely to play an important role. Herein, we present a study of

the weakening effect of weathering and hydrothermal alteration of phonolitic lavas, pyroclasts and ignimbrites from Tenerife. A comprehensive geotechnical characterisation of these materials reveals that, from weathering, the weakest units are porous, sandy-silty, non-plastic soils (SM) that are cohesionless, with high peak strengths and significantly lower residual strengths. In the case of hydrothermal alteration, the weakest units are porous, silty, clay-rich, medium plasticity soils (MH) with low cohesion values and varying angles of internal friction (17-45°). Secondary mineralogy produced by alteration, mainly halloysites and the presence of bonding in weathered soils and kaolinites or alunites in hydrothermally altered soils, appears to control the behaviour of the soils.

1.6-O-34

The Suitability of Volcanic Tuff from The Ethiopian Plateau for Earth Dam Construction and Foundation

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The intended site for the dam is located in a wide valley of the Gilgel Abbay River with an overall elevation difference between the upper plateau and the river level of about 85 m. The river has eroded a series of volcanic rock units of early Tertiary origin, with alternative levels of basaltic lava flows and ash or tuff deposits. The lava flows result in hard to medium rocks, jointed and fractured. The two volcanic units mentioned (lava flows and tuffs) are approximately laid in a horizontal manner. Tuffs and ash deposits, which have a very similar appearance, are white in colour and they are clearly identified when exposed. They constitute the substratum of a dominant proportion of the dam foundation. They tend to produce gentle slopes and, in the lower cultivated plots they are covered by alluvial clays. The exposed tuff is not cultivated. The exposed tuff is eroded by running waters and it shows erosion patterns similar to other soft clayey rocks. The resulting erosion forms tend to be rounded. However no firm evidence of piping was observed. The paper reports laboratory experiments on specimens of the intact tuff material. The suitability of the tuff, once compacted, as a core material for a zoned-earth dam was also investigated.

1.6-P-01

Characterization and Comparison of Pore Distribution in Weathered Volcanic Rocks by Different Techniques

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Volcanic rocks are widespread in different geological contexts and exhibit complex behaviors ranging from hard to extremely soft rocks, depending on mineralogy,

cementation, porosity, and weathering. Nevertheless, despite their influence on the geotechnical behavior of engineering structures and natural slopes, the relationships among physical and mechanical characteristics of these rocks are complex and still poorly understood. Mechanical properties of weathered /altered volcanic rocks are greatly influenced by the size and shape of pores. This study describes results of porosity characterization by different techniques: bulk weight and specific weight measurements, water immersion, mercury porosimetry, image analyses of thin sections, and X-ray tomography.

Ten different volcanic rocks (pyroclastic rocks and lavas) characterized by diverse degree of alteration were collected from the Ischia island, the Campi Flegrei and the Vulcini volcanoes (Italy). Weighting, water immersion and mercury porosimetry give information about total and interconnected porosity. Analysis of thin sections provides 2D estimates of porosity with data concerning pore size and distribution and their relationship with rock matrix and weathering.

X Ray tomography allows a complete 3D reconstruction of porosity distribution both before and after the performance of geomechanical tests. 3D reconstruction of pores from X-ray tomography has been performed for this study by means of images with different resolution (5 to 200 μm). Pore geometry, interconnection and distribution can be analyzed and introduced in numerical models or used to interpret rock behavior observed in situ and during laboratory tests.

Different methods of image analyses have been used in this study and they could be easily transported to other cases: image processing, data extraction and data analysis. Results are in terms of measured porosity, geometrical distribution, differences among the various adopted methods. Advantages and disadvantages are presented and discussed. The relationships with the physical and mechanical properties are presented in a companion abstract/paper.

1.6-P-02

Characterization by Impedance Spectroscopy of Porosity in Concretes with Basaltic Pyroclast Aggregates

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Clay shortage in the Canary Islands is the main reason why basaltic pyroclasts are used as aggregates for making concrete blocks employed for construction purposes. Basaltic pyroclasts as aggregates provide effective sound and thermal insulation, but its hygroscopic

behaviour is the main cause of building pathologies in the Canary Archipelago. The “picón” (local name) is a basaltic pyroclast of lapilli size with low physical, chemical and mechanical qualities to use as aggregate in cement pastes, due to its high porosity and water absorption. However, due to its abundance in the Canary Islands, it's the main raw material used in building. In this paper, we analyze samples from concrete blocks of different densities. Its structural properties are characterized by experimental techniques such as Impedance Spectroscopy (IS), Pycnometry and Mercury Intrusión Porosimetry (MIP). The aim is show that IS is a suitable technique to characterize physical properties of the material, mainly porosity.

1.6-P-03

Detailed Studies and Stabilization Methods of Volcanic Rocky Slopes in Coastal Areas, Canary Islands, Spain

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Natural relief on mountainous volcanic islands has deep ravines, steep rocky slopes and high coastal cliffs. Volcanic formations have very heterogeneous rocks and soils. Besides, civil and building works sometimes include high cuts on the terrain and, as a result, many urban areas have been affected by rock falls and landslides. We show two case studies of the Canary Islands: (1) Rock fall hazard study and stabilization methods on Los Teques slope, Mogán, Southern Gran Canaria Island, and (2) Geologic-geotechnical study for a foot-path project in Morro Jable coastal cliff, Pájara, Southern Fuerteventura Island. We conclude that sometimes classic methods of rock masses characterization are ineffective, while detailed geological studies are the best way to define and evaluate unstable zones on the slopes and to design the most convenient stabilization methods.

1.6-P-04

Geological Risk at World Class Astronomical Observatories

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Future large and extremely large ground-based telescopes will demand stable geological settings. The world class astronomical observatories of El Teide (Tenerife, Canary Islands), Roque de los Muchachos (La Palma, Canary Islands), Mauna Kea (Hawaii) and Paranal (Chile) are in or closer to volcanic environments, and hence the impact of volcanic activity has to be studied in detail. In this sense, seismic activity, the extent of lava flows, eruptive clouds and ground deformation associated to volcanic/tectonic activity have studied in terms of probabilistic risk analysis. This information might be essential in ranking astronomical sites for emplacing future large telescope infrastructures.

1.6-P-05

Geotechnical Characterization of El Verodal Tunnel in El Hierro, Spain

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El Hierro island, 0,2 million years old, is the youngest of the Canary Islands. Since it was recognized UNESCO Biosphere Reserve in 2000, the road infrastructure to be planned has to cause a minimum impact on the landscape of the island. This applies to El Verodal Tunnel to be built in the NW side of the island. Due not only to orography but also to administrative constraints, site studies are scarce. Moreover, the implementation of the existing rock mass classifications for volcanic rocks makes the design of the tunnel harder due to the great variability shown by these materials.

1.6-P-06

Geotechnical investigation guide for building in volcanic environments

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The recent emergence of the Spanish Building Technical Code (Código Técnico de la Edificación, CTE) set a regulatory landscape where the geotechnical studies become mandatory for construction in Spain. This code provides a classification for building and Terrain Types, depending on which performs the geotechnical research planning. It is therefore necessary to identify and classify the terrain as one of the three types defined in the code. For these reasons, the Regional Ministry of Works of the Government of the Canary Islands takes the initiative to develop a guide that will allow code enforcement to volcanic terrain of the Canary Islands. In this paper, the geotechnical units of the Canaries as well as their classification according to the code are defined. In addition, the number and type of minimum

geotechnical surveys carried out in each geotechnical unit is specified as a function of the planned building. Since the Canary Islands consist of a wide range of volcanic products, this guide can be applied to any other planet's volcanic region.

1.6-P-07

Geotechnical Map and Foundation Solutions of Santa Cruz de Tenerife (Spain)

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The town of Santa Cruz de Tenerife, NE Tenerife, Canary Islands, Spain, spreads on young volcanic materials which show a great heterogeneity. Very often this means a hard problem to overcome for building projects. This paper describes the geotechnical features of volcanic formations of Santa Cruz de Tenerife on data from building geotechnical studies, geotechnical maps, and rock geotechnical properties database of the Regional Ministry of Works of the Government of the Canary Islands. An inventory of different types of building foundations has been made in order to establish a correlation between volcanic terrains and foundation solutions. As a conclusion, a geotechnical zoning map of Santa Cruz de Tenerife is proposed as preliminary foundation solutions in building projects.

1.6-P-08

Hill Slope Stability Analysis in a Basaltic Rock along Western Express Highway, Bombay-A Case Study

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Stability of road cut slopes are prime concerned these days due to accelerated pace of development particularly in densely populated cities. Due to shortage of land and need of wider road compelled road designers to go for steeper slopes along the road. The basaltic rocks are exposed in undulated form within the Bombay and it's adjoining area. Western highway express is an important road which connects two important states Maharashtra and Gujarat. The problem has been more aggravated because of old transmission towers which are now more nearer to slope edge and some of them are prone to failure. In this paper, an attempt has been made to study the slope instability using numerical simulation. The rock types in study area are mostly of Deccan trap ranging in age between early Cretaceous to Eocene. They are of different kinds like massive, vesicular, amygdaloidal and weathered basalt. They are fractured and jointed in nature. Water seepage through fracture and jointed rock mass has been also observed during the field investigation. The representative rock samples were collected from the hill slope and all the pertinent geological and geotechnical parameters were determined in the laboratory which will be used as

an important input for numerical simulation. The rock properties has been converted to rock mass properties based on weakening coefficient recorded from the exposed slope face. To understand the health of the existing slope which are 40-60m high and transmission tower are 10-15m behind the slope face. A two dimensional finite difference code FLAC/Slope has been used under static and dynamic loading condition. It was found that out of three towers, one is vulnerable and needs immediate attention for strengthening. After, chemical grouting under pressure along the fracture and joint the factor of safety was again analyzed and found a substantial increase in factor of safety by 15%.

1.6-P-09

Passive Anchors within Retaining Walls to Stabilize Volcanic Rock Slopes in Road Widening

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An economical and environmentally-friendly solution to stabilize jointed vertical rock slopes in works of improvement and cross section widening of a local road section in Gran Canaria Island (Spain) is presented in this paper. Due to the mountainous relief of this territory, this road cross over an extremely narrow section between two deep cliffs with vertical rock slopes on jointed phonolitic ignimbrites, restricting widening solutions. With this aim, this paper describes a combined stabilization system designed to widen the road infrastructure and that includes numerous rock slope reinforcement measures, achieving the requirements of minimum environmental impact and maximum building simplification. The structural solution involves the construction of traditional gravity retaining walls with passive fully-grouted permanent steel bar anchorages within its foundation. The rock mass nailing under the foundation of the retaining walls and even the adjacent rock slopes is also designed. This system combines traditional constructions of high simplicity with modern techniques of rock reinforcement. The most significant advantages of the selected stabilization structural system can be summarized in: 1) Lower volume of excavation and easier construction procedure, especially on slopes with complicated access to working site and high irregularity; 2) Excellent landscape integration as a result of minimum impact and reclaiming some excavation products; 3) Longer long-term integrity of the retaining wall owing to the non-existence of concrete steel reinforcing, and 4) Achievement of elevated resistant reaction force in order to guarantee a specified factor of safety. Unitary construction cost of the proposed slope stabilization structural system was assessed around 126 €/m² slope surface (unit price in 2005), including health and safety at work measures. Based on this result, it is concluded that the required investment expenditure is notably lower with respect to other possible structural solutions.

1.6-P-10

Project for the study of radon emissions in lithotypes of the Canary archipelago. Preliminary results: geochemical characterization

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This paper presents the first results of a research project to study the possible correlation of radon concentration with chemical and geo-technical properties in lithotypes of the Canary Islands and its implications in geo-engineering and civil works. Since volcanic rocks are commonly used in the construction engineering on the Canaries, radon exhalation is an important parameter to take into account when calculating indoor radon concentration for radiological protection. First geochemical data from a selected sample of rocks show a geochemical variability in the rocks of the Canary Islands, consistent with the fact that the archipelago is one of the best natural laboratories in the world from the volcanological point of view. This is coherent with a high lithological variability highlighted in many previous investigations as well as on this occasion. In a previous work (Eff-Darwich et al., 2006) a direct relationship between radon concentration and silica content was presented. However, this correlation appears to be incomplete due to lack of data on the concentration of certain radioactive elements which may be related to the radon activity as in the case of Uranium. It is emphasized here that some studied samples of quirky character in the Canaries and commonly used as ornamentals in civil works show high radon concentration in accordance with high uranium content. Such is the case of the well known Tindaya quartztrachyte in which the scaled radon concentration is the highest of the studied lithotypes, a fact that corresponds with the highest uranium concentration (10.6 ppm) found among all the analyzed rocks hitherto.

1.6-P-11

Relationships Between Porosity and Physical Mechanical Properties in Weathered Volcanic Rocks

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Volcanic rocks are frequently found under weathered/ altered conditions. Degradation / transformation can occur both at the surface and at large depth causing a progressive change in the physical mechanical properties. Degradation can cause an increase in porosity and this can control the rock behaviour. In this paper we discuss the relationships between porosity characteristics, micro-structure and -texture, and the mechanical behaviour of different lithologies (pyroclastic rocks and lavas from the Ischia island, the Campi Flegrei and the Vulsini volcanoes, Italy). For each one of these lithologies a set of samples characterized by different degrees

of weathering were available.

The performed laboratory tests include: soft oedometer tests uniaxial compression, indirect tension, isotropic compression and triaxial compression with ultrasonic wave measurements. A complete description of the mechanical behaviour is obtained and a detailed description of the rock behaviour is performed through a series of pre and post failure non destructive analyses. X-Ray tomographies have been completed and compared showing deformation and compaction within the samples and allowing to analyze the influence of porosity distribution. Pore size characterization is presented in a companion abstract/manuscript.

Volumetric deformation of samples has been accurately measured during uniaxial and triaxial compression tests to evaluate pore collapse during loading. Results are interpreted in the key of degree of weathering and its related characteristics. An empirical linking the change in strength with the degree of alteration is presented and discussed.

1.6-P-12

Slope stability in the Canary volcanoes based on geotechnical criteria

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The stability of natural slopes in different areas of the Canary Islands have been analysed through the relation between cohesion, friction angle and slope height. The combination of estimates for geomechanical parameters of intact rocks of the Canary Archipelago, the geological strength index (GSI) and textural features were used to deduce geomechanical parameters of rock massifs. This paper discusses the changes in cohesion and friction angle as a function of the slopes height for different rock massifs and geological conditions expressed in the form of GSI. Such differences may define the threshold between stability and instability of slopes and have relevant implications in the volcanic hazards of certain areas of the Canary Islands which are discussed here.

1.6-P-13

Stability of Palaeo-Volcanic Sediment Series Weakend by Cellars in NE Hungary

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Ratio of terrains formed by palaeo-volcanic sediments is high in Northern Hungary These areas are often characterised by anthropogenic activity (historical castles, settlements, wine cellars). In the city centre of Miskolc (Hungary) the northern, steep (25°–65°) slope of the Avas hill with a relative vertical height of 80 m extends over 0.75 km² containing more than 570 wine cellars. Wine houses and buildings with no or poor utilities are

found on the surface of the densely excavated terrain. The road network is developed from the material excavated from cellars, and it is threatened by failure and landslides under dynamic load. The geological framework of the site enhances significantly this stability problem. As a preliminary investigation for the reconstruction process, environmental geological analyses including surveying the conditions of surface and sub-surface establishments and the connection between them were completed and a complex database was set. This helps to define stable and unstable areas. The hill is composed of late Badenian – mid Sarmatian (13.7–12.5 million years) acid dust tuff, variably bentonitic rhyolite tuff, re-worked sandstone, intercalated placer and extraclastic andesite tuff. Mineralogical analyses including XRD, DTA proved high content (20–60%) of clay minerals (montmorillonite). Microtectonic investigations showed significant correlation between the joint and fault network of the hill and the surrounding mountains. The stability of several cellars and the road is upset by water infiltrating through micro-fissures, the major joints and faults and along the planes of formation contacts. The database of the survey and the results of the laboratory works were inserted in to GIS system, in which classification was achieved by the Jenks method. Results reflect close correlation between on surface and underground anthropogenic activities.

1.6-P-14

Study Of Lunar Soil From Terrestrial Models (Canary Islands, Spain)

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The Moon has a surface constituted mainly of basaltic materials. They are mostly vacuolar-like basalts that are also abundant in soils of volcanic origin on Earth. The geotechnical features of these rocks from the Canary Islands are supported by the basic characteristics deduced by NASA for this type of basalts. This paper deals with the geotechnical parameters of the lunar basalts taking into account the knowledge we have of the basalts from the Canary Islands used as terrestrial models as well as their suitability as building materials in future lunar bases. It is concluded that the lunar basalt, because of their abundance, ease of management and structural strength, is the best material for the construction of roads, tracks and even blocks with regolith for shielding of dwellings and facilities required on a lunar base.

1.6-P-15

Tunnel Inventory of Grand Canary Island (Spain), Geology and associated geotechnical problems

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In the last two decades more than 30 road tunnels has been built in Grand Canary Island, using a variety of construction methods and reaching a total extension of 14.66 km. They are 156 to 1200 m long, with an average length of 458.20 m per tunnel. The inventory of tunnels includes basic design data (i.e., geometry, widths and number of lanes, velocity), geological formations and materials and the most relevant geotechnical problems. The article shows three tunnel examples which were excavated in different volcanic rocks: (1) Basanite pyroclast and lava flows in the Tafira ring road (GC-4); (2) Phonolite lava flow and agglomerates at La Laja (GC-1); and (3) Phonolitic, trachytic and rhyolitic ignimbrites and lava flows at Arguineguín-Puerto Rico stretch (GC-1). It is intended that this tunnel inventory could be useful for future projects and works in the Canary Islands.

1.6-P-16

Volcanic Dikes Engineering Properties For Storing And Regulation Of The Underground Water Resources In Volcanic Islands

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The main feature of aquifers in volcanic islands with high rainfall rates and steep topography is that they are on raised, mainly due to the presence of volcanic dikes. Dikes are igneous bodies with very high aspect ratio, which means that their thickness is usually much smaller than the other two dimensions and tend to be vertical or of high dip angle. It can be considered as impermeable and interconnected walls where aquifers, which are recharged by rain, raise the water table between the dikes. This is especially important in volcanic rift zones. The method to obtain water in these volcanic areas involves digging horizontal galleries with explosives. The galleries cross the dikes and drain the water from the water saturated area. The main problem of this type of perforation is to obtain the water continually, without the possibility of water regulation. This question has been solved by means of the reconstruction of several technically viable dikes, to enable the store of water resources through channels in order to regulate the water wealth of the built galleries. Methods, results and viability on the use of the volcanic materials as relevant works of civil engineering highlights on the following paper.

1.6-P-17

Contribution to Geotechnical Characterization of Basaltic Pyroclasts

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Both the Azores and Madeira islands, located in North Atlantic Ocean, are of volcanic nature. The present work focuses on the geotechnical characterisation of basaltic pyroclasts from the Azores and Madeira, in order to get some comparison among them. In order to characterize, evaluate the geomechanical properties and get some more geotechnical data about basaltic pyroclasts, some samples were collected in both archipelagos, to do some laboratory tests. In situ tests were also made with these materials. Results include data on SPT tests, plate load tests, Los Angeles tests, in situ dry density and specific weight tests, determination of particle size distribution, compaction and CBR tests and consolidated drained (CD) direct shear tests. Some correlations between several properties are presented, namely between the strength and the deformability of volcanic materials. Finally, some considerations are made about the potentially utilizations and problems related to engineering applications.

1.6-P-18

Tindaya Mountain Cavern: Art and Underground Engineering

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Chillida's visionary artwork to create a large Space in the Tindaya Mountain represents a big technical challenge. On the one hand, dimensions of the span and flat profile of the cavern roof are unique in underground engineering. On the other hand, the transmission of the artist's idea and the realization of an aesthetic concept combining art, technique and nature in a natural way will require an innovative support solution.

Session 2.1

2.1-O-01

A Fast and Comprehensive Risk Assessment for Tephra Accumulation Using Easily Accessible Data: the Example of Cotopaxi Volcano (Ecuador)

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In order to produce risk mitigation and efficient emergency planning prior to a crisis, planners require the knowledge of both the expected hazard (frequency and magnitude) and the vulnerability of elements at risk. As an example, we present a multidisciplinary GIS-based

method for risk assessment of tephra deposits, which is flexible enough to work with datasets of variable precision and resolution depending on data availability. Due to the constant increase of population density around volcanoes and the large dispersal of tephra from volcanic plumes, a wide range of threats such as roof collapses, destruction of crops, blockage of vital lifelines and health problems concern even remote communities. In this framework, our risk assessment method is able to provide fast and rough insights on possible eruptive scenarios and their potential consequences on surrounding populations with only few available data, which can easily be refined later.

The Cotopaxi volcano, one of Ecuador's most active volcanoes, was used to develop and test this method. Cotopaxi volcano is located 60 km south of Quito and threatens a highly populated valley. Based on field data, literature information and the Smithsonian catalogue, our hazard assessment was carried out using the advection-diffusion model TEPHRA2. We first applied a deterministic approach that evolved towards a fully probabilistic method in order to account for both the most likely eruptive scenarios as well as the variability of atmospheric conditions. We also assessed the susceptibility of lahars triggering from heavy rainfall on newly deposited tephra. In parallel, we carried out a vulnerability assessment of the physical (crops and roofs), socio-economics (populations) and functional elements-at-risk by using mainly free and easily accessible data. Both hazard and vulnerability assessments were compiled with GIS tools to draw comprehensive and tangible thematic risk maps, providing thus the first necessary step for efficient preparedness planning.

2.1-O-02

First Probabilistic Volcanic Hazard Forecasting Of The Lava Field Of Harrat Al-Madinah, Kingdom Of Saudi Arabia

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Harrat Al-Madinah Quaternary lava field, a part of a vast Cenozoic monogenetic volcanic field in western Saudi Arabia, is immediately contiguous to the boundaries of the major city of Al-Madinah. The Harrat comprises seven episodes of Quaternary volcanicity of basaltic flows and associated scoria cones. Two volcanic eruptions only ~600 years apart occurred close to the city, and their flows reached the current city bounds. The youngest of these erupted only ~750 years ago and was preceded by a swarm of felt seismicity, the strongest of which was estimated to be of magnitude ~5. The City is currently expanding right into the Harrat lava field, exposing it to a significant volcanic risk and warranting a comprehensive evaluation of volcanic hazard. Therefore, long-term volcanic hazard forecasting in Harrat Al-Madinah was carried based on vent count and structural alignment of scoria cones determined guided by aeromagnetic data. These were probabilistically treated based on a non-homogeneous Poisson process, and spatial re-

currence was obtained using a Gaussian kernel. Probability of lava invasion subsequently estimated using a Monte Carlo approach (Felpeto et al., 2007) indicated the volcanic vulnerability of the southeastern parts of the current city. The proposed extension of the City into the Harrat is thus expected to be even more volcanically vulnerable. Further, based on a vent count of 500 Quaternary vents, an average temporal recurrence rate of 3.4×10^{-6} event/year was deduced, falling within the range of average recurrence rates of monogenetic volcanic fields of the world. This recurrence, however, was deemed to only represent the lower bound of expected recurrence in the Harrat based on drilling, published aeromagnetic interpretations, and recently conducted passive seismic investigations. The results of applying a similar treatment to Harrat Al-Shaqah, the scene of the recent volcanic unrest and seismicity, indicated the robustness of the applied forecasting approach.

2.1-O-03 - Keynote lecture

Hazard From Eruptive Activity at Stromboli Volcano (Southern Italy): What we Have Learnt From the 2002-3 and 2007 Eruptions

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Stromboli is a volcanic island in southern Italy renowned for its explosive activity that has been almost continuous during the last 2000 years. The persistent explosive activity is interrupted every 3-5 years by effusive phases, with the last two occurred in 2002-3 and 2007. These effusive eruptions displayed similar sequence of events. In both cases, magma upraise within the feeder conduit led to breaching of its uppermost portion, fissure opening, and lava flow emplacement within the barren Sciara del Fuoco depression. These two eruptions displayed also a "paroxysmal" explosive event during lava flow output, with a 2-4 km high eruptive column triggering fires on vegetation and fallout of metre-sized blocks also on the populated areas. In addition, the 2002-3 eruption started with a large landslide causing a tsunami wave that hit the coast of the island and spread as far as 60 km away. A monitoring network of web cameras allowed INGV to keep constantly under control the eruptive activity, and daily helicopter surveys using a thermal camera allowed calculation of effusion rate, cumulative lava volume, and monitoring of the lava flow field growth. Images recorded from the network of web cameras allowed us to detect the opening and displacement of effusive vents, accompanied by a significant increase in the number and duration of landslides, and to follow the 2007 paroxysm with time-lapse infrared thermal and visual images recorded from fixed positions. A new conceptual model based on these new results has been recently proposed to explain the occurrence of paroxysms during lava flow output. Considering that Stromboli is a typical steady-state volcano, and that the last two effusive eruptions displayed the same sequence of events, if our model will be confirmed by further examples, this conceptual model might be the basis for forecasting paroxysmal events during future effusive eruptions.

2.1-O-04

Georisk hazard assessment and preparedness at Mt Cameroon volcano, W. Africa

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Mt Cameroon (MC) is one of the steepest and biggest inland basaltic lava-dominated volcanoes and the most active densely populated one in W Africa. MC is a type example for numerous volcanoes in the developing world, i.e. not systematically mapped for their geology, hazards or risks, or monitored with state-of-the-art techniques, or for which there has not been any sophisticated hazard experience surveys, risk awareness campaigns, any integration of stakeholder efforts, or disaster preparedness or communication strategy in advance of geohazard crises. Thanks to a long-term bilateral cooperation (VLIR) between Belgian and local/regional stakeholders, progress is being made for capacity building and training in geohazard-relevant observations, measurements, monitoring and modeling as well as for applications enhancing hazard experience and risk awareness knowledge, and risk awareness raising, stakeholder participation, improved communication and overall integration via GIS for disaster preparedness and response. Examples of advances include 1) first systematic RS and field mapping studies of historic lava flows, RS hazard and risk zoning and ongoing thermo-mechanical modeling including for lava flow risk assessment; 2) first systematic field, lab and risk susceptibility studies for small devastating volcano landslides; 3) first field and lab modeling of the overall volcano structure demonstrating MC spreading; 4) ongoing assessment of volcanic tremor and toxic ash fall impacts and assessment of the outgassing hazard from local crater lakes. These efforts have been accompanied by the setup of an RS monitoring unit. Three independent surveys relevant to understanding of geohazard experience have also been carried out and insights helped the stakeholder group in the design and deployment of public billboards to raise collective awareness. Advances are GIS-integrated, linked to active stakeholder participation at all levels, helping local geoscientists and the authorities alike in their effective disaster preparedness before the next crises.

2.1-O-05

Far-range Volcanic Ash Hazard from Somma-Vesuvius. Consequences for Civil Aviation over the Central Mediterranean Area

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8. Volcanic ash causes multiple hazards. Among them, one aspect of increasing importance is the threat posed

to aerial navigation, which occurs from proximal to far-range distances. Ash fallout disrupts airports and the presence of airborne ash at low atmospheric levels near airports affects visibility and safety of landing and take-off operations. On the other hand, low concentrations of ash at airplane cruise levels are sufficient to force re-routing of in-flight aircrafts. Volcanic fallout deposits from Somma-Vesuvius volcano have been recognized at large distances for several Holocene explosive eruptions. We elaborate hazard and isochrone maps for distal ash fallout from Somma-Vesuvius volcano and hazard maps for critical ash concentrations at relevant flight levels. Maps are computed by coupling a meteorological model with a fully numeric tephra dispersal model that can account for ash aggregation processes, relevant to the dispersion dynamics of fine ash. The simulations span continuously along a meteorological year that is statistically representative of the local meteorology during last decades. Seasonal influence is also analyzed. The eruptive scenario is based on the AD 472 eruption of Somma-Vesuvius, which is in the range of the maximum expected event at this volcano. Results allow us to quantify the impact that an event of this magnitude and intensity would have on the main airports and aerial corridors of the Central Mediterranean Area.

2.1-O-06

Combining Probabilistic Hazard Assessment With Cost-Benefit Analysis To Support Decision Making In A Volcanic Crisis From The Auckland Volcanic Field, New Zealand

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One of modern volcanology's challenges is to provide useful information for decision-making in land-use planning and emergency management. In practice, the scientific community has to provide reliable and quantitative long- and short-term volcanic hazard assessment and eruption forecasting, and, due to the complex nature of volcanic events, a probabilistic approach is necessary. In recent years, a probabilistic code has been developed for quantitative volcanic hazard assessment (BET_VH), based on a Bayesian Event Tree. At each node of the tree, a probability is computed by taking into account heterogeneous sources of information (models, past occurrences, expert opinion and numerical models). The output of the tree is a probability distribution accounting for aleatory and epistemic uncertainty.

In this study, we apply BET_VH to quantify volcanic hazard due to base surge invasion in Auckland, New Zealand's most populous city. Currently, we are focussing on the scenario simulated during Ruauumoko, a national disaster exercise.

Based on recent papers, we suggest a possible quantitative strategy to link probabilistic scientific output and

Boolean decision-making, based on Cost-Benefit Analysis. This strategy does not guarantee to recommend a decision that we would have taken with the benefit of hindsight, but it will be successful over the long-term. Furthermore, it provides a quantitative decision rule that is set before any emergency.

In our present application, we set up a Cost-Benefit scheme for the call of an evacuation to protect people in the Auckland Volcanic Field against base surge invasion. Considering the heterogeneity of the urban environment and the size of the region at risk, we propose a Cost-Benefit scheme that is space dependent, to take into account higher costs when an eruption threatens critical sites, such as the international airport or the harbour. Finally, we compare our findings with the present Contingency Plan for Auckland.

2.1-O-07

Safety Assessment of Volcanic Hazards on Nuclear Power Plants in Japan

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Some of 55 nuclear power plants (NPPs) operated in Japan locate not far from active volcanoes. The installation was planned unfortunately in the time, relatively calm time of the volcanic activity had continued in Japan from the beginning in the 20th century. It is likely that the situation could have induced insufficient assessment on volcanic hazards at the sites of NPPs, although they, off course, had paid attention to avoid natural hazards that may ruin the safety of NPPs in non-volcanological point of view. Presently, IAEA is preparing the Safety Guide of volcanic hazards in site evaluation for nuclear installations (Hill et al., 2009), which insists transparency and traceability of the assessment in both probabilistic and deterministic approaches. Japan Electric Association prepared its own technical standard on the volcanic hazard assessment on the nuclear power plants in 2009, referring to the IAEA guide. The present technical standard is, however, using only the deterministic approach, taking the presence of abundant and detail volcanological database in Japan into consideration. In the same time, Nuclear and Industrial Safety Agency (government organization) also issued their comments on volcanic hazard assessment involving the probabilistic approach and geophysical monitoring, again referring to the IAEA guide. Evaluation using the above technical standard has been carried out for the radioactive waste interim depository in Japan. Nevertheless, simple deterministic approaches for the existing NPPs in Hokkaido and Kyushu may not be sufficient to some NPP sites within the arrival distance of caldera-forming pyroclastic flows that occurred there in the prehistoric time. Consideration based on recurrence rates and eruption scenarios of large pyroclastic flow events becomes very essential at these sites. In Kyushu, caldera-forming climactic events were repeated at intervals of approximately >50 kyrs and were preceded by multiple plinian events in smaller scales or effusion events of high-temperature lava flows.

2.1-O-08

Risk assessment of lava flows

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The flanks of several basaltic volcanoes are highly populated, with towns, cities and associated infrastructures at risk of being impacted by lava flows during effusive eruptions. Although lava flows only rarely cause human fatalities or injuries, Etnean flank eruptions have often caused severe damage to human property. We use the probabilistic code DOWNFLOW to simulate a very large number of possible future effusive events, with the aim of assessing lava flow hazard and risk. DOWNFLOW has been already extensively used and validated at Mount Etna, Cameroon and Nyiragongo volcanoes. This code is based on the steepest descent path (SDP) as first order approximation for lava flow paths, with added higher order deviations (flow dispersion, obstacle and depression overcoming, etc.) controlled by the local stability properties of the SDP. At Etna we calculate lava flow emplacement areas from more than 70,000 potential vents distributed according to their estimated probability. Statistics from past lava flows are used to constrain the expected flow lengths. In addition to standard risk maps, which classify areas according to the expected damage at each point, we classify each point of the volcano with respect to the damage that would occur from a vent at that point. Sensitivity analyses are performed in order to assess the relevance of uncertainties in input data. In particular, the topographic changes of the volcano in the time interval 1986–2007 are recognized to influence the preferential lava flow paths. We conclude that the persistent activity of this volcano requires frequent updating of the topography and DEM production for reliable lava flow hazard and risk assessment.

2.1-O-09

Seismic Series Accompanish the 1704-1705 Eruption of Sietefuentes-Fasnía-Arafo and their Effects. Volcanological and Seismological Implications

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In the island of Tenerife, since 1496 five eruptive episodes have been reported with documental information, (Eruptions of S. XVI, 1704-1705, 1706, 1798 and 1909). The eruptive episode of December 1704 to March 1705 has large documental information, including details of the seismic series that preceded and accompanied the different eruptive phases. In this eruption three different eruptive centres were defined. Each eruptive centre is characterized by a set of individual craters, from 4 to 24, all of them aligned to the NE-SW direction. This fissure is 10.6 km long and it is parallel to the topographic edge of the NE dorsal range of Tenerife Island. The eruption had a VEI index low (2,3) and the emitted material was of basaltic nature with moderate explosions, and altitude of the eruptive columns of around 1000-2000 m.

The elevation of the volcanic centres did not produce any personal damage during the eruptive episodes. However, the seismic series that preceded and accompanies the episodes generated 16 people died, many injured, severe damages over infrastructures and houses and a strong social alarm. The effect of the seismic activity was so strong that the main of the historical documentation was centred more over the seismic effects than over the volcanic activity.

In the present work we recovered the majority of the historical documentation related with the seismic crisis of this volcanic episode. We have described the main effect, evaluated the constructive typology and assigned a tentative value of the expected intensity of those that produced damages. The maximum intensity evaluated was of VIII and several events with intensity between VI and VII have been identified.

Finally we evaluated this seismic activity in term of volcanic processes and its significance in relation to the volcanic risk but more in the seismic risk of the island.

2.1-O-10

Characterization of the deposits and evaluation of the impact parameters on the surrounding areas of gas-eruptions at the Fossa Cone (Vulcano, Southern Italy): the Commenda eruption.

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Many small-scale explosive eruptions expel non-juvenile rock only eventually entrained in a mixture of gas, steam or liquid water. In terms of muzzle velocities of pyroclasts, non-juvenile gas and steam-blast eruptions are comparable with those of most large magmatic or phreatomagmatic eruptions. Associated phenomena include the onset of dilute to dense pyroclastic density currents and generation of weak, often vapor-rich convective plumes. In this work the features of the Commenda Eruption, the biggest non-juvenile eruption occurred at the Fossa Cone (Vulcano, Southern Italy) in the last 1000 years, are summarized and interpreted in the context of a detailed new tephrostratigraphic analysis. The Fossa Cone is characterized by clear signs of volcanic unrest and is known to produce a variety of eruption styles and intensities, each posing their own hazards and threats. The Commenda Eruption deposits have been traced all around the Fossa cone in more than 100 stratigraphic sections including both natural outcrops and trenches. These deposits, display a widespread distribution around La Fossa Cone and a large range of deposit features (geometry, dispersion, facies variation) compatible with various types of emplacement: dilute PDC, dense PDC and fallout. We have also identified secondary transport-sedimentation processes by a detailed facies analysis of deposits. Grain-size and componentry analysis were used, in conjunction with facies-analysis, to reconstruct the eruptive activity and derive quantitative parameters for the transport-sedimentation behavior of dilute density currents. Failure to recognize the non-magmatic origin of these deposits, or underestimate the intensity of these eruption could

result in a misinterpretation of actual hazard.

2.1-O-11

Long-Term Discharge Rate in Step Diagram For Forecasting Caldera Volcanism

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Large explosive volcanism has often been dormant longer than ten thousand years but is a potential threat to give a severe damage into modern society. Due to this hazardous reason, an adequate and systematic tool is needed to assess a volcanic hazard from future large explosive eruption. The geologic tool is a realistic approach for the assessment. Changes of style, magnitude, timing and location at past eruption play an important role to give a plausible scenario of future eruption and its hazard. Precise measurements in eruption age and volume of ejecta at a volcano or a volcanic field are essential to analyze long-term discharge rate of erupted magma and its change, drawn as "step diagram." The discharge rate curve at an actual volcano shows diverse patterns, and the curve gradient often changes in stage of volcano evolution. Careful observations in the change of discharge rate linked with change of magma property and evolutionary stage are necessary. The average of long-term discharge rate in three Japanese calderas is amount of a few km³ (DRE)/ky. A number and amount of eruption event, magma property and a total duration of volcanism are distinct in those calderas. Nevertheless, the similarity observed in discharge rate is fruitful to discuss the process of preparation for the large explosive eruption. Duration of smaller amount of discharge rate than total rate occurs between each large explosive eruption. Such duration is in the range of ca. 15,000 years in Towada, ca. 20,000 years in the Kuttara and ca. 60,000 years in the Aira. It could correspond to the period for accumulating a sufficient amount of magma in the magma chamber. This study was performed under the sponsorship of Japan Nuclear Energy Safety Organization (JNES) Fundamental Research Project on Nuclear Safety.

2.1-O-12

Fate and Hazards of Medium-Size Resurgent Calderas: the Case of Campi Flegrei, Ischia and Pantelleria Structures

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Assessment of time and space relationships among magmatism, volcanism, and resurgence of medium-size calderas is a necessary tool to formulate a general model for their dynamics which also permits to forecast their evolution.

To define a general hypothesis for the Campi Flegrei caldera, in a persistent state of unrest, the Ischia and Pantelleria medium-size resurgent structures, in variable stages of evolution, have also been investigated. In particular some parameters such as the structural and volcanological evolution, with emphasis on resurgence dynamics and coeval volcanism, and the evolution, present state and role of the magmatic system in resurgence, have been defined. For the Campi Flegrei caldera, the data collected during unrest episodes have also been taken into account, together with those from past eruptions. They corroborate the hypothesis that the unrest episodes are transient short-term events within the long-term deformation related to caldera resurgence. The geometry of the short-term deformation is strictly related to the structural setting of the caldera. The sub-surface processes have been dominated by joint degassing of two magmatic bodies, at 3-4 and 8 (or more) km depth, with the shallower formed by magma ascending from the deeper body. Both bodies contribute to the hydrothermal system, but the shallow magma is fluxed by the continuous upstream of CO₂-richer gas released by the deep body. The two-layer degassing magma allows explaining geochemical and petrological features of unrest and volcanism.

The joined interpretation of geological, geodetic, and geochemical data on the three calderas is an innovative approach that adds a time-perspective on how resurgent calderas behave. The proposed general hypothesis will help in long- and short-term volcanic hazards assessment and will support Civil Defence Authorities in elaborating actions devoted to volcanic risk reduction.

2.1-O-13

Analysis Of The LaMEVE Database On Global Quaternary Large Magnitude Explosive Volcanism.

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A database of Quaternary large magnitude explosive eruptions ($M \geq 4$) is under development as part of the VOGRIPA project on global volcanic hazards and risk. The database currently consists of 1929 entries from 481 Quaternary volcanoes. The database can be applied to constraining the magnitude-frequency relationship of global and regional volcanism. Under-recording is a major feature of the data with the proportion of events recorded from written records or geological data decreasing markedly back in time. In the Holocene the

proportion of eruptions recorded by geological studies prior to 2000 years BP is assessed at about 15%. Prior to 100 ka less than 1% of eruptions have been recorded. Under-recording is more marked for smaller eruptions because preservation potential of deposits increases with eruption magnitude. Analysis of the data indicates that, notwithstanding under-recording, temporal changes in global volcanism are apparent, notably a late glacial increase in the 13 to 9 ka period. Application of extreme value statistics to a Holocene subset of data, corrected for under-recording, enables construction of a magnitude-frequency relationship for global volcanism. Return periods based on maximum likelihood statistical analysis are 7.9 years for $M \geq 4$, 35 years for $M \geq 5$, and 370 years for $M \geq 7.0$ with uncertainty increasing with magnitude. The return periods depend on the threshold chosen between the main part of the distribution and the extreme value tail and the results cited here are for a threshold of $M = 4$. For the largest magnitude eruptions ($M > 7.5$) the Holocene period is too short to obtain a meaningful result. Data from Japan constitutes almost 50% of global data. The LaMEVE database is to be made publically available in early 2011 with a web interface allowing the input of new data and corrections by the volcanological community.

2.1-O-14 - Keynote lecture

Volcanic Eruptions and Insurance

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The Smithsonian catalog lists the VEI 6 eruption of Pinatubo as beginning on 2nd April and ending on 2nd September 1991. Damage to houses and other buildings by lahars continued for months, even years, after the "end" of the eruption. Similarly, New Zealand's biggest volcanic disaster of the 20th century occurred on Christmas Eve 1953 when a lahar ejected from Ruapehu's crater lake resulted in the deaths of 151 people on the overnight Wellington-Auckland express train. But Ruapehu did not "erupt" between July 1952 and November 1956. In 2000 hydrothermal activity in Rotorua, New Zealand, damaged several houses. On Montserrat numerous houses, barely damaged by tephra fall, are effectively "total constructive losses" to their owners as they lie deep within the Exclusion Zone that has endured for more than a decade.

Would the damage implied in each of the examples above be covered under an average insurance or reinsurance contract which might include the phrase: "The words 'loss occurrence' shall mean all individual losses arising out of and directly occasioned by one catastrophe. However, the duration and extent of any 'loss occurrence' so defined shall be limited to: ... (b) 72 consecutive hours as regards earthquake, seaquake, tidal wave, and/or volcanic eruption".

Other insurance contracts might refer to "volcanic eruption event", "volcanic activity", "volcanic eruption (seismic) events", or even "losses caused by earthquake, volcano, tsunami, ...". Do all these phrases mean the same thing? What effect does limiting a 'loss occurrence' to 72 hours have, when most eruptions last considerably longer? Who pays for debris removal and/or clean up? How might insurers respond if a major erup-

tion was predicted more than 12 months in advance?

These and other exciting questions should exercise the minds of policy holders and insurance underwriters alike.

2.1-O-15

Volcanic induced Mega-Tsunamis in the Galapagos – Tectonics, Monitoring and Early Alert System

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There is little recorded information about regular tsunamis in Ecuador or its coast, as result of the lack of research about paleotsunamic deposits (Chunga et al., 2005). Nonetheless, there are some eleven tsunamis registered, which stroke the Ecuadorian coast in the last two centuries, one of them being generated in 1906 with an intensity of 8.8 Mw. There is even less information about the potential of mega-tsunamis induced by volcanic activity or by volcanoes of the Galápagos Islands. However, there is evidence of a megatsunami that has occurred in the islands of Galapagos with the flank collapse of the dissected volcano Ecuador some 100,000 years ago (Geist et al, 2002). Due to a study of images (GEOMAP STRM 50 and GTOPO30 DEM) above and below sea surface a further potential megatsunami can be triggered due to the instability of the small roughly circular islet belonging to the active Roca Redonda volcano, also at the Galapagos (Cando et al., 2006; Glass et al., 2007). Based on this analysis, four different trends of lineaments or fault systems have been identified, some of them being still active. The conjunction of some of these lineaments and or faults at Roca Redonda clearly indicate evidence for a potentially massive, mainly submarine future sector collapse with a volume of several cubic kilometers perpendicular towards the southern side of the last identified lineament direction. Tsunami arrival times calculated indicate impacts of less than 36 minutes for all three major villages at the Galapagos Islands and some 2 hours 15 minutes for major villages around the Ecuadorian coast (Cando et al., 2006). As it is very unlikely, that a future potentially catastrophic event cannot be mitigated due to the volume of material in movement, a new early alert system (Toulkeridis et al., 2007), will be installed during this year.

2.1-O-16 - Keynote lecture

Volcanic Mega-Landslides in Tenerife (Canary Islands, Spain)

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in the last two decades it has been accepted the occurrence of prehistoric mega-landslides in volcanic buildings, as well as the influence of these processes in the evolution and growth of volcanic islands. More than 20 paleo-landslides have been described in the Canaries. Güimar and La Orotava valleys in Tenerife are two exceptional examples, because of their outstanding geomorphological features and the fact that the landslide deposits have been identified in the ocean floor, as well

as inside the underground adits excavated for water supply purposes in the island.

In spite of their importance only few investigations have been carried out to explain these large instability processes based on geomechanical criteria, including why and how these mega-landslides have taken place, which were the mechanisms responsible for such processes and the role of the influencing and triggering factors on the instability.

In order to investigate the causes and mechanism of the flank failure processes in Tenerife, the geological and geomechanical models of the volcanic edifice have been established, and stability analysis of the flanks have been carried out.

Detailed surveys on the volcanic rock masses affected by the mega-landslides have been carried out, and the geological and morphological conditions of the pre-failure volcanic edifices have been established. Site investigation includes boreholes and geophysical surveys, inside borehole deformability tests, geomechanical laboratory tests, absolute age determinations and petrological and mineralogical analysis. These investigations have been carried out in order to determine geological and geomechanical models. Based on these data, an assessment on the stability conditions have been carried out. The geomechanical behaviour of the rock masses and the role of other influencing factors on the failure mechanisms of Güimar and La Orotava mega-landslides have been analysed.

The role of the submarine fragmentary materials on the global stability of the island flanks, as well as other contributing factors such as dike intrusion pressure, seismic dynamic forces, geomorphological conditions and groundwater pore pressures have been considered.

2.1-P-01

Map of the Volcanic Risk in the Ceboruco Volcano, Nayarit, Mexico.

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The Ceboruco Volcano is located in the northwestern part of the Tepic-Zacoalco graben. Its volcanic activity can be divided in four eruptive cycles differentiated by their VEI and chemical variations as well. As a result of andesitic effusive activity, during the first cycle was constructed the “paleo-Ceboruco” edifice. The end of this cycle is defined by a plinian eruption (VEI between 3 and 4) which occurred some 1020 years ago and formed the external caldera. During the second cycle an andesitic dome built up in the interior of the caldera. The dome collapsed and formed the internal caldera. The third cycle is represented by andesitic lava flows which partially cover the northern and south-southwestern part of the edifice. The last cycle is represented by the andesitic lava flows of the nineteenth century located in the southwestern flank of the volcano. Actually, moderate fumarolic activity occurs in the upper part of the volcano showing temperatures ranging between 20° and 120°C. Some volcanic high frequency tremors have

also been registered near the edifice.

According with the eruptive history of the volcano, the most dangerous expected volcanic activity should be related to lava flows, ash falls, pyroclastic flows or lahars.

In 2005, the population around the Ceboruco Volcano was the 65,000, concentrated in 107 localities showing an increasing annual rate of 1.2%. The most important economic activity in the area is agriculture. Regional commercial activities are concentrated in the localities of Ixtlán, Jala and Ahuacatlán. In addition, the most important commercial routes along the Pacific are located near its flanks.

The results, summarized in maps of risk due to ash fall and volcanic flows, are designed to be used as instruments for Territorial Ordering, elaboration of operative plans to be use in case of a volcanic emergency and economic reactivation after an eruptive event.

2.1-P-02

Application of FLOWGO Model in Hazard Zoning of Lava Flow at Tianchi Volcano in China

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Tianchi volcano of the Changbaishan Mountain is one of the most active Holocene volcanoes in Northeast China. The recent lava flows erupted by the Tianchi volcano are composed mainly of pantellerrite characterized by high SiO₂ content, high viscosity, high phenocryst content and low flow velocity. We select 15 gullies or valleys on 1:50,000 digital topographic map as the possible channels of the future lava flows, with the assumption that the lip of the crater will become the future parasitic vent. The possible traveling lengths of lava flows along 15 channels at effusion rate of 50m³/s to 500m³/s are calculated with FLOWGO program in the light of the kinematic model of lava flow proposed by Harris and Rowland in 2001 based on thermal rheologic theory. As the slope of Tianchi crater is steep, the traveling length of high-viscosity pantellerrite under action of gravity is still relatively great. In addition, variation of such parameters of lava flow as flow velocity, viscosity, temperature and phenocryst content were calculated as well. According to the results of calculations incorporating with the DEM topographic data, the lava flow hazard areas in the Tianchi volcano are classified into 4 classes. The most dangerous area I (<100 m³/s) is distributed within the range of 3 km around the crater; distribution of the third dangerous area III (<350 m³/s) and the fourth dangerous area IV (<500 m³/s) are affected greatly by terrain. At southern slope of the crater, the flow front reaches about 7km and 9km from the crater, while at other slopes the flow front reaches as far as about 10km and 14km from the crater. This preliminary hazard zoning of lava flow may provide reference for the local government in land planning volcanic hazard emergent management.

2.1-P-03

Study Of Volcanic Risk Through ⁴⁰Ar/³⁹Ar Elevated Precision Datings Of Neapolitan Area Volcanic Deposits.

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The Neapolitan area extends, virtually unbroken, from the Bay of Naples to the Bay of Pozzuoli hosting some of the most densely populated districts in Europe. The geological nature of this volcanic territory, and the presence of three active volcanic zones (Vesuvius, Campi Flegrei, and Ischia), poses a high risk for all the inhabitants (1.5 millions) and the tourists. The autochthonous volcanism in the Neapolitan urban area has been investigated to fully evaluate the volcanic risk in this urban environment. That has been made through ⁴⁰Ar/³⁹Ar elevated precision dating on samples obtained from eight volcanic deposits cropping out in the Neapolitan area. By using this dating technique, it is possible to obtain radiometric ages with a 2% less than 1000 years. Instead, through stratigraphic hypothesis has been only stated that the volcanism in the Neapolitan urban area started before the Campanian Ignimbrite eruption (39 ka) and possibly ended about few thousand years ago with minor eruptions building small tuff cones. Therefore, there have been measured, with the high sensitivity MAP216 mass spectrometer, argon isotopes extracted stepwise thermally from those samples previously irradiated. Then, from these measurements, the ages were evaluated in two ways. One way is to plot all the apparent ages vs the cumulative ³⁹Ar released (Age Spectrum), to calculate a Weighted Mean Plateau Age (WMPA) with a 2% precision. The other way is to plot the ⁴⁰Ar/³⁶Ar ratio vs the ³⁹Ar/³⁶Ar ratio on an Isotope Correlation (Isochron) Plot, to calculate an Isochron Age (IA) with a 2% precision. The oldest ⁴⁰Ar/³⁹Ar predates local tuff cones above 78.43 ± 0.57 ka ago, and the youngest below 15.56 ± 0.36 ka. These results testify the existence of a volcanic field in the Neapolitan area active for a much wider period of time than previously believed.

2.1-P-04

Risk reduction in a volcanic-island setting: the example of the island of Vulcano, Italy

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A volcanic eruption is an event capable of producing a variety of hazards that can affect the built environment in a variety of ways, over different time scales and with different degrees of intensity. Our model for the assessment of exposure-based volcanic risk is tested on the island of Vulcano in southern Italy. The main active system of Vulcano Island (La Fossa cone) is known to produce a variety of eruption styles and intensities, each posing their own hazards and threats. The urbanization on Vulcano took place with no real planning. The population (800 inhabitants) mostly subsists on tourism in summer months when the island's population swells to around 20,000. Most tourist facilities are located in the Porto area, beneath the lowest flank of La Fossa

cone, resulting in a multi-facet territorial vulnerability associated with a complex range of potential eruptive scenarios. Our proposed model is based on the compilation of three types of maps: hazard maps, hazard-specific vulnerability maps and exposure-based risk maps. Hazard maps identify the spatial distribution of individual volcanic hazards and it includes both event analysis and impact analysis. Hazard-specific vulnerability maps represent the systematic evaluation of physical vulnerability of the built environment to a range of volcanic phenomena. Hazard-specific vulnerability maps are then overlapped with hazard maps in order to compile exposure-based risk maps and so define the potential damage. Special attention is given to the critical facilities and lifelines that play an important role in the characterization of autonomy/dependency of the community to those systems during a crisis. The important aspect is not only the physical capacity of a system to resist, but also its capacity to continue functioning. The analysis is fundamental for both strategies of risk reduction and evacuation planning.

2.1-P-05

The El Hierro Volcanic Hazard Database

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Volcanic hazard studies need a complete database that allows inferring the volcanic activity history. In the Canary Islands the historical period includes only the last 500 years. So, the main handicap for these studies is the lack of well reported data. For this reason, the Spanish Geological Survey (IGME) has started a systematic organization of the existing data, starting with El Hierro island. The El Hierro database is based on a GIS and includes several groups of information like topographical, geomorphological and geological maps, geochronological data, geochemical data and climatic data. All of these data have been subjected to a quality control before they have been included in the database. We have incorporated all the previous information and generated new data through field studies. The published data includes 38 topographical maps at a 1:5.000 scale, an elevation digital model, the geological and geomorphological maps at a 1:25.000 scale, 43 geochronological records and 136 geochemical records. The geochronological and geochemical data are located mainly in the eastern part of the island, and they are not concentrated in the recent deposits. Structural information has been generated during this study. We have identified up to 312 volcanic vents and inferred 54 eruptive fissures. In addition, 564 dykes have been studied, both on field outcrops and inside water galleries. The analysis of these data suggests that it is necessary to carry out new geochronological and geochemical studies in the southern and western sectors of El Hierro. In addition, it is necessary to compile other data such as volumetric data, lava flows thickness, pyroclastics distribution, etc. The filling of the database and its volcanological analysis will allow to map volcanic hazards and to run reliable models of these volcanic hazards.

2.1-P-06

The Southern Boundary Of The Seaward-Sliding Eastern Flank Of Mt. Etna: Evidences On Active Faults In Urban Areas From Soil Gases And Satellite Data

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From October 2008 to November 2009, soil CO₂ and Rn surveys have been performed, in order to get insights upon active tectonic structures in a densely populated sector of the South-Eastern flank of Mt Etna, which seems to be involved in the flank dynamics, as highlighted by satellite data (INSAR). The investigated area extends about 150 km², in an area, where INSAR data detected several lineaments not known from geological surveys. The method adopted to perform the 345 soil CO₂ measurements is the “dynamic concentration” method (Gurrieri and Valenza, 1988; Camarda et al., 2006), which provides a proxy for soil CO₂ fluxes. The gas measurements have been performed along transects roughly orthogonal to the lineaments, with measurement points spaced about 100m. The method appeared more efficient than a regular grid, which would have requested much more measurements and a time-consuming field work. CO₂ data show the highest values, along each transect, very close to the lineaments evidenced by INSAR observations. Anomalous values also occur in correspondence of eruptive fractures. In some portions of the investigated area, rather broad anomalies are observed, and this would imply that, instead of a single well-defined lineament, a wider fault zone probably exists. A set of both CO₂ and Rn measurements, performed at about 900m of altitude, are worth of note, because they allow identifying the lengthening of detected lineaments at higher elevation, where the INSAR data are poorly informative. Finally, at the base of the volcanic edifice, the soil gas anomalies strikingly define the active structures until almost the coastline through the northern periphery of Catania town. The coupling of the two methods thus revealed as a powerful tool to detect buried active structures, which conversely do not show significant field evidences. References: Gurrieri and Valenza, 1988, Rend SIMP; Camarda et al., JGR.

2.1-P-07

Turrialba volcano's threat to the cities of the Central Valley of Costa Rica

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Turrialba volcano lies on the easternmost edge of the Central Volcanic Range of Costa Rica, <30 km away from the western Central Valley (~2.1 million inhabitants in 2010). Since the winds mainly blow from the Caribbean into mainland (E-W), and Central Valley is downwind from Turrialba, this poses a potential major threat to cities in there. Six powerful eruptions have taken place from Turrialba during the last 3400 years, and isopachs show that ashfall affected the western Central Valley. Turrialba has had summit fumaroles at least since 1723 and a strombolian-vulcanian eruption occurred in 1864-66, severely affecting a radius of 3 km around the volcano, and blowing ashes over the capital San José, and down to the Pacific coast, ~130 km away. Since then, fumarolic activity (T~90°C) has been present. Tectonic swarms with epicenters along the main tectonic feature (a SW-trending zone with craters, faults, pyroclastic cones and fumaroles) have been recorded at least since 1982. A restless stage initiated in 1995 and particularly since 2007, when wider fumarolic areas, escalating temperatures (T=200-300°C) in them, and seismicity around the southwestern crater have appeared. Resulting acid rain (pH<5) has remarkably affected ~50 km² on the western flank. On January 5-6, 2010, lithic ash was erupted due to strong fumarolic-phreatic activity from a small newly-opened fumarolic vent (T>500°C). The very fine ashes distributed in well accordance to previous expectations, to southwest and west, reaching the eastern suburbs of San José (35 km away). Future eruptions (months to decades on), phreatic or magmatic, pose a major threat for farms and housing 5 km around the volcano and significant threats to agriculture, pastures and telecommunications on the western side of the volcano. The most likely "biggest-scenario eruption" would affect up to 1.5 million people and aerial transportation, because the main Costa Rican international airport lies on the ash dispersion trend.

2.1-P-08

Reconstruction of the lava flow field evolution and lava discharge from the great and destructive 1669 Etna eruption: implication for volcanic hazard assessment

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The 1669 flank eruption was the most destructive event on Etna volcano in historical times. During this eruption, lasting 120 days, lava flows emitted from a vent at 700 m a.s.l. in the lower SE flank destroyed several villages and towns and part of the city of Catania. In addition to considerable economic damage, the wide area covered by the lava flow (39.84 km²) and its maximum length of 17 km caused a major modifications to the urban setting of the entire southern flank of Etna, strongly conditioning subsequent expansion of Catania. The presence of several quarries in the 1669 lava flow and the collec-

tion of subsurface data allowed both directly collecting thickness measurements and observing the lava field internal structure. In addition, the analysis of the numerous and detailed historical sources allowed reconstructing the temporal evolution of the lava flow field. Moreover the different datasets and in particular the chance of observing the flow internal structure, brought to light by the quarries, evidenced that, during the first eighteen days, the lava flow field was emplaced as single wide flow units. In addition the collected data allowed to reconstruct, for the first time, the temporal variation of the lava discharge of an historical eruption at Etna. The results show that the first days of the 1669 eruption were characterized by an huge average effusion rate and that the 70% of the lava field formed during the first period when most of the damages occurred. Finally, the reconstructed lava discharge trend was adopted as input of numerical simulations, performed by MAGFLOW Cellular Automata model, aimed at assessing the effects of the most hazardous eruptive event expected at Etna volcano in its highest urbanized area.

2.1-P-09

Volcanic Risk Metrics At Mt Ruapehu, New Zealand: Some Background To A Probabilistic Eruption Forecasting Scheme And A Cost/Benefit Analysis At An Open Conduit Volcano

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Bayesian Event Tree for Eruption Forecasting (BET_EF) is a probabilistic model that was created to compute probabilities related to pre-eruptive phases at long-dormant, but monitored, volcanoes. It assumes that movements of magma in closed conduit volcanoes will produce detectable changes in the monitored parameters at the surface. Here, we attempt to apply BET_EF to Mt Ruapehu, a very active and well-monitored volcano exhibiting typical features of open conduit volcanoes. In such conditions, current monitoring at the surface may not detect short-term changes at depth occurring seconds to minutes before eruptions. This results in the so-called "blue sky eruptions" of Mt Ruapehu, i.e., volcanic eruptions apparently not preceded by any presently detectable signal in the current monitoring. A further complication arises from the hydrothermal system and crater lake on top of the magmatic conduit, as these may mask monitoring signals produced at depth.

Notwithstanding these potential drawbacks, we attempt to apply BET_EF at Ruapehu, because (i) apart from a few "blue sky" events, monitoring data can be helpful in forecasting major events, and (ii) in setting up BET_EF, we are forced to define quantitatively what the background activity is, and consequently identify what changes in monitored parameters influence the prob-

ability of eruption.

In the last 50 years, syn-eruptive lahars have been generated, and some have reached the ski fields on the slopes of Ruapehu. Here, we use BET_EF in a decision scheme based on cost/benefit analysis. In this scheme, we compute the C/L ratio, where C represents the costs of a practical mitigation action and L is the potential loss if no mitigation action is taken and a syn-eruptive lahar reaches the ski fields. By comparing the probability of syn-eruptive lahars and C/L, we can identify when to take a mitigation action to reduce risk to people on ski fields.

2.1-P-10

Emergency Preparedness: Community-Based Short-Term Eruption Forecasting At Campi Flegrei

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A key element in emergency preparedness is to define advance tools to assist decision makers and emergency management groups during crises. Such tools must be prepared in advance, accounting for all of expertise and scientific knowledge accumulated through time. During a pre-eruptive phase, the key for sound short-term eruption forecasting is the analysis of monitoring signals. This involves the capability (i) to recognize anomalous signals and to relate single or combined anomalies to physical processes, assigning them probability values, and (ii) to quickly provide an answer to the observed phenomena even when unexpected.

Here we present a > 4 year long process devoted to define the pre-eruptive Event Tree (ET) for Campi Flegrei. A community of about 40 experts in volcanology and volcano monitoring participating to two Italian Projects on Campi Flegrei funded by the Italian Civil Protection, has been constituted and trained during periodic meetings. The ET model has been calibrated through public elicitation sessions, preceded and followed by devoted meetings and web discussion on the monitoring parameters, and their accuracy, relevance, and potential meaning. The calibrated ET allows the recognition and interpretation of anomalies in the monitored parameters, assigning probability values. This process de-personalizes the difficult task of interpreting multi-parametric datasets during on-going emergencies, and provides a view of the observed variations that accounts for the averaged, weighted opinion of the scientific community.

An additional positive outcome of the described ET calibration process is a picture of the degree of confidence by the expert community on the capability of the many different monitored quantities of recognizing significant variations in the state of the volcano. This picture is particularly useful since it can be used to guide future implementations in the monitoring network, as well as

research investments aimed at substantially improving the capability to forecast short-term volcanic hazard.

2.1-P-11

Using Historical Databases for the Identification and Analysis of Future Volcanic Risk: VOGRIPA

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VOGRIPA (Volcano Global Risk Identification and Analysis Project) originated as part of the Global Risk Identification Programme (GRIP under the auspices of the United Nations and World Bank. GRIP is a 5-year programme aiming at improving global knowledge about risk from natural hazards. VOGRIPA is also a formal IAVCEI project. The objectives are to create a global database of volcanic activity, hazards and vulnerability information that can be analysed to identify locations at high risk from volcanism, gaps in knowledge about hazards and risk, and allow scientists and disaster managers to analyse risk within a global context of systematic information. The inclusion of risk and vulnerability as well as hazard sets VOGRIPA apart from most previous databases.

The University of Bristol is the coordinating centre for the project, which is an international partnership including the Smithsonian Institution, Geological Survey of Japan, British Geological Survey, University of Buffalo (SUNY), University of South Florida and Munich Re. The partnership is intended to grow, and any individuals or institutions that are able to contribute resources to VOGRIPA objectives are welcome to participate.

Work has already begun on populating a database of large magnitude explosive eruptions reaching back to the Quaternary, with extreme-value statistics being used to evaluate the magnitude-frequency relationship, and also an assessment of how the quality and completeness of records affect the results. The following 4 years of funding from the European Research Council will be used to establish international collaborations to develop different aspects of the database, with data being accessible online once it is sufficiently complete and analyses have been carried out. It is anticipated that such a resource would be useful for the scientific community, civil authorities with responsibility for mitigating and managing volcanic hazards, and the public.

2.1-P-12

What is Volcanology? Expertise and Experience in Risk Assessment on Active Volcanoes

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The ever-increasing exposure of people and infrastructure to volcanic hazards worldwide continues to raise questions about monitoring needs, as well as the role of different kinds of expertise and experience in forming scientific judgements about risks and hazard assessment. It also calls for clearer guidelines both on expert advisory structures, and on the function and role of volcano observatories in the social context. While some of this is impacted by local governance structures (or lack thereof), pooling of volcanological expertise and systems for providing politicians with emergency advice in practice comes down to the scientists themselves (Aspinall, 2002, for example).

This paper will present quantitative and qualitative data from a survey of volcanologists carried out on Volcanonet early in 2008. It will first discuss respondent's ranking of different monitoring technologies, and their perceptions and impressions concerning the likely impact on volcano surveillance of future technological trends. It will then examine volcanologists' views of hazard management scenarios and the different types of knowledge involved in providing scientific advice. This will be placed in the broader context of the philosophy of science literature, with some input from social studies of the role of science and scientists, leading into discussion of volcanological epistemologies and the peculiarities of volcanology as a discipline (or collection of multiple disciplines within a framework), as perceived by those surveyed. Some conclusions about future research directions and the combination of different types of scientific data and models in risk assessment will be discussed.

2.1-P-13

An Interdisciplinary Approach to Volcanic Risk Reduction Under Conditions of Uncertainty: A Case Study On Tristan da Cunha

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Tristan da Cunha is a large oceanic volcano in the South Atlantic Ocean. Rising over 7,560 metres from sea floor to summit, Tristan emerged subaerially approximately 140,000 years ago (Dunkley, 2002). Summit-centred alkali lava flows dominate, with occasional intercalated pyroclastic deposits. Scattered parasitic centres penetrate the flanks, many of which are breached by discrete lava flows. Most recently, activity has become effusive with more evolved lavas erupting from localised dome-building events. The volcano last erupted in 1961 forcing the temporary evacuation of all 264 residents. This research adopts an interdisciplinary approach to hazard and risk assessment, integrating both geophysical and social science methodologies within an analytic-deliberative framework. Our approach includes a temporal evaluation of geological activity using ⁴⁰Ar/³⁹Ar geochronology and cosmogenic ³He dating. A precise chronostratigraphy

accompanied by detailed field data will address questions regarding episodicity, eruption size, eruption location and composition. Data will be used to inform an expert deliberative process which is designed to produce a rational consensus on future eruptive scenarios, and which provides a systematic way of compiling scientific advice under conditions of uncertainty (Aspinall, 2010). The resultant scenarios will be introduced to a local deliberation process involving the Tristan Island Council who will consider appropriate responses and preparedness measures. Island communities such as Tristan can often develop strong and successful coping mechanisms (Kelman & Mather, 2008) and provide lessons in resilience which can be carefully applied elsewhere (Twigg, 2004). Tristan is an interesting case in this regard, with islanders' exhibiting unusually resilient social capacities whilst confronted by a number of sources of vulnerability associated with their remote island situation, which will help to highlight the factors contributing to social resilience (Yin, 2009). References: Dunkley, 2002, FCO/DFID; Aspinall, 2010, Nature; Kelman & Mather, 2008, JVGR; Twigg, HPN, 2004; Yin, 2009

2.1-P-14

Using Titan2D, on an Enhanced DEM, to Evaluate Lahar and Flood Hazards on El Misti Volcano, Peru

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Arequipa is located 17 km SW of El Misti Volcano with suburbs within 9 km of the summit. The last major eruption occurred ~550 years ago, with smaller events occurring more recently. Lahar volumes range from 0.01x10⁶ m³ to 11x10⁶ m³, whilst floods have occurred historically in the Rio Chili and tributaries near the city centre. The results of Titan2D modeling focus on the sensitivity of the model to changes in the topography, and its ability to outline lahar- and flood-prone areas. DGPS surveys were conducted on four terraces of the Río Chili valley from the entrance of the canyon downstream to the boundary of the city centre - an area of ~15 km². After post-processing approximately 50,000 DGPS points were interpolated (kriging method), combined with a 30 m ASTER DEM and resampled at 10 m to create an enhanced DEM of the river channel. Titan2D, a code designed to simulate volcanic mass flows, outputs flow depth and momentum throughout the spatial domain at specified instances in time. Field observable variables such as run-up height (<20 m), inundation areas (<40 km²), deposit thickness (<12 m) and velocity (<13 - 22 m/sec) were computed. Problems encountered on the 30 m DEM were overcome with the enhanced DEM. At abrupt changes in channel direction the Titan2D modeled flows form temporary ponds or cease to move on the 30 m DEM, creating shorter runouts than expected (<10 km). Conversely, simulations on the enhanced

DEM feature longer flow runout (9 - 14 km) along the reaches of the Río Chili valley and in one of its tributaries, and are more representative of actual lahar deposits. Simulations undertaken on the enhanced DEM will improve outlining lahar inundation zones in Arequipa and will help in assessing the vulnerability of housing and infrastructure from mass flows.

2.1-P-15

Physical Vulnerability and Quantitative Risk Assessment of Housing and Infrastructure from The Potential Impacts of Volcanic Mass Flows in Arequipa, Peru

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Volcanic mass flows (debris flows, hyperconcentrated flows), and flash floods represent destructive phenomena within Arequipa City (Peru), in which a population exceeding 860,000 lives 9 – 17 km SW of El Misti volcano. This case study includes the physical vulnerability of buildings and infrastructure in Arequipa from potential impacts of volcanic mass flows, and the quantitative risk assessment of their effects on buildings, infrastructure, and other essential elements. Three reference scenarios were used based on geological studies: a vulcanian eruption (VEI 2, recurrence interval of 300 – 1000 years) and a (sub)plinian eruption (VEI 3 – 5, recurrence interval of 5000 – 20,000 years) scenarios, and a non volcanic scenario in case of an earthquake-triggered flank collapse or a lake breakout flood in the Río Chili valley. A GIS database was developed using an enhanced resampled 10 m DEM, constructed from DGPS surveys and ASTER data. The database includes geological studies; conventional and computer-aided mapping of volcanoclastic and fluvial deposits; field surveys of buildings and infrastructure; deterministic and probabilistic statistical analysis (including multivariate analysis for the building survey); numerical flow modeling (using LAHARZ and TITAN2D); and geotechnical characteristics of building materials (including compressive strength, void ratio, and density). Inundation zones were defined using geological mapping with magnitude/frequency analysis and simulation codes. Mechanical effects of lahars on buildings and infrastructure were investigated to elaborate vulnerability functions. The risk analysis has been based upon selected eruption scenarios, ranked upon hazard types and eruptive styles, implying several hazardous phenomena including non-eruption processes. An Event Tree has been constructed using the analysis of past volcanic events, the determination of activity sites and eruptive behaviour, and probabilistic analysis of each type of eruption style and its evolution. Both Event Tree and probabilistic analysis help determine how each urban district is exposed to hazards and its vulnerability to risk.

2.1-P-16

The contribution of volcanic emissions (Etna, Stromboli and Vulcano) to the atmospheric trace metals budget in the Mediterranean basin.

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Volcanic emissions represent one of the major natural source for several trace metals (Cd, Cu, As, Pb, Hg and Zn) into the atmosphere both as gaseous and aerosol forms. The Mediterranean Sea can be considered a large geochemical sink for these elements whose source are the huge amounts of aerosols of different origin. The industrialized areas located in the northern part of the basin represent a nearly constant source of the anthropogenic-dominated aerosol. By contrast, the arid and desert regions located at the southern and eastern parts of the Mediterranean, are the sources of frequent dust “pulses” perturbing the “steady-state” conditions of the local atmosphere through the input of several millions of tons of desert dust. In this context, Mount Etna, Stromboli and Vulcano represent the biggest volcanic point-sources in the Mediterranean area by introducing several thousands of tons of gases and particles per day in the troposphere, both during eruptive and passive degassing periods. Comparison between estimated annual metal fluxes from the three Italian active volcanoes and the local emissions (Environmental Protection Agency - APAT), evidences the significant contribution of the volcanogenic trace metals (Cu, Se, Cr, As, Hg and Cd) to the metropolitan area of Catania and the whole Sicily. On a regional scale, volcanic degassing plays also an important role accounting for about 1 to 10% for the total European anthropogenic emissions of As, Cd, Cr, Hg, Ni and Pb (European Monitoring and Evaluation Programme - EMEP).

2.1-P-17

Volcano-Tectonic Fault Failure Promoted By Recharging And Intrusive Phases Preceding An Eruption: The Pernicana Fault Case At Etna Volcano

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Relationships between the activation of tectonic structures, earthquake swarms, and volcanic eruptions have been well documented on Etna volcano. Eruptive sequences and local seismicity have often revealed a significant correlation between the occurrence of large earthquakes along the main volcano-tectonic structures and period of volcanic unrest. One of the most outstanding tectonic structures is the Pernicana Fault System (PFS), which delineates the northern border of the sliding eastern flank of Etna volcano. The PFS is characterized both by aseismic continuous “slow” movements associated with the eastern flank sliding and by shallow earthquakes, which can cause severe damage to the man-made infrastructures. To investigate a possi-

ble relation between PFS ruptures and volcanic unrest, we examine the most energetic earthquakes (about M4) occurred in the last three decades. The effect of magmatic intrusions and inflation processes on the PFS are studied through the estimate of stress redistribution using numerical deformation models constrained by high-quality geodetic data. Our results put into evidence that the loading and rupture of PFS occur mostly as a response to accommodate the stress change induced by pre-eruptive injection of the magma when this penetrates inside the northern sector of the volcano. In that case the seismicity along the PFS would represent a potential early-warning for an impending volcanic eruption at Etna volcano.

2.1-P-18

Does Regional Tectonism Control The Rate Of Volcanism Along Convergent Margins?

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Successive volcanic eruptions around the “Pacific Ring of Fire” are often thought to be related, but co-genetic links of distant eruptions are readily discounted. For individual volcanic arcs, however, independence of the timing and genesis of eruptions from separate volcanoes is highly debatable. Do arc volcanoes erupt in synchrony or follow any systematic pattern? If the frequency and size of arc eruptions are strongly influenced by the recharge of fresh (mafic) magmas into mid-crustal reservoirs, AND if regional tectonic processes control periodic magma rise, then along a convergent margin, such as the Taupo Volcanic Zone (TVZ) of New Zealand, recharge may be coincident between volcanoes and hence their eruption behavior may be indirectly coupled. A central difficulty in proving this relationship is the completeness of geological records. Notable coincidences in New Zealand include that the cataclysmic Oruanui eruption of Taupo caldera was contemporaneous with the largest eruptions known from the andesitic Mt Ruapehu, large-scale collapses and eruptions of Mt Taranaki, the greatest pulse of activity from the basaltic Auckland Volcanic Field, and between large scale eruptive phases from Okataina caldera. Similarly, huge eruptions of Mts. Tongariro and Ruapehu around 10 ka B.P. coincided with two events from Taupo caldera, and a flare-up in Auckland. If an underlying regional tectonic control to arc volcanism can be proven, it will provide a means for spatial control of time-varying eruption probabilities. The association of multiple series of events can be measured using cross-correlation or mutual information. However, a causative relation can best be established in this situation using the theory of (coupled) point processes with history-dependent intensities. A complication is that the range in compositions of TVZ volcanism possibly adds too much complexity to any underlying signal relating to regional tectonic processes.

2.1-P-19

The Vatnajökull Subglacial Eruptions: A GIS Volcanic Hazard Map

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Volcanic hazards related to subglacial eruptions in Iceland are a major issue due to the presence of several volcanic complexes, which are covered by glaciers and ice. This study focuses on jökulhlaups resulting from subglacial eruptions beneath the Vatnajökull ice cap in south-east Iceland. Data on historical eruptions beneath the Vatnajökull ice cap have been collected to reconstruct the dates, locations and frequencies of the eruptions. The power of jökulhlaups is controlled by the eruption volume, the respective volume of melted ice and the topography of the volcanic complex. Measurements of the erupted volumes are rare, since the eruptions take place below the ice making it difficult to get direct information. Therefore, jökulhlaup volumes associated to a range of erupted volumes spanning between VEI 0 and 4 (Newhall and Self, 1982) for the different eruptive centres were calculated applying the equations proposed by Gudmundsson et al. (2004). The VEI values used are in agreement with the historical records. The areas potentially affected by jökulhlaups were identified using LAHARZ (Schilling, 1998) and the required data on ice distribution and the three-dimensional elevation model of the Vatnajökull area were obtained from free online sources. A sensitivity study has been performed with the development of the volcanic hazard map to characterise the areas of major risk and vulnerability. While the historical dataset points out that the south-western area of the Vatnajökull complex is the most sensitive to jökulhlaups due to the highest eruption frequencies and preferential drainage areas, LAHARZ allows determining the extent of the flooded area. The assessment of volcanic hazards and their attendant risks related to magma ice interaction would help prepare the Icelandic population to eruptions and identify the safest regions to build fundamental infrastructures. References: Gudmundsson et al., 2004, BoV; Newhall and Self, 1982, JGR; Schilling, 1998, USGS.

2.1-P-20

The CASAVA Project: Understanding And Assessing Volcanic Hazards, Scenarios, And Risks In The Lesser Antilles – Implications For Decision-Making, Crisis Management, And Pragmatic Development.

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Authorities and civil society are still confronted with Hamlet's dilemma when they need to reconcile efficient, pragmatic crisis reduction strategies that will also foster the rise of a society of prevention and a state of well-living with the region's live volcanoes instead of a short-sighted society of repair. Effective risk assessment and management require that scientists, engineers, governments, civil protection agencies, communities develop synergistic activities. This constitutes the scientific challenge to which the CASAVA multidisciplinary project (ANR funding) will strive to contribute in innovative ways over the next 4 years through a research consortium that spans a wide spectrum of disciplines. CASAVA proposes a state-of-the-art integrated research strategy for achieving quantitative volcanic risk assessments that takes into account the socio-cultural dimension and is focused on active volcanoes of the French Lesser Antilles, Soufrière (Guadeloupe) and Montagne Pelée (Martinique). It aims at: 1) reconstructing the eruptive past and understanding volcanic processes; 2) defining calibrated volcanic scenarios and modelling hazards in a probabilistic GIS framework; 3) assessing social, cultural, and economic vulnerability; 4) quantifying territorial, human, and institutional vulnerability including an innovative look at legal and insurance risk policies; 5) developing tools for probabilistic risk assessment and crisis management that consider impact analysis and mathematical modelling of evacuation strategies; 6) elaborating an eruption display and simulation software that will use artificial intelligence to model eruption scenarios, impact, and the behavior of population and crisis managers; and 7) integrating scientific knowledge, community-based initiatives and government policies into effective and sustainable disaster risk reduction. In this project we will aim at identifying avenues for civil society and decision-makers to turn risk assessment into an economically viable model in which proper risk management could also generate economic growth by developing mitigation measures that stimulate engineering innovation, development, and regional transfer of technology and expertise.

2.1-P-21

Risk Exposure Databases for Disaster Risk Reduction and Risk Financing for the Pacific Region

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Pacific nations are exposed to a range of natural hazards such as cyclones, earthquakes, floods, tsunami and severe storms. There is a need to compare the risks posed by each hazard in a standardized manner using potential impacts such as cost and casualties. Such comparison of risk can then support decision making by determining which hazard represents the greatest risk to various communities; enabling mitigation investments to be prioritized; avoiding inappropriate land development through planning; contributing to effective emergency management plans; and thus assist in minimizing the negative social and environmental impacts of catastrophic events. The Pacific Applied Geosciences Commission (SOPAC) in collaboration with the Asian Development Bank (ADB), the World Bank (WB), the Institute of Geological and Nuclear Sciences Limited (GNS Science) and the Pacific Disaster Center (PDC) is developing a database outlining built infrastructure in the Pacific as well as the risk posed to infrastructure by various natural hazards. The countries covered under this project are Cook Islands, East Timor, Federated States of Micronesia, Fiji, Kiribati, Papua New Guinea, Republic of Marshall Islands, Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu. Data is collected on country specific assets such as buildings, roads, water and power networks and other related infrastructure. The information and data gathered will be used to calculate the risk different hazards pose to infrastructure and communities and will also assist in the decision-making process for disaster risk reduction and climate change adaptation initiatives. All data collected will have spatial reference and be in a form that is GIS platform independent and use open source software to ensure that the data have greater utility in risk modeling.

2.1-P-22

Local Site Amplification in Tenerife Island. The Example of Some Historical Seismic Series Accompany Volcanic Eruption and the Implications on the Seismic Risk Evaluation.

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In the island of Tenerife there is documental information of at least five eruptive episodes from the end of the XV century to the present. At least three of them, those occurred in 1704-1705, 1706 and 1909 (Sietefuentes-Fasnia-Arafo, Garachico, and Chinyero respectively) have been reported with a strong associated seismicity,

preceding and accompanying the eruptive processes being the responsible of the main number of injured and died people.

In relation of the details of how population felt this seismicity we observed that those references associated to the Orotava or Güimar villages indicated, in the majority of the situations, an increase in at least one degree of the intensity estimation. This increase of the intensity estimation is still present in the actual felt seismicity. These two orographic depressions are filled by volcanoclastic materials and their shallow structure is considered as soft soil. The presence of this type of soft soil is responsible in many examples of the effect of local seismic amplification, than in many cases increase clearly the degree of damages and effect of the earthquakes. In the present, many villages and cities of the island of Tenerife are growing towards areas with an important presence of volcanoclastic deposits, and hence they are increasing the seismic risk associated to them.

In the present work we have evaluated the documents and data related to the effect of earthquakes in these sensible regions and estimated the presence of site amplification effects. Additionally we have started a microzonation study on the base of measures of seismic noise in three component broad band stations. The preliminary results of this microzonation is also reported in the present work.

It is clear that these amplification factors must be taken into account in any work that could value the seismic risk in the Tenerife Island.

2.1-P-23

Numerical Simulation of Pyroclastic Density Currents Using Locally Refined Cartesian Grids and Experimental Validation

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Pyroclastic density currents are ground hugging, hot, gas-particle flows representing the most hazardous events of explosive volcanism. Their impact on structures is a function of dynamic pressure, which expresses the lateral load that such currents exert over buildings. Several critical issues arise in the numerical simulation of such flows, which involve the turbulent evolution of a rheologically complex over a wide range of scales and in a realistic geometry fluid. In this paper we consider a numerical technique which aims to cope with the difficulties encountered in the discretization domains when adequate resolution in the regions of interest is required. Without resorting to time-consuming body fitted grid generation approaches, we use Cartesian grids locally refined near the ground surface and the volcanic vent in order to reconstruct the steep velocity and particle concentration gradients. The grid generation process is carried out by an efficient and automatic tool, regardless of the geometry complexity. In this paper we show how analog experiments can be matched with nu-

merical simulations for capturing the essential physics of the multiphase flow, obtaining calculated values of dynamic pressure in reasonable agreement with the experimental measurements. These outcomes encourage future application of our method for the assessment of the impact of pyroclastic density currents at the natural scale.

2.1-P-24

Shimabara from Rag (1991 Eruptive Disaster) to Riches (2007 COV International Conference)? the Complex Relationship between Disaster and Risk Assessment.

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Shimabara (Kyushu, southern Japan) suffered twice in her history from a major volcanic disaster due to Unzen Fugen dake eruptions, in 1793 and in 1991. This last eruption is sadly well known, because 43 peoples, among who experienced volcanologists, died during a pyroclastic flow, pushing this volcanic phenomenon to the mediatic lights. Becoming the last city hosting the Cities on Volcanoes international conference, the case invites us to think about the way risk can influence territorial dynamics and disasters, mitigations, from local to international scale. The complex relationship between these past disasters and the current risk can be summarized in three types: complementarity, antagonism and competition (Morin, 1990). Disaster and risk are contributing together to spatial dynamics, but even without the occurrence of a disaster, the risk is influencing the spatial policies and planning. Nevertheless, the eruption is still needed for understanding, measuring and mitigating the risk. The red queen theory (coming from Van Valen, 1973) applied to the mitigation field allows to understand the coevolution (Pigeon) between the risk and the mitigation efforts of the society, explaining how the necessary adaptation is also endless. This case study illustrates the connexity of the risk (November), putting together a territorial risk and actors representations from different scales, local, national and international.

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2.1-P-25

Threat of Eruption in the Uturuncu Volcano Area, Sud Lípez Province, Potosí Department, Bolivia.

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The Uturuncu volcano is located in southwestern most Bolivia. The stratigraphic sequence includes Lower Ordovician sediments and Eocene to upper Oligocene redbeds, which underwent the Tacsarian and 2nd An-

dean tectonic cycles that originated the only sedimentary structures in the area. Volcanic activity began in the Early Miocene with the outpouring of the lava flow of the Peña Barrosa, which was followed by an alternation of explosive (pyroclastic deposit) and effusive (lava flow) events. From a petrographic viewpoint, the rock range in composition from hypersthene andesites to hypersthene-biotite-hornblende dacites. The ignimbrites which are genetically related to the Uturuncu volcanic center are mostly dacitic. Field work evidenced the occurrence of a variety of xenoliths from mafic rocks to crystal through recrystallized Ordovician and Neogene sediment that, along with petrologic characteristic bear witness of crustal-contamination and magma-mixing processes. The presence of pyroclastic (Nbat) issued from the Uturuncu proto-volcano much before the lava flow of the first (Nykl) and second (Nute) recent effusive episodes makes manifest that the lifespan of this volcano has been long and that the recurrence of its important eruptions has been separated by prolonged periods of quiescence (>270.000 years). Since the main areas which been so far reached by eruptions are located northwest of Mt. Uturuncu, it is possible to forecast that in the future the principal threats would point at the Quetena Village, at the local livestock and at the surrounding wild fauna and flora. However, taking into account the easterly predominant wind direction, the eastern slopes of the volcano might result the most threatened by ejecta falls. According to the studies that have been carried out up till now, the Uturuncu volcano does not show any sign of having been active during the Holocene. While the present fumaroles emission, hot-spring occurrence slight, seismic activity and imperceptible ground deformation all suggest the persistence of late-stage magmatism at shallow depth, these typical manifestations of a vanishing volcanism apparently preclude any unexpected outbreak of a major eruptive event for a long time.

2.1-P-26

Trajectory Calculation of Volcanic Contaminants using Graphics Processing Units

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The contaminants released into the atmosphere by a volcanic eruption (gases and particles) can pose a major risk for humans. In order to mitigate these risks it is of great importance to forecast the contaminant dispersion as reliable and fast as possible. Despite the fact that right now there are many methods and models for such a forecast (mainly using the Lagrangian approach) their computational work is almost exclusively done on computers on a conventional basis: using the great power of their Central Process Unit (CPU). In this work we present a relatively new approach: the use of parallel power of the Graphics Processing Units (GPU) of the last generation Video Cards (e.g. such as for example NVIDIA gtx285), which can be used -depending on the kind of numerical problem- for highly efficient parallel computing. In that sense, the very nature of the dispersion of pollutants emitted by volcanic activity and its

numerical simulation seems to represent an ideal case for taking advantage of the aforementioned parallel GPU capacity: the trajectory of a single particle can be modelled as an independent event. Hence, if a certain number of particles being emitted to the atmosphere in a given moment of time is considered, each of their trajectories can be solved in parallel calculations. In this work we will present a forecasting system using highly efficient parallel computation based on the most recent GPU technology. The system is very flexible in terms of meteorological model data input, allowing both the use of global and regional models. It also includes a user friendly graphical interface for the easy use of the numerical model and the visualization of its results and, therefore, contributing to a faster and more efficient risk management.

2.1-P-27

The Challenges of Service Restoration During an Ongoing Eruption: Rabaul Town, Papua New Guinea

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Rabaul was a thriving town prior to the September 1994 twin volcanic eruptions of Tavurvur and Vulcan. It was the administrative center of East New Britain Province. Its majestic harbour served as the hub for domestic and international shipping services for both East New Britain Province and New Guinea Islands region of Papua New Guinea. It had a population of about 30,000 people. A similar number of people lived in local villages that surrounded the town. The 1994 twin eruptions devastated nearly the entire township of Rabaul and the surrounding villages.

After the eruption the administrative center for the province was transferred to what was then a sleepy little town called Kokopo, about 20 km southeast from Rabaul. People from villages around Rabaul were moved to new settlements distant from Rabaul. The East New Britain Provincial Government divided the devastated town into three sectors; Sectors 1, 2 and 3. Sector 3 was designated a no go zone for any form of infrastructure development in the future due to its close proximity to Tavurvur volcano. Sector 2 was earmarked for future development. The Provincial Government gave its blessing for any restoration and future developments in Rabaul Town to focus in Sector 1 only.

Restoration work in Rabaul Town commenced in 1995 and seemed good in the initial stages but when Tavurvur resumed eruption in November 1995 and continued for the next sixteen years, the restoration process suffered. The eruptive products, mainly volcanic ash and gas, have constantly affected the progress of the restoration efforts. The rate of restoration has been slower than the rate at which the eruptive products have destroyed infrastructure. For instance, the rate of corrosion has been so high that roofs of buildings, made from corrugated iron, have to be changed almost every few years. Destruction of road infrastructure and sedimentation from debris flows in Sector 1 has been higher than the rate of cleanup. The unsuitable conditions in Rabaul forced many business houses to close operations there

and move to Kokopo. The decline of Rabaul and

concomitant growth of Kokopo represent a strong and positive response to the challenges to provision of community services imposed by an enduring volcanic eruption.

Session 2.2

2.2-O-01

VHub – Cyberinfrastructure for Volcano Eruption and Hazards Modeling and Simulation

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VHub is a project aimed at developing a virtual organization and cyberinfrastructure to promote collaborative research in volcano processes and risk mitigation. Overarching goals of the VHub project are: Dissemination. Make advanced modeling and simulation capabilities and key data sets readily available to researchers, students, and practitioners around the world. Collaboration. Provide a mechanism for participants not only to be users but also co-developers of modeling capabilities, and contributors of experimental and observational data sets for use in modeling and simulation, in a collaborative environment that reaches far beyond local work groups. Comparison. Facilitate comparison between different models in order to provide the practitioners with guidance for choosing the “right” model, depending upon the intended use, and provide a platform for multi-model analysis of specific problems and incorporation into probabilistic assessments. Application. Greatly accelerate access and application of a wide range of modeling tools and related data sets to agencies around the world that are charged with hazard planning, mitigation, and response. Education. Provide resources that will promote the training of the next generation of volcanologists and hazards specialists such that modeling and simulation form part of a tripartite foundation of approaches, alongside observational data and experimentation. Adaptation. Conduct ongoing, rigorous self-assessment to study the impact of the virtual organization and promote continual adaptation to optimize its impact, as well as to understand emergent collective learning and collaborative patterns. In addition to the authors, VHub involves a large group of international collaborators. VHub development is just beginning and we are very interested in input from the community and the addition of new partners to the effort. The effort is being funded by the US National Science Foundation.

2.2-O-02

Dynamics and Hazards of Block-and-ash Flows at Merapi Volcano, Indonesia

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The integration of results and constraints from field-derived data and experiments into improved numerical models is the main challenge for future research into the dynamics and hazards of small-volume pyroclastic flows. The latest eruptive episode of Merapi volcano (Central Java, Indonesia) produced block-and-ash flows (BAFs) that affected the densely populated areas on the southern flank. The flows were not confined to the existing valleys but spilled over the valley sides to create overbank flows that resulted in fatalities and strong damages in the village of Kaliadem, ~5 km away from the summit. This testifies the unpredictable behaviour of BAFs, not only at this volcano but also at similar locations around the world, and the need for an improved understanding of the flow transport and depositional mechanisms. In this respect, the interdisciplinary approach presented here allows a better understanding of the dynamics of BAFs and their related hazards. The 2006 deposits were examined both immediately after flow emplacement and after the first rainy season following the eruption, allowing detailed correlations between their surface characteristics and internal architecture. Two main types of BAFs (short- to medium-runout and long-runout BAFs) are recognized based on parameters including generation mechanism, flow volume, travel distance, deposit morphology, distribution, lithology and grain size distribution. The effects of topography on flow dynamics have been examined through the development of conceptual models for the two types of BAFs. Integration of high-resolution field-based data into numerical models allows their validity to be tested and rapid quantification of best-fit input parameters. Sensitivity analyses and inundation maps based on the probability of impact were used to produce a suite of potentially inundated areas from future collapse events affecting the southern flank of the volcano. Results provide the basis for defining hazard zonations of key areas at risk from BAFs at Merapi.

2.2-O-03

GEO Grid Volcanic Gravity Flow Simulation: Toward the Next Generation Real-time Hazard Mapping

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GEO Grid is an E-Infrastructure to accelerate GEO sciences related information retrieval, storage and processing based on the concept of virtual integration of all data related to earth observation, with certain access management. The GEO Grid system using a set of Grid and Web service technologies would be easy to handle by the end users. Numerical simulation of volcanic gravity flows on volcanoes is one of the major applications of the GEO Grid project. A web-based GIS system combining various types of information with real-time

numerical simulations are necessary for the next generation of volcanic hazard mapping system. Volcanic gravity flow simulations using the energy cone model are currently implemented on the GEO Grid system. An interactive user interface to evaluate the probability of an area to be affected by volcanic gravity flows is available on the GEO Grid website. The ASTER Global DEM (G-DEM, 30m resolution), STRM-3 (90m) and GSI 10m DEM are planned to be installed on the GEO Grid system this year. With this information, users could simulate any volcanic gravity flow for any volcano in the world on the GEO Grid system. The OGC standards WCS (Web Coverage Service) and WMS (Web Mapping Service) are used in the system. The simulation results could be downloaded as shape or KML files. The energy cone simulation on the GEO Grid system could be applied to other geological hazards such as debris avalanches and landslides. The gravity flow simulation is open to all scientists and local government officials. More sophisticated simulations such as Titan 2D and LAHARZ, and the usage of ALOS satellite data such as PALSAR and PRISM (2.5m resolution) are also planned to be installed on the GEO Grid system in the future. Collaboration between the GEO Grid and the V-Hub projects is another important target.

2.2-O-04

GeoProMT Meets VHUB: Integrated Information Management For Collaborative Research In Geo-Hazard Modeling and Simulation

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Practical decision-making for civil protection based on predicting volcano hazards often involves latest available observations, remote sensing imagery, process models and Geographic Information Systems (GIS). Optimum use of these techniques for such decision-support requires careful and coordinated consideration of process, data and model scales and their related uncertainties (Renschler, 2005). The Geospatial Project Management Tool – GeoProMT (Renschler, 2006) is an internet-based interface that enables collaborative researchers, observatory personnel, students and the interested public to systematically share and investigate representations of earth systems' properties and processes at various scales. Scaling is here referred to as the transformation of information from one spatial/temporal scale to another, such as aggregation and disaggregation of geospatial and temporal data (Renschler, 2003, 2005). GeoProMT is in the process of being implemented in a new virtual collaborative platform known as VHU that facilitates the integration of multidisciplinary computational thinking into volcanology research and applications (Valentine et al., 2010). The VHub cyberinfrastructure will provide a mechanism for globally collaborative research and development of computational models of volcanic processes and GeoProMT will facilitate the communication of complex geospatial, observational, and experimental data. Each scaling step in a user-defined project is documented and validated before moving to the next step, ensuring traceability,

the capture of uncertainties, and reproducibility. The information shared through GeoProMT is not only limited to geospatial data but can also be used to share transformation of information of other relevant documents such as literature and images. VHUB and GeoProMT will facilitate the creation of a more resilient community by using information and tools for response to and recovery from extreme events, as well as provide the ability to proactively manage extreme events through mitigation, risk reduction, prevention and preparedness of GeoHazards in volcanic landscapes.

2.2-P-01

The Geological Database for the Reviews of Long-term Volcanism in Japan

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Reviews of long-term volcanism are indispensability to assess that the interaction with volcanism and tectonics or volcanism affects underground geological environment. In Japan, The database of Quaternary volcanoes was published Committee for catalog of Quaternary Volcanoes in Japan (1999), also GSJ/AIST opens the database gQuaternary Volcanoes in Japan h on the Web. However, these database are not fully reflected the latest geological and chronological issues. So we review Quaternary volcanoes in Japan to use the latest data, and construct the database based on the specifications of to reworked items, and also pick up the Quaternary volcanic rocks, volcanic bodies and intrusive bodies that haven't been checked in previous studies. Additionally, it was ratified that Neogene-Quaternary boundary was changed at 2.588 Ma by IUGS Executive Committee in June 2009. Therefore, we also screen gGelasian h volcanoes in Japan.

This database is consolidated many data of each volcano into volcanostratigraphy, eruptive style, duration of activities, location of crater (estimated eruption center), reference and beautiful photos. We expect that this database is served as how to study of the long-term volcanism and the temporal and spatial change of volcanic field, to support safety controls for the volcanic hazard, national land using plan (e.g. construction of nuclear facilities) and other. In the near future, this database will continue to publish on Web from GSJ/AIST at any time.

This research project has been conducted under the research contact with the Nuclear and Industrial Safety Agency (NISA).

References: Committee for catalog of Quaternary Volcanoes in Japan, 1999, Catalog of Quaternary Volcanoes in Japan ver.1.0, The Volcanological Society of Japan.

2.2-P-02

Active Mexican Volcanoes @online: a web application for global data access.

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Mexican volcanism is typically concentrated on the Trans-Mexican Volcanic Belt, an east-west trending, Neogene to Quaternary volcanic province with a large variety of volcanoes, including calderas, monogenetic fields and active stratovolcanoes such as Popocatepetl, Colima, Citlaltépetl and Colima volcanoes. But active volcanoes can be also found in other geological regions, such as El Chichón and Tacaná towards the south, Tres Vírgenes in the Península de Baja California and Bárceña, in the Pacific Ocean. A large variety of publications are available about Mexican volcanism, including volcanological studies and geological and hazard maps. For active volcanoes, previous published studies are essential in case of volcanic crisis, such as the distribution of past deposits, hazards zonification and simulation of possible future eruptive scenarios. The Active Mexican Volcanoes @nline represents an initiative aimed to collect, on a systematic basis, the complete set of data obtained so far on the active volcanoes in Mexico, and to continuously update the database with new data. All the information is compiled from published works and updated frequently. All maps (such as the geological map of a volcano and its hazard zonations) and point data (such as stratigraphic sections, sedimentology and geochemistry) can be viewed with Google Earth and is really straightforward to be accessed by the scientific community and general public. In this format everyone with Internet access can view the information and zoom to the scale they wish. The WebGIS is hosted on the Computational Geodynamics Laboratory web server and it is based entirely on Open Source software. The website can be visited at: http://www.geociencias.unam.mx/mexican_volcanoes/index.php.

2.2-P-03

Multi-Particle Numerical Simulations Of Collapsing Volcanic Columns

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A multi-particle thermo-fluid dynamic model was developed to assess the dynamics of the transient two-dimensional behavior of collapsing columns and associated pyroclastic currents. The model accounts for mechanical and thermal interactions between a continuous gas phase and N solid dispersed phases, each characterized by specific physical parameters and properties. The dynamics of the process were simulated by adopting a RANS approach, able to resolve the main features of the flow, as well as turbulence and fluidization. Numerical simulations were carried out by using the computer code GMFIX. These describe the formation of the vertical jet, the column collapse (namely, the building of the pyroclastic fountain), the generation of radial spreading pyroclastic current, and the development of thermal convective instabilities from the whole flow. In particular, pyroclastic currents were described as formed by a dilute fine-rich suspension current overlying a dense underflow rich in coarse particles. So, finer particles tend to follow the hot ascending gas, mainly in the phoenix column and, secondarily, in the pyroclas-

tic current generated by the fountain. Coarser particles, instead, tend to segregate mainly along the ground in the proximal area close to the crater rim because of the recycling of material from the fountain, and in the distal area because of the loss of radial momentum. The results highlight the importance of the multi-particle formulation of the model and describe several mechanical and thermal interaction effects. These effects between particles of different sizes appear to be controlled by particle-particle collisions in the basal layer of the pyroclastic current, whereas by the gas-particle drag in the suspension current and ascending columns. In addition, the simulations indicate that a fine-grained mixture produces a thicker current, a larger run-out distance, and a greater elutriated mass than the coarse-grained mixture.

2.2-P-04

An Expert System: Automatic Alert Level Estimation and GIS Visualization as application of the multi-parameter Database, SeisHub

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A successful volcano fast response systems lives through its connection capability of already installed monitoring systems to new rapidly installed temporary networks and the combination of multi-parameter data.

During the field experiment of the Exupery project on the Azores GPS, INSAR, SO₂, geothermal, stress field simulation and seismic data were stored in the SeisHub database. SeisHub, a multi-parameter database, offers the full functionality of a native XML database combined with the versatility of a RESTful Web service. The XML database itself uses a standard relational database as back-end. In practice this allows to store and to analyse any high-dimensional, complicated data stream in decent performance.

While data providers primary store the data in the database, a GIS connects to SeisHub to retrieve relevant information, thus allowing the decision maker to interactively/visually analyse the situation based on the multi-parameter data. In addition to the GIS also an automatic alert level system connects to SeisHub. This allows an expert to verify her/his own decision versus the automatic system and if necessary identify the problematic parameters.

Within the real-time part of Exupery, seismic data are feed into the online systems (EarthWorm, Seiscomp3) and the outputs (events, locations) as well as the continuous waveforms are automatically uploaded to SeisHub. In order to easily include data from local networks in the online system an intermediate layer was developed as part of a Python library (www.obspy.org). On the Azores seismic data are continuously recorded with NI digitizers which are storing data in a binary format every 10s. A few lines of Python code (based on ObsPy) are used to feed the data to the online systems by decoding the binary format every 30s and appending

the new data to a MiniSEED file, which is then automatically scanned by a seedlink plug in.

2.2-P-05

The Estimated Presence Of Differentiated Highly Explosive Magmas Beneath Vesuvius And Campi Flegrei: Evidence From Geochemical And Textural Studies.

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Highly catastrophic explosive eruptions are supplied by Si-rich magmas, generated at shallower level in crust by the evolution of mantle liquids. The timescale of these evolution processes is a crucial factor, because of its control on the length of volcano repose interval leading to high explosive events. Campi Flegrei and Somma-Vesuvius alkaline volcanic systems, located respectively at few kilometers west and east of Neapolitan metropolitan area, produced a variety of eruptions ranging from not explosive lava flows and domes to highly destructive eruptions. Both these high risk volcanoes are in repose time since the last eruption occurred in the 1538 and 1944 BP, respectively. A wide low velocity layer interpreted as an extended magmatic body has been detected at 8-10 km depth beneath these volcanoes by seismic data. The capability of this reservoir to erupt explosively again strongly depends on magma differentiation degree, therefore the knowledge of the time lapse necessary at not explosive mafic liquids to differentiate toward explosive magmas is very crucial to predict the size of a possible short-term future eruption in Campanian area. Our petrologic data indicate that a multi-depth supply system was active under the Campanian Plain since 39 ka. Moreover our CSD data on phenocrysts reveal rapid crystallization and differentiation time for alkaline Campanian magmas (in the order of decades to few centuries). This evidence implies that the partial melting zone detected by tomography study at 8-10 km depth beneath Vesuvius and Campi Flegrei, should consist of differentiated magma already capable to produce also large scale (plinian) explosive events in case of renewal of the activity from the present closed-conduit state.

2.2-P-06

Hazardous Present Emergency Plans For Volcanic Eruptions In Neapolitan Area: Evidences From Volcanic And Magmatological History And Modeling

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New evidences from volcanic and magmatological features, archaeological findings, and modeling provide key constraints on the mechanisms and the effects of the explosive eruptions of Somma-Vesuvius and Campi Flegrei, from the prehistory to the modern times. For both volcanic areas, the probability of plinian events (VEI 5) with their complete range of variability is not negligible, differentiated highly explosive magmas are likely

already available at depth, and the associated effects of the possible eruption may affect the whole heavily urbanized metropolitan area. Particularly, results of our numerical simulations consistently with field evidences indicate that tephra accumulation during fallout phase of eruption may preserve critical load for roof collapse up to a distance even exceeding 30 km from the vent, while physical proprieties of PDCs may exceed the threshold for human survival even at distance from the vent in the order of 20 km. These results indicate that the appropriate action for the mitigation of volcanic risk should be the complete evacuation of the whole potentially affected area. In contrast with the single intermediate event (1631 sub-plinian eruption) adopted as reference scenario in the present emergency plan for Vesuvius (at present an emergency plan is not available for Campi Flegrei), the adequate reference scenario should correspond to the worst case (VEI 5, for both volcanoes) that not simply reflects the worst eruption occurred in the past but the entire range of the possible events for that VEI. The adoption, during a volcanic crisis, of any minor scenario that accepts variable levels of risk for the people leaving around the volcano, even with the justification of the cost/benefit approach, always may introduce a false perception of safety that may increase the risk.

2.2-P-07

Suite for simulation and visualization of volcanic phenomena: VolcWorks

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Scientific visualization is a powerful tool to explore and gain insight into complex data from instruments and simulations. The workflow from data collection, quality control and preparation for simulations, to achieve visual and appropriate presentation is a process that is usually disconnected, because it requires many tools that are not built for the solution of a specific problem, or were developed by research groups to solve particular tasks, but disconnected. In volcanology, due to its complexity, groups typically examine only one aspect of the phenomenon: ash dispersal, laharcic flows, pyroclastic flows, lava flows, and ballistic projectile ejection, among others. However, when studying the hazards associated to the activity of a volcano, it is important to analyze all the processes comprehensively, especially for communication of results to the end users: decision makers and planners. In order to solve this problem and connect different parts of a workflow we are developing the suite VOLCWORKS, whose principle is to have a flexible-implementation architecture allowing rapid development of software to the extent specified by the needs including calculations, routines, or algorithms, but especially allowing to include new knowledge, models or software transferring them to software modules. The design is component-oriented platform, which allows incorporating particular solutions (routines, simu-

lations, etc.). The platform includes a graphical interface with capabilities for working in different visual environments. This platform aims to integrate simulation and visualization phases, incorporating proven tools (now isolated). VOLCWORKS can be used under different operating systems (Windows, Linux and MacOS) and fit the context of use automatically and at runtime: in both tasks and their sequence, such as utilization of hardware resources (CPU, GPU, special monitors, etc.). The application has the ability to run on a laptop or even in a virtual reality room with access to supercomputers.

Session 2.3

2.3-O-01

Tourists, Volcanoes and Education – Are Hazards, Risks and Emergency Response Procedures Effectively Communicated in Southern Iceland?

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Research in 2007 in southern Iceland examined the relationship between volcanic risk and the tourism sector and the complex challenge emergency management agencies face in developing effective volcanic risk mitigation strategies. The popular tourist region of Þórsmörk was the focus of this survey due to its location within the jökulhlaup hazard zone of Katla. The survey, conducted prior to the implementation of education and training campaigns, showed that tourists lacked volcanic hazard knowledge and both tourists and tourism employees lacked knowledge of the early warning system and the recommended emergency response procedures. These issues of knowledge were reassessed in a follow-up survey conducted in 2009 after education and training campaigns had been implemented. The results of this survey suggest that these mitigation efforts have not been successful at increasing tourists and tourism employees' knowledge. Only a quarter of the tourists had seen the Eruption Emergency Guidelines brochure and only 21% of employees had received appropriate emergency response training. One critical point raised by many participants was the inadequacy of the hazard map. The map failed to 'communicate to them' the location of the hazard zones and evacuation routes. Tourists found the map confusing and inappropriately scaled for the region. Also, those who had read the Eruption Emergency Guidelines brochure likened it to a tourist advertisement. Further examination and discussion of various communication and education techniques will be provided. Additionally, we will make recommendations to facilitate improvements in hazard, risk and emergency response communication, education and training.

2.3-O-02

Socialization of Geoscience Information for Reducing Volcanic Disasters in Arequipa – Perú.

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The city of Arequipa has a population of about one million inhabitants and is considered the second largest city of Peru. During the last 60 years, it has expanded into areas of high volcanic risk, without considering that the Misti during the last 2000 years has presented four major eruptions.

For these reasons, since 2006, the INGEMMET is implementing a project of education and awareness in volcanic hazards with the aim of reducing volcanic risk and improve quality of life of communities at risk, advising on prevention, planning and land management.

Based on the dissemination of geoscientific knowledge, it was made sense into population and authorities, in front to volcanic hazard, starting with the making land management in Arequipa through municipal ordinances that prohibit urban sprawl into areas of high volcanic hazard.

Likewise, the Alto Selva Alegre's municipality, has prepared a contingency plan against the possible eruption of Misti, where they have designed maps of evacuation, routes and stages for the district. Based on this map they are signaled the streets indicating the evacuation routes and boarding zones to evacuate people in case of volcanic eruption.

On the other hand, has managed to train public and private institutions and NGOs, armed forces, national police, firefighters, Red Cross, Health-sector, Education-sector, journalists, electricity generating companies, water companies, etc. All they were involved from the organization of first evacuation drill by volcanic eruption of Misti, in the district of ASA. The INGEMMET participated from training of those involved, eruptive scenario planning, preparation of material's dissemination and reporting the increased activity of Misti for purposes of drill.

2.3-O-03

Preliminary Study about Conceptions and Perceptions of Natural Risks on High School Students at Tenerife, Canary Islands.

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Results of a preliminary study about the conceptions and the perceptions on risk of students from the Canary Islands as well as the methodology used are shown in this paper.

The study has been carried out in two schools in Tenerife. This study is part of an empirical survey designed within the PhD entitled "Development of a Curriculum Project and Web Didactic Materials to Educate on Natural Risks in the Canary Islands".

Educating students on risks is cited by many experts

on risk management as a strategy to reduce such risks. (Ayala-Carcedo and Olcina-Cantos, 2002). In an international context, the United Nations' strategy to reduce disaster risk (ISDR) recommends inclusion of curricula to educate about the prevention of such risks in primary and secondary schools.

Experts on risk management demand an increase of scientific knowledge in society in order to improve the citizens' response during alerts and emergencies.

The main aim of the study is to obtain objective and actual information concerning the students' point of view about conceptions and perceptions on risk.

An open questionnaire was answered by 570 students belonging to two different high schools, one in a rural area and the other in an urban zone. The age of the students ranged from 12-18. This case-analysis represents a first approach to risk culture and to the perception of risks in the Canary Islands. The questionnaire was completed after Tenerife had suffered several risk situations, such as floods in 2002 where 8 people died, the Teide volcano unrest situation in 2004, and the Delta tropical storm in 2005 with very strong winds.

The results reveal that risk perception is not only a function of risk knowledge; it also depends on how information is reported and transformed, so as to provoke unrest or tranquillity in the population.

2.3-O-04

The Museum of Vesuvius Observatory and its audience. Years 2005 – 2009.

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The museum of Vesuvius Observatory was created through the enlargement and updating of a permanent exhibition, set up in 2000 with the aim of make citizens aware of volcanic phenomena, volcanic hazard and surveillance of active volcanoes in high risk areas, such as Naples and surroundings. The museum is located into the historical building of the Vesuvius Observatory, the first volcanological observatory in the world, currently part of the National Institute of Geophysics and Volcanology (INGV).

In the museum the dominant theme is Vesuvius: scientific issues are strictly interlaced with historical, archaeological and literary topics. The exhibition path goes from the presentation of volcanic hazard to volcanological methodologies used to define the eruptive history of a volcano. It traces the eruptive history of Somma-Vesuvius pointing out the most famous eruptions of 79 AD and 1944. Volcanic products are also displayed. The path is enriched by the exhibition of historical documents as the geological map of Somma-Vesuvius by Johnston-Lavis and copies of Ercolano and Pompeii casts. Also historical scientific instruments are shown, including the first electromagnetic Palmieri seismograph. The tour ends with a practical experience of simulation of an earthquake. Since the year 2000 checking of visiting public was carried out. This work presents statistics related to the public of the museum in the years 2005 - 2009. The monthly occurrence of visitors, visitors origin, category of visitors (distinguish-

ing among schools, universities, groups and others) percentage, amount of visitors during weekdays and holidays are presented. Statistics put in evidence that the audience is mostly made up of school groups, coming from the Campania region preferentially in the months of April and May. The accurate identification of the public allows the museum staff to arrange a tour tailored for different types of visitors, enhancing the quality of the communication.

2.3-O-04 - Keynote lecture

Building Effective Community Partnerships for Volcanic Hazards Education

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Volcano hazards communication is most effective when multiple groups work as a team to deliver consistent and complementary messages. Each group serves a different function. Emergency managers and public officials strive for a well prepared community; educators seek a more informed younger generation; community and tourism officials, park interpreters and managers seek effective interpretation and management of their resource; scientists strive to provide accurate information, technically sound interpretations and useful hazards assessments; the media seeks an interesting story. Partnerships provide potential for efficient dispersal of information that can lead to improved safety policies, heightened personal preparedness, and increased appreciation of volcanic parks and preserves. Consider these guidelines when initiating a volcano outreach plan in your community.

Determine your desired outcomes such as governmental policy change, mitigation plans by emergency responders, and heightened personal preparedness.

Seek the support of managers in vested groups.

Choose audiences carefully. Confer less attention on the diffuse "general public" and more on focused social groups that can re-transmit and act upon your messages efficiently.

Seek partnerships with groups that can be advocates for your cause—emergency managers, educators, health advocates, community and business leaders, park interpreters, media, and others with interest in general preparedness.

Develop consistent messages about volcano history and hazards.

With partners, craft complementary messages using recommendations for community risk mitigation, personal preparedness, and further actions citizens can take to educate their community

Measure effectiveness. Plan pre- and post-outreach assessments of community knowledge.

Develop outreach products and services in partnership.

Extend your effectiveness. Use multiple approaches to establish your message. Plan for a long-term commitment. Show how cooperation leads to legal compliance, increased safety, and community benefit. These guidelines can significantly increase the effectiveness of volcano hazards education and mitigation, even when resources are limited.

2.3-O-05

An Experience Of Volcanic Risk Education In Italian Nursery, Primary And Secondary Schools

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Among its objectives, the Italian EDURISK project (<http://www.edurisk.it/eng.html>) includes the realization of educational tools and projects for volcanic risk reduction. In 2007 the project published the booklet "I Vulcani e Noi" ("Volcanoes and Us"), an educational tool for primary schools, written and illustrated by Roberto Luciani (also available in English and Spanish). This volume is the result of a multi-layered process of planning, elaborating and revising scientific information, involving researchers with very different competences and background (volcanologists, historians, psychologists). The resulting product is brilliant indeed, as witnessed by praises expressed by several Italian schools who first used it within the EDURISK experience. In particular, the booklet was the centerpiece around which a totally new volcano-oriented educational campaign was launched in the schools of Ercolano (Naples), Lipari (Aeolian Islands) and the province of Catania (Sicily). The projects submitted in these three different volcanic areas have involved several hundreds of children in nursery, primary and secondary schools. In each area, the students developed itineraries for knowledge of volcanic history and hazard in their area of belonging, through the elaboration of local traditions and of traces of volcanic risk in religion and local folklore. The main objective was to start up a process of Knowledge of the territory, generate Wisdom and motivate the Action to reduce the risk.

2.3-O-05

An Experience Of Volcanic Risk Education In Italian Nursery, Primary And Secondary Schools

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2.3-O-06

The Contribution to Earth Science Outreach from the Staff of Istituto Nazionale di Geofisica e Vulcanologia (Italy)

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Science outreach is traditionally committed to individual scientists, who communicate to the public to promote awareness of science. Becoming increasingly important to bring science to a wide audience, the Istituto Nazionale di Geofisica e Vulcanologia, shortly after its foundation in 2001, has organized a team of part-time outreach scientists aimed at promoting science education, with particular emphasis to volcanic and seismic hazard. We present here an overview of the science outreach activities developed by our Institute, which have schools and public as their target groups. There are several venues of these activities: the headquarters of INGV in Rome and its many departments in Italy, from Milan to Catania. The Neapolitan region, with Vesuvius and the Phlegrean fields, and Sicily, with Stromboli, Vulcano, and Etna volcanoes, are the subject of several initiatives of scientific dissemination we organize, sometimes with the contribution of local authorities and Civil Defense, to explain how volcanoes work. Aim of these initiatives is to convey public understanding of the many-facet risks of Italian volcanoes, from paroxysmal eruptive activity to the menace of lava flows and ash fallout to infrastructures and inhabited areas, to landslides and tsunamis. Our activities also encompass a wide variety of formats, such as the opening of our labs to guided visits, contributing to national (e.g., the Italian "Week of the Scientific Culture", launched by the Ministry of Education and Research) and international (e.g., the European "Night of the Researchers") events, editing educational videos, creating multimedia tools also available on web. In museums and academies, and in concomitance of expositions and science festivals, we also organize exhibitions with experiments, models and exhibits designed to teaching and learning geophysics. Finally, we offer guided visits to the control rooms run by our institute, which ensures the round-the-clock volcanic and seismic surveillance of the whole Italian territory.

2.3-O-07

Volcano Observatory, Unified Command, and Community Emergency Response Team: Partners for Emergency Preparedness and Response in the Long Valley Caldera region of California (USA).

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Three decades of unrest in the Long Valley Caldera and Mono-Inyo Craters (LVC-MIC) has forged a strong partnership between scientists, emergency service agencies, and the public. This youthful volcanic region in Mono County, California (USA) is home to Mammoth Lakes, a resort town of approximately 7,500 residents nestled against the spectacular peaks of the eastern Sierra Nevada mountains. Opportunities for world-class skiing and other outdoor activities draw roughly 2 million visitors a year to Mono County. The County is also a critical infrastructure corridor (transportation, power, water) to communities to the south, including Los Angeles, with a population approaching 10 million. While the pattern of volcanic activity in LVC-MIC region suggests a < 1% probability of eruption in any given year, recurring earthquake swarms, ground uplift, magmatic gas emissions, and hydrologic disturbances remind scientists and officials alike that the volcanic hazard is real, and the potential consequences great. The last eruption occurred sometime between the mid-1700's and mid-1800's. The U.S. Geological Survey's Long Valley Observatory (LVO) is responsible for monitoring unrest and providing hazard information to civil authorities. Communication links are strengthened through observatory participation in local Community Emergency Response Team (CERT) and Unified Command (UC) programs. CERT is a jointly-funded government and private program that trains citizens to help with response efforts during natural or man-made disasters. Volcano and earthquake hazard mitigation taught by LVO scientists is an integral and popular part of CERT training. The UC unites LVO scientists with other government agencies and aid organizations with diverse functional authorities and responsibilities in the region into a common organizational structure designed to improve emergency response operations. The interactions afforded by quarterly UC meetings, garner trust in the community and teach LVO scientists to provide relevant information in formats that are readily understood by decision makers and responders.

2.3-O-08

The Impact of Community-Based Disaster Preparedness Training on Citizens' Knowledge of and Attitudes Toward Preparedness

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The problem of educating and motivating at-risk populations to take self protective actions to mitigate the effects of various natural hazards is an important issue for emergency management personnel. Research from

the social sciences has identified several factors which apparently mediate the relationship between hazard awareness and subsequent preparedness/ These include feelings of self efficacy and personal responsibility, behavioral intentions, and sense of community. In 2007 and 2008 Marin County, California offered dozens of two-hour long disaster training sessions free of charge at various locations throughout the county; over 2,500 people took advantage of these training sessions. In addition, the county regularly offers longer, more advanced training through its Community Emergency Response Teams (CERT) program. These disaster training sessions focused on earthquake, flood and fire hazards given that these are the most likely natural hazards to affect northern California. To evaluate the effectiveness of these efforts, two studies were conducted to study the impact that such training has on participants' level of knowledge and attitudes toward preparedness. In one study, 180 attendees of the Get Ready Marin sessions were sampled, and in a second study, 66 students from CERT training classes served as participants. In both studies, participants' knowledge of existing hazards and of proper preparedness strategies, as well as attitudes of self efficacy, personal responsibility, and sense of community were measured and compared prior to and after training. Results showed significant improvements in overall knowledge, as well as significant increases in participants' feelings of self efficacy. After training, participants more strongly viewed preparedness as a personal responsibility, and felt more bonded to their community. Although this work was not directly related to volcanic hazards, the results of these studies can be generalized and have implications for developing successful education campaigns for a variety of different natural hazards.

2.3-O-09

An Interdisciplinary Approach For Teaching About Volcanic And Other Natural Disasters At The Undergraduate Level

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Natural disasters are seemingly ubiquitous in the news. News reports, however, provide only small snapshots of the disaster and cannot always portray all the processes and events leading up to, and the crises that undoubtedly result from, the event – such limited exposure can ultimately give the public an obscured view of natural disasters. Here, we describe a course we are putting together as part of our interdisciplinary freshman seminar series that takes a three-dimensional perspective on various natural disasters. The course will address: 1) the science behind various natural disasters, 2) the long and short-term environmental effects of these phenomena, and 3) how various cultures deal with these events including how their history may influence the severity of the resulting disasters. Each one of these points relates directly to the discipline field of the three instructors; however, depending upon the specialty of faculty

involved, a course such as this can be easily modified to also address issues such as: 1) the role and responsibility of governmental and non-governmental organizations during a natural disaster, 2) the psychology of how people react to a natural disaster (i.e., post-traumatic stress disorder), and 3) how do various faiths interpret and respond to such crises. Due to very recent events such as the January 2009 Haiti earthquake, the long-standing eruption of Soufriere Hills, and Hurricane Katrina, special attention will be paid to the Caribbean Sea/Gulf of Mexico region. In addition to typical class formats of lectures, readings, discussions, and exercises, the course will also feature guest speakers who have first-hand experience in mitigating and dealing with the aftereffects of specific natural disasters. In addition, we are including a service learning component where students will gain a first-hand experience with the aftermath of a disaster by working with refugees from regions devastated by recent events.

2.3-O-10

Experiences on Galeras Volcano eruptive process (2004 – 2010)

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Galeras volcano in the SW of Colombia is characterized by permanent periods of activity and the location of around 500.000 inhabitants, 8000 of them live in the high risk area, at distances less than 6 km, where the volcano had produced pyroclastic flows among other phenomena. According with historical records (last 500 years), this volcano produce eruptions each seven to ten years and bigger eruptions roughly each 70 to 100 years. However, the last pyroclastic flow occurred in 1936. In the last 5 years, the volcano has produced eighteen explosive eruptions of small to medium size, eleven of wich occurred from February 2009 up to January 2010. The towns in the volcano area, includes the city of Pasto, capital of Nariño Province, with a total population of 400.000 inhabitants which have different risk perceptions about the phenoma. The people who lives inside the high risk zone, most of them with rural customs, believes the volcano is a friend or a "Taita" and for this it will never damage them. As a part of the National Committee for Disaster Prevention and Attention, the OVSP of INGEOMINAS in Pasto use different strategies and tools in order to inform the Institutions and communities about the Galeras activity levels and give explanations of the meaning of its hazard map. Local authorities have decided that evacuation order will be given for the high risk zone at activity level II and the community can return to their places at level III. In addition the National Government has a program focus on the final relocation of the people that lives in the high risk zone. All these process are development in paralell with the volcanic evolution, so the situation is problematic, with few progress and under a volcano with clear signals of its eruptive power. Learn from another experiences could be usefull for the Galeras region.

2.3-O-11

TELEPLANETA: Using Mass Media to Spread Natural Hazards Impact and Geoscientific Research

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One of the main and toughest goals for a geoscientist is to have a properly communication with the society when the time comes for showing results, scientific advances or whatever kind of remarkable event. The complexity of the scientific terminology, and the existence of a few communication channels, often prevents lay people to know about how the advance of science is occurring or how new discoveries are helping us to have a better understanding about the Planet Earth. In that respect, mass media provide the most powerful tool to enhance this communication, both radio and TV broadcasting, since the wealth of Earth-sciences' related information available on issues like global climate, water, energy and natural hazards remain largely unknown to the public and often untapped by policy and decision makers. Almost 75% of the Earth population lives in areas that had been hit, at least once in the last 20 years, by earthquakes, severe storms, flooding or droughts. TELEPLANETA is a joint effort of the Spanish National Public Television in the Canary Islands (TVE-Canarias) and the Institute of Technology and Renewable Energies (ITER) for raising public awareness of the impact of these natural hazards in the society, with an understandable language away from too much technical terms but basically avoiding the gruesome side of this kind of events. TELEPLANETA tries to give a scientific explanation of why these hazards occur, focusing on the visual communication with the viewers. This weekly TV program is broadcasted through the worldwide coverage news channel - 24 Hours Channel - of the Spanish National Public TV (TVE).

2.3-O-12 - Keynote lecture

Why Volcanic Disasters Can Still Occur Despite Good Scientific Knowledge

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Many disasters need not be disasters, if only scientific knowledge were utilized. Here are some factors that still make disasters possible: 1) Personal trust between scientists and decision makers is never built. Would-be users aren't asked to help fund or gather information. Thus, they don't feel ownership. Yet, many decisions in life are made as much on trust and ownership as on facts; 2) Scientists don't recognize that their worldview conflicts with the worldview of those at risk, e.g., along religious or fatalistic lines, so scientific information doesn't "fit" into decision processes; 3) Scientific information is hard for laymen to understand. Scientists use jargon and 2D. On the other side, officials may ask for oversimplified black and white. Visualization tools and scientifically-literate journalists and public leaders are missing; 4) Scientists release either too much or too little information, especially if they haven't talked with

decision makers to know what is and isn't needed; 5) Information isn't quantitative enough, or doesn't describe mitigation options clearly enough, for informed cost-benefit mitigation decisions; 6) Scientific caution or debate is misunderstood as indecision or incompetence. Scientifically literate people appreciate caution and debate, but most people will understand "error" as "mistakes," and "differences of data or interpretation" as "incompetence." Front-page scientific disagreements will usually cause all scientists to lose credibility; 7) Scientists don't take the same precautions that they urge others to take. Risk-taking by scientists should be discreet and only when truly necessary. The public will follow our own lead; 8) Scientists embarrass public officials into defensive inaction; 8) Poverty and population pressures, and/or unavailability of safe, attractive mitigation option, lead people to simply take their chances; 9) Failure of civil defense to integrate and communicate across topical or geographic jurisdictions; 10) Short-sighted profit focus by business, or popularity gambles by politicians, overrule official caution.

2.3-O-13

Canary Islands: A Volcanic Window In The Atlantic Ocean

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One of the most important problems of living in a volcanic area without a frequent eruptive activity is to evaluate the knowledge and perception of volcanic hazards and/or volcanic risks by the population living close to the volcano. Canary Islands are a perfect example of this type of volcanic areas. For this reason, ITER Volcano Group decided to evaluate the level of perception by the inhabitants of the Canaries and to provide an educational and formation channel for the population to learn about volcanic hazards and volcanic risk issues, and also about the Canary Islands volcanic risk phenomena. This program called "Canary Islands: A Volcanic Window in the Atlantic Ocean", started in 2008, by running a three days (three didactic units) educational program at each of the 88 canary municipalities plus the populated islet of La Graciosa.. The first two days, the edited and commercial UNESCO-IAVCEI Educational Video Programs, "Understanding Volcanic Hazards" and "Reducing Volcanic risk" are shown to the audience, respectively. On the third day, a specific PowerPoint slideshow about the volcanic phenomena and volcanic risk management in the Canary Islands is also shown. Developing this educative programme for the third year in a row, up to 7500 persons have attended the program, improving their knowledge on these topics. Along these three years, new activities have been added to this program, including a volcanic trivia to be filled by the audience before and after every didactic unit, in an attempt to calibrate not only the knowledge of the assistants but also the level of comprehension once the didactical units are finished. With this innovative tool we have been able to carry out a quality control of our own teaching capacities.

2.3-P-01

U.N. Global Platform For Disaster Risk Reduction

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The recent second session 2009 of the UN Global Platform for Disaster Risk Reduction highlighted the importance of education and sharing knowledge, including indigenous and traditional knowledge, and ensuring easy and systematic access to best practice and tools and international standards, tailored to specific sectors, and to necessary cross-border data. It also stressed the necessity for investment in research and development and higher education, and for the more effective integration of science and technical information into policy and practice. Educational level and cultural background of the population constitute determinant factors for the success of any prevention and mitigation and particularly concerning volcanic eruptions. Also, since some years ago, many risk-prone countries are now giving high priority to disaster risk reduction and wish to move ahead quickly in the design and adoption of policies and strategies to address their risks. Increasingly, the urgency for this movement is coming from the vulnerable developing countries, which are likely to bear an increasingly disproportionate share of disaster impacts in times to come (i.e. most high-risk volcanoes lying in these areas). A variety of national and regional platforms and organizations are being rapidly developed or strengthened to guide and coordinate this action. The international community needs to support these initiatives and facilitate better access to resources, assistance and expertise as a matter of urgency. The development of platforms for disaster risk reduction at both national and sub-national levels needs to be accelerated again in order to create an enabling environment, and to inclusively engage varied government and civil society interests and address cross-cutting issues.

2.3-P-02

On the Public Attitudes to the volcanic Hazards in Japan, - Case Studies of the Yakedake Volcano and Chokai Volcano -.

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Volcanic hazard maps are very useful not only for the hazard mitigation plan but also the understanding of the volcanoes for inhabitants. Already 33 volcanic hazard maps issued by the local governments in Japan, however, it is hard to say that is conjugated enough by inhabitants. The authors carried out the questionnaire surveys on the 2 areas of inhabitants (Yakedake volcano and Chokai volcano) in order to know their attitudes to the volcanic hazard map and the level of their understanding of the contents of the hazard map. From the comparison of these 2 areas respondents, we can find common characteristics as followed as; (1) the elders

have a tendency to have deeper understanding hazards than younger, especially in elder who have experience to meet some kinds of natural disasters, (2) People who attend the explanatory meeting of the volcanic hazard map also tend to have more proper understandings. (3) The people who are engaged to the tourism give more attention to the volcanic hazard than others. (4) And also respondents have strong tendency to require more knowledge about the volcanic activities and hazards. These results indicated that the respondents required having the communication with scientists, engineers and administrative officers, and that the further activities by scientists, engineers and administrative officers are expected to establish an informed consent, that is, should be a decision-making by inhabitants themselves and support by scientists and officers in charge with detailed explanations.

2.3-P-03

Awareness and risk perception on communities located near active volcanoes: Methodology applied on Caviahue-Copahue area (Argentina).

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In this work we present a model program designed to inform and promote the interest in volcanoes and their characteristics, in communities located near active volcanoes. Caviahue and Copahue towns (Argentina) are located near Copahue volcano (6 and 2 Km., respectively) and have a stable population of about 600 people, being tourism their main source of income. This volcano has a recent eruptive history (1992, 1995 and 2000), both communities have not been exposed to systematic programs of information about the characteristics of the volcanic area where they live, this fact was evidenced in the confusion and fear shown during the eruption on 2000. In this regard, and in order to inform about the risks and benefits of living in a volcanic area, a competition was organized, with students of the public school, to prepare a diffusion brochure for visitors to the area on three main topics (a) environmental characteristics, (b) how to act before the contingency, (c) the studies to monitor an active volcano. Previously workshops were organized to provide information on general volcanology and the Copahue volcano characteristics in particular. With this information and expanded on the web, xx brochures were made up and three of them were selected to be printed and distributed among tourists this year. Students were chosen as major receivers to possess ideal characteristics to support long-term activities as well as their ability of transmission to adults. Thus we believe that was achieved: (a) knowledge and awareness in children and through them to the community about the risks of living on a volcano, (b) information and awareness to tourists (transient population) who visit place, (c) to bring scientists into the community.

2.3-P-04

Education and Outreach Activities for Reducing Volcanic Risk at Tarumae Volcano, Hokkaido, Japan

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Tarumae is one of the major active volcanoes in Japan. Plinian eruptions with pyroclastic flow occurred in 1667 and 1739, and dome growth eruptions occurred in 1867 and 1909. Population within 30 km area from the summit is about 400,000. Major industrial cities and an important airport in Hokkaido Island are located at the eastern to southeastern outskirts and leeward of the volcano. As former inhabitant Ainu do not have their own letters, none of detailed documents on Tarumae eruption is existing until late 19th century. This means nobody knows tradition of hazardous volcanic eruption of the Volcano. Volcanic hazard map was published and distributed in 1994. Since then, lahar control facilities are constructing.

We started several public education programs since 2004 under the financial support by Hokkaido Development Agency (HDA), Ministry of Land, Infrastructure and Transportation. We have supervised foundation of exhibition hall owned by HDA to learn Tarumae Volcano. We have recommended to preserve an excellent exposure of pyroclastic flow deposit derived from the volcano. We have published textbooks on Tarumae Volcano for school children. Also, we have edited a DVD to learn Tarumae volcano and its disasters.

We are doing lectures to learn the volcanic activities and associated disasters for community leaders, teachers and school children. We are doing field excursions for children and teachers to visit the preservation exposure site, lahar control facilities and the exhibition hall showing a demonstration of simulated plinian eruption. Also, we have guided community leaders and teachers to summit area of the volcano. We have prepared an imaginary eruption scenario and directed a map exercise for the government officials who are taking charge of natural disasters. Advises for business continuity plan in case of volcanic eruption were done for some local industries.

2.3-P-05

The Volcanic Risk Perception During the Eruptive Process 1998-2010 in the Volcan de Colima, Mexico.

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Volcan de Colima (19°30'44"N & 103°37'02"W) is the most active volcano in Mexico. The lava dome growth in the summit (2007-2010) shows the beginning of a new effusive activity with similar characteristic to those of

1998, 2001-2002 and 2004. These activities surpassing the border of the crater and originated lava flows, pyroclastic flows, collapses, ash rain, and generated explosions from the summit with columns of 5 km altitude (1999, 2005). These caused the fall of ballistic projectiles on the volcano slopes.

In the last twelve years the volcano has presented different activity types that have affected some near populations located around the volcano and resulted in the relocation of "La Yerbabuena" town (2002), which is 8 km southwest of the volcano summit and seated on a pyroclastic flow deposit from the 1913 eruption (Plinian activity). In a radius of 50 km more than 500 thousand people reside, whom are exposed to the volcanic activity presented in the last five centuries. The activity occurred between November 1998 - February 2010, provides us important experiences which the actions of risk mitigation can be coordinated between scientists, authorities and population. It always represents an important part in the administration of volcanic risk. The knowledge about the volcanic hazards and the perception of volcanic risk has changed in Colima during the last twelve years. This work picks up the experience acquired during these years of volcanic activity.

2.3-P-06

Volcanic Risk Perception In The Towns Around Mt. Vesuvius

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In the Red Zone around Mt. Vesuvius hundreds of thousands people have to be evacuated if a new eruption is expected within a few weeks. Observers believe that Napoli is not an ordinary city and Campania not an ordinary region because discipline is not the main attitude of the local people. It is evident that the management of such a large quantity of people, possibly not adequately aware to the volcanic risk, is a difficult task. To systematically examine if people are able to make decisions concerning different volcanic scenarios, a survey of risk perception and preparedness had been conducted in several communities located in the Red Zone. Five towns were chosen because owing to their geographical position they are subject to different hazards. The towns also vary in size (from about 13,000 to 89,000 inhabitants). Two main social targets have been identified: working class people and students. Furthermore, numerous local experts belonging to civic emergency management authorities have been interviewed. Actually we have collected respectively 345 (working class people) and 1657 (students) questionnaires. Results indicate : a) there is little statistical evidence to suggest that increased educational qualifications auto-

matically increases hazard and risk knowledge and the levels of preparedness of the sample population; b) the use of the media for information was the most common source, yet was also the biggest cause for distrust amongst the sample. The most trusted source was the official scientists and experts; c) there was the opinion that the evacuation plan would not be successful due to a combination of the population's under-preparedness and the logistical issues surrounding an evacuation.

2.3-P-07

The "Laboratorio Di Geodinamica – Le Scuole Per Il territorio" (Laboratory Of Geodynamics – Schools For Territory) Project

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Italy and, especially, Sicily has been characterized by the rapid growth of cities and villages, which occurred too often ignoring the geological characteristics of the territory. The tragedies that frequently affect its territory (eruptions, earthquakes, etc.) causing death and destruction are evidence of misuse of the territory, due to the unforgivable lack of knowledge of geologic hazards. From 2008, a project, named "Laboratorio di Geodinamica – Le Scuole per il territorio" (Laboratory of Geodynamics – Schools for territory), started in cooperation between the section of Catania of INGV and "N. Colajanni" high school for land-surveyors, involving the students in the geodetic monitoring activities by GPS and terrestrial measurements. The project is aimed to the divulgation of information about the volcanic and seismo-volcanic hazard of the territory, through a didactical program characterized by practical and field activities. By this project, students are involved in the GPS monitoring activities on active faults on Mt. Etna volcano and participate also to the EDM measurements on the La Fossa crater at Vulcano during a 1-week stage, in order to acquire the necessary knowledge of the scientific techniques for investigating and mitigating the geological hazards. The project introduces the young high school students to the scientific method, providing them the necessary skills to carry out high-precision measurements and to adopt the right strategies to investigate natural phenomena. The objective of the project is to educate the surveyors to a greater sensibility to the natural and, especially, geo-volcanological hazard in order to promote a more sustainable development based on the awareness of the risk. The surveyors, in fact, will be responsible of the environment in which they operate and it is essential to make them informed about the characteristics of the territory and able to correctly evaluate them, adopting also the correct strategies to mitigate the risk.

2.3-P-09

Culture, Education and Communication about Volcanic Hazards in Chile: a Proposal

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Associated with the highly-active east-dipping subduction of the Nazca plate beneath the South American plate, the Chilean continental margin has 123 geologically active volcanoes (Lara, 2008). During the XXth century, more than 89,000 people were affected during 20 eruptions that took place in Chile, two of them being the biggest ones in South America for that period (Whitam, 2005; Lara, 2008). Despite the recurrent volcanic activity and other common geological phenomena such as subduction-related earthquakes (two of the five largest earthquakes of the XXth century took place in Chile, <http://earthquake.usgs.gov/earthquakes/>) and all their secondary effects, we still have an insufficient culture about geological hazards. Thus, the aim of this contribution is to present effective ideas conducing to a short- to long-term strategy to communicate and to educate about volcanic hazards from the school and through the Chilean society. Special attention will be given to a strategy of work with the communities living near active volcanoes (Segura y otros, 2008) where Sernageomin is generating information about volcano geology and monitoring. References: Whitam, 2005, JVGR; Lara, 2008, SERNAGEOMIN; Segura y otros, 2008, SERNAGEOMIN.

2.3-P-10

Web Page Actualidad Volcánica de Canarias (AVCAN.ORG): Volcanoes, to Everyone

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The seismic volcanic crisis experienced in 2004 in Tenerife, stirred the interest of part of the population about the volcanic phenomenon. However, one of the weaknesses was that the available information was not sufficient and that it was scattered. Even different broadcasts were in conflict with each other. This caused mistrust and unnecessary alarm. It's been six years since the crisis and this situation has not improved, as the information is still limited and/or difficult to access for the general public.

AVCAN.ORG is a portal web of the Internet which intends to help to minimize this deficiency by acting as a link between scientists and citizens. Emerging from this trend is the idea of stimulating the knowledge and study of the volcanic phenomenon in the Canary Islands, promoting in a responsible manner, the knowledge gained to the benefit of the population.

AVCAN.ORG has been developed with the intention of focusing all the available public information with regard to the volcanic phenomenon in one place. In this way any person interested will be able to access to this information in a simple manner. AVCAN.ORG also has the facility for consultation of data 'à la carte', expressed either numerically or graphically as well as providing real time maps. That is why we believe that it could be as useful for amateurs as it is for students and professionals who work or research in the Canary Islands Volcanology field.

One fundamental premise of its founders is the reli-

ability of the contents, ensuring only the official information or that signed by experts is published and put together with its source.

AVCAN.ORG is a portal designed for its continuous evolution, easy for updates with any new information, as there are always new ideas in process.

2.3-P-11

Developing an Outreach Plan: The Montserrat Volcano Observatory Case Study

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The Montserrat Volcano Observatory (MVO) continuously monitors the Soufrière Hills Volcano to provide timely advice to the authorities in order to reduce the impact of volcanic activity. Although primarily a scientific monitoring agency, scientists at the MVO have been involved in education and outreach activities since the agency's inception. Prior to 2008, however, the majority of these activities have been reactive (e.g. facilitating media interviews or lecture requests) as opposed to proactive. In January 2009, the MVO launched its 'Outreach Plan 2008-2010' the objective of which was to deliver a comprehensive strategy for effectively providing information on the Soufriere Hills Volcano to residents of Montserrat in the first place and to non-residents with an interest in Montserrat in the second. This presentation looks at the methodology used to develop the Plan, outlines the strategy and activities in the Plan and discusses successes and challenges faced in implementing the outreach plan.

2.3-P-12

PLANETA VIVO RADIO: a challenge of Spanish National Public Radio and ITER to increase awareness of the importance of Earth Sciences

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PLANETA VIVO RADIO is a radio program broadcasted by the Spanish National Radio (RNE) in Canary Islands and the ITER Canary Foundation since October, 2008. The aim of this radio program is to divulgate scientific and technological developments related to the Planet Earth. This initiative of RNE and the ITER Canary Foundation was born in a very special year (2008), the International Year of Planet Earth, with the attempt of contribute to the spreading and achievement of the objectives of this important international declaration proclaimed by the General Assembly of the United Nations. The main goal of this statement is to make society aware of the existing relation between the Humanity and the Planet Earth, and to highlight the importance that Earth Sci-

ences have in the attainment of a balanced and sustainable future that improves the quality of life and protects the dynamics of the planet. PLANETA VIVO RADIO is also linked to the Cities and Volcanoes meetings philosophy, since contributes to the reduction and mitigation of volcanic risk making communities like Canary Islands aware of living in active volcanic areas. Therefore, PLANETA VIVO RADIO provides a useful and innovative communication tool to improve the knowledge of the population about the environment and its interactions with the human impact. This radio program interviews every weekly experts and scientists to discuss and talk about a specific issue related to the Planet Earth and is broadcasted through Radio 5 in Canary Islands and Radio Exterior de España, both radio channels of RNE.

2.3-P-13

Chinyero, 100 Years of Silence: A Scientific-Historical Film Document for Education and Outreach on Volcanism in the Canary Islands

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Antonio de Ponte y Cologan was a historical chronicler and an exceptional witness of the last volcanic eruption occurred in Tenerife, Chinyero 1909. His description of this important eruption, entitle "Historical memory describing the Chinyero eruption occurred on November 18, 1909", is an ideal opportunity to make a Scientific-Historical Film Document about this natural event. Chinyero volcano eruption does not stand out not for the duration of the eruptive process (only 9 days) or by violence and devastation caused by the lava flows. However, there are many other remarkable aspects that become Chinyero volcano in a well remembered volcanic eruption in the Canary Islands, the rest of Spain, and in many other countries in Europe and America. Chinyero volcano eruption was, at that time, one of the best studied historical eruptions by those who witnessed this volcanic event, due to their scientific knowledge. During the nine days Antonio de Ponte y Cologan reported the progress of the eruption, took samples, made geomorphological descriptions of lava flows, drew maps with extraordinary precision and took daily pictures of the eruption. In addition, he used carrier pigeons as a curious communication system, to send information to the authorities that managed the crisis without leaving his privileged position. That information was disseminated with enormous impact through the media of Canary Islands, the rest of Spain and Europe, allowing the world to know what was happening in the Canary Islands in 1909. The scientific-historical film document "Chinyero, 100 years of silence" honors the scientific work of this enthusiastic disseminator of volcanoes, Antonio de Ponte y Cologan, which was witnessed, 100 years ago, the force of nature. "Chinyero, 100 years of silence" seeks to recall the past with an eye to recent history of volcanism on Tenerife and the doubt whether we are really prepared to deal with another volcanic crisis in the future.

Session 2.4

2.4-O-01

Galeras Volcano, Crisis Management and Resettlement of Inhabitants

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Within the handling of the emergency without doubt, one of most difficult things is to convince the inhabitants of the zone of high volcanic threat (ZAVA), on the necessity to evacuate to save their own lives, since its constant refusal. Galeras has not been the exception since the mayor of Pasto, has had to order in several occasions, the evacuation of the population to the temporary shelters that the Local Committee for Prevention and Attention of Disasters has constructed for such aim, surprising everybody with the attitude of the community and its refusal to the preventive evacuation. The affected communities have the firm belief that the volcano will give a warning signal a few minutes before the eruption occur or that the Virgin of the Rosary will protect them of the pyroclastic flows. 18 explosions have occurred between June of 2004 and January of 2010, none with fatal victims. For the evacuees it hasn't been enough adapting the temporary shelters, to give blankets, food, to construct schools, health centres, and all the necessary to facilitate its temporary permanence in these sites properly equipped. The efforts made by the local authorities in front to the religious faith of people and the attachment by parcels will never be enough. After almost seven years of temporary evacuations, today the communities demand definitive solutions to the National Government, being perhaps the resettlement of population the only exit to a problematic of almost 8.000 inhabitants in all the area of influence of Galeras. Happily the resettlement has begun and the first houses were bought. Is expected that over the next two years at least 60% of the inhabitants of the high risk area have left this territories, waiting for a new kind of life in company of their loved ones.

2.4-O-02

The Impact of and Responses to the 1957/1958 Capelinhos Volcanic Eruption and Associated Earthquake Activity on Faial, Azores.

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The 1957/58 Capelinhos eruption on Faial Island in the Azores is well known for being an excellent example of Surtseyan hydromagmatic volcanic activity. Less well known are the responses of the Portuguese authorities to the eruption and subsequent earthquake in May 1958,

and the ways in which well-thought-out and generally effective recovery programmes were put in place. At the time Portugal was ruled by a dictatorship, the Estado Novo (New State). Only superficially similar to other fascist governments in Southern Europe, the Estado Nova collected huge amounts of data on the responses of the authorities to the disaster and their programmes of recovery, but never encouraged academic evaluation, although it ensured that the scientific aspects of the eruption and earthquake were meticulously recorded and published.

In this study we remedy this situation by discussing the details of the immediate response to the emergency and the ways in which the island recovered in its aftermath. Study is based not only on archival data sources and numerical data, but also on detailed interviews with survivors some of whom were also decision makers. We argue that response, recovery and rehabilitation were generally highly successful and assess the lessons of the 1957/8 emergency which are relevant to future geophysical disasters in Faial and the wider Azores. We conclude by answering in the affirmative the question over whether such strong and successful direction of an emergency response to a disaster would be possible within today's democratic context.

2.4-O-03

Disaster Prevention Measures of Kagoshima City against Eruptive Activity of Sakurajima Volcano, Japan

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Sakurajima volcano repeated large-scale eruptions in history. Great eruption with a lava flow in 1914, minor lava flow in 1946 and frequent Vulcanian eruptions at the summit crater since 1955 were recorded in 20th century. Eruptive activity of the Showa crater at eastern flank resumed in June, 2006 and the activity gradually increased. The damage by ash fall gives the life of inhabitants living in Sakurajima. Kagoshima city area disaster prevention plan for volcanic eruptions of Sakurajima was established by Kagoshima city. In crisis due to great eruption, Mayor Kagoshima announces evacuation advisory by radio broadcasting system. Inhabitants evacuate from a port built at each village by ship to move from Sakurajima to opposite bank of Kagoshima city area and stay at a refuge (gymnasium and school) appointed beforehand. Concrete shelter is built to protect evacuees from a cinder at each port. In normal state, we cooperate among each engine and promote refuge measures in "Sakurajima anti-disaster measures liaison conference". The Central group of it; Ministry of Land, Infrastructure and Transport (erosion control department, Meteorological Agency), Kyoto University, Kagoshima Prefecture and Kagoshima city hold a degree meeting once a month to discuss disaster prevention and exchange information. In order to enlighten disaster prevention awareness of inhabitants,

we conduct evacuation drill at one or two villages and disaster prevention workshop every year and distribute hazard map to show prohibition area and refuge information to all houses, business establishments and tourist facilities. In 2013, IAVCEI General Assembly will be held at Kagoshima city. We will advance refuge support measures for senior citizens and enlighten disaster prevention awareness of inhabitants and support improvement of the eruption forecast precision.

2.4-O-04

UME, a Force to Respond to Volcanic Eruptions Disasters

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Spain recently created a new Central Government Emergency Response Force. Its role covers the whole spectra of emergencies, thus volcanic eruptions disasters. This Force is intended to react as quickly as possible, when needed. It is a part of the Spanish Armed Forces specifically trained to act shoulder to shoulder with the Civilian Emergency Services. It should only be used when the civilian authorities are fully committed and require the assistance of military assets in support of the ordinary, but overwhelmed Emergency Services; should this occur, it would be the first military unit to deploy: Notwithstanding, it could pull other Military Forces into the spot as requested; in this case, these Military Forces would be under UME's Tactical Command.

Regarding its employment in a disaster caused by a volcano, the unit could deploy simultaneously two Battalion and one Regimental Command Posts (CP), as well as a CP for UME's Commanding General Officer; these are not only able to control Air and Ground assets, but also to provide Telecommunications support to the full spectrum of Civilian Agencies.

The capabilities that UME offers are: First teams to start the deployment without delay: 2,5 hours in Canarias (1 hour in the rest of Spain), once the mission is issued; Transport support (i.e. to the scientific community); Evacuation capability; Encampment capability, up to 1,000 people; Special and comprehensive Command Information and Telecommunications Systems; Search and Rescue Teams, to include search dogs; Water Purification capability; Reestablishment of Vital Infrastructures; First Aid assistance; Fire-fighting capacity; Mechanical Diggers to remove stone blocks and debris; actions against Technological Catastrophes; and in every operation, not only being logistically autonomous, but also offering the possibility to support both affected civilian personnel and other Emergency Services in different fields.

2.4-O-05

Mitigation of Lava Flow Invasion Hazard Through Optimized Barrier Configuration

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In order to mitigate the destructive effects of effusive eruptions along volcanic slopes, the building of artificial barriers is a fundamental action for controlling and slowing down the lava flow advance. Starting from the experience gained in recent Etna eruptions, in this work we investigate how the combination of numerical methods to simulate the flow propagation with optimized barrier construction procedures can improve the effectiveness of this mitigatory actions. As a matter of fact, the simulated lava path are used to optimize methods and actions for the barrier construction work providing a robust and quick procedure to define the location and the geometry of a barrier system. The work is supposed to be realized by using a gabion based structure instead of the usual barrier built up using earth, lava blocks and incoherent, low density material. The proposed solution overcomes many operational constraints and logistical problems posed by a barrier construction. This approach has been applied to simulate the lava flows emplaced on Etna south flank during the 2001 eruption (Coltelli et al., 2007, Vicari et al., 2007) permitting to assess the performance of the realized barrier system against a simulated alternative solution. The same analysis was then extended to another case study, the 1981 Etna eruption, for which a hazard assessment analysis for simulated scenarios was conducted.

2.4-O-06

Emergency System Diagnosis in the Canaries

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In the last couple of years, a number of natural events have occurred in the Canary Islands (seismic crisis of 2004, Tropical Storm Delta 2005, March 2002 rainfall in Santa Cruz de Tenerife and the Canaries February 2010, wildfires 2007 in Gran Canaria and Tenerife, etc.). Since 2000, only the ones with a climatic origin have resulted in tens of millions of Euros in losses and thirty fatalities.

The General Directorate of Security and Emergency of the Canary Islands Government has proposed to the Canarian universities to conduct a work that is aimed to diagnose management system emergencies and disasters at the local level, using a sample of twelve municipalities of the Canary Islands.

In this work, an analysis of the rules and protocols for emergency action in the Canary Islands are exposed. The study of the documentation related to possible volcanic crisis and the main conclusions regarded to the diagnosis and activation of emergency procedures will be seen in this work. One of the first conclusions obtained in this study, is that the pyramid structure of emergency management system in the Canaries, with the municipalities in the base, generates significant deficiencies regarding the lack of trained personnel and assumption of competence and responsibilities of the

municipalities. This and other factors explain why - after more than twelve years the adoption of legislation that requires the preparation of emergency plans at municipal level - the percentage of municipalities canarian that achieve legality is still so low.

2.4-O-07 - Keynote lecture

The Certainty of the Uncertainties: Colombian Experiences During Volcanic Crisis Management

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In risk reduction, crisis management or disaster prevention geoscientists have to work together with authorities, policy makers, community and private sector representatives. The main challenger is to work together, in a coordinated and effective way, in a multi-disciplinary, multi-institutional approach, learning from past experiences and involving scientist, community and authorities at national, regional and local levels. One of the most complicated tasks is to understand and manage the uncertainties involved in many of the information provided by the geoscientists, in other words, the certainty of the uncertainties in volcanic activity. Geoscientists working in a particular volcano, during a volcanic crisis know that they play a very important role in crisis management, but not always they are prepared or they know the necessities of information that is needed for the partners in the multi-disciplinary, multi-institutional group and they know even less, how the geoscientific information is going to be used, managed or interpreted. The first involvement of the geoscientists is the assessment and zoning of the hazard of the volcano and the second involvement is the information provided by the monitoring of the volcano. It is necessary to define how the Volcano Observatory will communicate the stage of the volcano in a particular moment and to who will be informed. In most of the cases, the information provided implies several uncertainties, such as, how precise is the line in a hazard zone map, can someone be sure that the volcano will erupt tomorrow, so the person can evacuate today and comeback tomorrow? How long communities have to leave their houses and the animals unattended? An important point towards a success of crisis management is that authorities and community understand the hazards, the volcanic monitoring status of the volcano, including the uncertainties imply in those evaluations and the responsibilities of the decision makers at all levels. During the crisis management at Galeras and Nevado del Huila volcanoes at Colombia, we were confronted with this kind of situations, the presentation will share our experiences in this kind of situations, during volcanic crisis of the most recent eruptions at those volcanoes.

2.4-P-01

The Concept of Real-Time Hazard Map for Volcano Crisis

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In case of the volcanic crisis, we need much information on the state of volcanic activity, as well as the estimation of hazards around the region. NIED executes a research project for volcanic eruption prediction and disaster mitigation, consisting of monitoring of volcanoes, remote sensing and numerical simulations of volcanic phenomena. Most important strategy is to realize the effective and dynamic linkage between monitoring, source estimation and simulation for hazard estimation, so we are developing the system whose data is as follows: 1) Monitoring data acquisition, 2) Data processing & analysis (hypocenter determination, abnormal signal detection), 3) Identification of activity (modeling of source location, size, geometry and changes, parameter decision), 4) Eruption scenarios (combining the old data, historical eruptions, event trees), 5) Numerical simulation (dike migration, lava flow, pyroclastic flow, etc.) and 6) Hazard and Risk evaluation (real-time hazard map). One key point is to get "correct" source model under the volcano, which leads to the superficial phenomena like fissure opening, lava flow, lava dome, ash fall, pyroclastic flow and so on, and these directly attacks human beings and facilities. Actually, once the eruptive activity starts and it may be too fast to issue the real-time hazard evaluation, so it is important to build a database as the archives of the case-studies of volcanic hazards. This database will be well-collaborated with WOVodat.

2.4-P-02

"They Said What?" Exploring the Understanding and Impact of Science Advice on Volcanic Emergency Decision Making.

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In the lead up to, during, and after a volcanic natural hazard event, a number of critical emergency management decision-making challenges arise within Emergency Operations Centres (EOCs). These are often based upon limited and uncertain information. Successful decision-making is fundamentally dependent upon the situational awareness of the Emergency Management Officers (EMOs), which is their assessment and understanding of the available information, the definition of the problem at hand, and the time and risk pressures. The New Zealand Cabinet directed national "Exercise Ruamoko" was run in 2007/2008, to comprehensively test the local, regional and national arrangements for dealing with the lead up to a volcanic eruption in the Auckland metropolitan area. One of the key recommendations from this exercise was the refinement and coordination of scientific advice from "one trusted source" during a crisis. This requires a rationalization and integration of a wide range of scientific opinions, model outputs and outcome scenarios. In particular, scientific uncertainty was identified as a challenging environment for response planning and decision making. In N.Z.,

"Science Advisory Groups" (SAGs) have been identified as the pathway for the formation and dissemination of this advice to EOCs. However, there is currently limited understanding of how this information is effectively used during the decision making process of the volunteer EMOs. We present planned test simulations to be conducted in a new "EOC Lab" to investigate how the presentation style of the scientific information, and the methodology for forming a consensus, affect the situational awareness of EMOs and the effectiveness of the critical decisions they make. These will involve re-running challenging aspects of Exercise Ruamoko to test the suitability of various scientific advice formats for different behavioural decision making strategies, with a goal to establish guidelines for the provision of scientific opinions and model outputs during hazardous events.

2.4-P-03

Emergency Military Unit, a Central Government Force to Respond to Disasters

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The Law on National Defense (2005) remarked among others, the role of the military in case of catastrophe. In accordance with it, the Government created the Emergency Military Unit (UME). Relief efforts had never been considered before a primary mission for the military. The Armed Forces will be used through UME in the front line in case of any emergency, therefore against volcanic eruptions. This unit tries to complement the Civil Protection System, enhancing their nowadays capabilities. UME is a Public Service ready on a 24 hours/day, 7 days/week basis.

About its main features: it is a permanent Military Joint Unit, encompassing all necessary means to fulfil its mission. UME operates within the structure of the Ministry of Defence (Not Home Office). UME emphasizes all Armed Forces skills, such as logistics to move large amounts of materials and equipments, and mobilize a large number of personnel. Additionally, it has specific capabilities: Logistic Autonomy; Non-stop Activities, with Night shifts; and Telecommunications support.

This unit's backbone are 5 Battalions. It has moreover, a Support Regiment, an Air Task Force and a Headquarters Support Unit. These units enable our main capacities, such as: Fighting wild fires; Floods and Earthquake Search and Rescue; Winter Snowfalls assistance; Shelter for homeless; Technological catastrophes; Water purification; Transport; Reestablishment of Vital Infrastructures. Among these assets, let me notice the Air Task Force with an Air Force Group (with 17 water bombers) and an Army Helicopter Battalion (new unit under constitution, currently with 4 light EC-135 and 4 medium type Cougar helicopters).

UME met with Government Institutions and all the Autonomous Communities and Cities reaching coordination and cooperation agreements with most of them. Since it started its operations last June 2007, it has had more than 70 commitments, proving its reliability both in Spain and abroad.

2.4-P-04

Contingency Plan for Eruption of Galeras Volcano -Nariño -Colombia

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The Galeras volcano is considered one of the most activity in Colombia, in the latter period of revival have submitted 17 eruptions in the period 2004 to 2010. In the area of influence of 500.000 people live volcano, of which 8.000 are on the high volcanic hazard area where there have been dangerous phenomenon such as pyroclastic flows.

Procedural guidance was developed to guide the development of preparedness and response actions that will support the institutions that participate in the National System for Disaster Prevention and Assistance, which aims to overcome efficiently and quickly an emergency situation or disaster with minimal impact to the population. This plan has early warning systems, communications, alarm, built temporary shelters for up to 6.000 people, in 2009 the average discharge was 600 persons, which is considered low, for the primary purpose of saving the life of people.

This experience has left lessons learned, as it has been a difficult situation especially for communities living in the catchment area of the volcano, who consider the volcano as his friend, so that preventive measures such as evacuation are not considered appropriate far has been the need to work with communities and institutions to enhance efforts to reduce volcanic risk.

2.4-P-05

Community Understanding of and Response to the Lahar Risk at Mount Rainier: Implications for Public Education

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Mt. Rainier is an active volcano, located in the state of Washington in the United States. It is the highest peak within the Cascade Range and is considered to be one of the most dangerous, given its proximity to heavily populated areas such as metropolitan Tacoma and Seattle. While a variety of volcanic hazards at Mt Rainier threaten the region, the greatest risk comes from the threat of lahars, or volcanic debris flows. Since the early 1980s a number of actions have been taken to mitigate the lahar hazard and its effects on downstream communities. The installation of an automated lahar detection system (consisting of Acoustic Flow Monitors) which triggers an alert when a lahar is generated was a key component of this warning system. To compliment the warning system hardware, the USGS, local educators, and emergency managers have been involved in a public education program with the intention of informing residents and visitors about volcano hazards, evacuation routes, and other appropriate response measures. Despite these efforts to mitigate the

effects of potential lahars, the way in which the at-risk population responds to warning systems or complies with recommended evacuation procedures will determine how successful these measures have been. Following several survey studies conducted with middle school and high school students to examine the impact of school educational programs, a 2006 survey of 257 adult residents measured their understanding of the lahar risk, and their familiarity with and confidence in the details of the warning system and evacuation plan. An important finding from this survey was that large percentages of the sample believe that official evacuation routes will be inadequate and intend to use an alternate route. Such views may have important implications for emergency management officials in the local area.

2.4-P-06

Auditing the Basic Guideline for Civil Protection Planning to Volcanic Risk in Spain

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During the International Symposium CHINYERO 2009, which was held at Puerto de la Cruz on November 2009 to commemorate the 100th anniversary of the last eruption at Tenerife (Chinyero eruption, 1909), a working group was established for auditing the actual Basic Guideline for Civil Protection Planning to Volcanic Risk in Spain which was approved by the National Government in 1996. A SWOT analysis was the applied auditing method. The major observed weakness of this Basic Guideline were (i) it is not updated since 1996, (ii) it does not specify deadlines for the preparation of National Plan and the Special Plan of the Canary Islands Autonomous Community for volcanic risk management, (iii) describes the existence of two emergency plans (National and Autonomic) for volcanic risk management in the Canaries enhancing confusion and promoting duplicated public efforts and resources, (iv) lays down procedures for informing and warning the population only in times of volcanic crisis, and (v) shows a lack of an accurate and complete rules on the functions of committees and systems established by the Basic Guideline. On the contrary, the major observed strengths were (1) defines and delimits undoubtedly the application in the Canary Islands, (2) reinforces the requirement to elaborate National Plan and the Special Plan of the Canary Islands Autonomous Community for volcanic risk management in the Canary Islands, and (3) establishes the minimum content of both emergency plans. Among the external factors, the major observed threats are (a) a significant delay in the preparation of the emergency plans, (b) the potential for different interpretations as a result of the Basic Guideline ambiguities, (c) an uncoordinated management in relation to the description in paragraph 3.3.3 of the Basic Guideline, (d) an absence or lack of collaboration between different volcanic sur-

veillance programs, (e) a lack of interest and apathy of the administration to update the Basic Guideline for Civil Protection Planning to Volcanic Risk in Spain, and (f) a poor information and training program on volcanic risk management for the Canary Islands society. On the contrary, the major observed opportunities were (I) the unanimous statements of the Spanish Congress and Senate, the Canary Islands' Parliament, FECAM and other institutions on the urgent implementation of the Canarian Volcanological Institute, (II) the recent creation of the Militar Emergency Unit, UME, (III) the fact that Canary Islands is a tourist region per excellence, (IV) the existence of a society that requires and demands security, (V) the educational program "Canary Islands: a volcanic window in the Atlantic" which visit yearly the 88 municipalities of the Canaries, and (VI) the existence of an educational guide on volcanic risk for the scholar community. After crossing these internal and external factors a major and simple strategy is urgently needed, a strong revision of the Basic Guideline for Civil Protection Planning to Volcanic Risk in Spain.

The results achieved by this document come from the personal opinion of the co-author (Jorge Serra Llopart) and cannot, in any case, express the official statement of the Emergency Military Unit with regards to this subject.

2.4-P-07

The 2006 Volcanic Emergency Simulation Exercise at Cape Verde

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The Cape Verde islands are all of volcanic origin and all islands show, to a larger or lesser degree, volcanic activity. The eruption of a volcano is therefore seen by the inhabitants of Cape Verde as one of the major natural risks. The most recent eruptions at Cape Verde occurred at Fogo Island in 1951 and 1995. Fortunately with no or only a few casualties, but of course causing major damage to houses and infrastructure and a lot of economic damage. A national emergency plan for volcanic eruptions has been prepared by the Cape Verde Civil Protection (SNPC) and during the most recent volcanic emergency simulation exercise in 2006, elements of the NATO Response Force were called on to help evacuate residents of Fogo Island (Cape Verde) as were threatened by a volcanic eruption. This SNPC and NATO joint effort was part of the scenario for NATO exercise Steadfast Jaguar 2006. This major exercise in the Cape Verde Islands was carried out in June 2006 and was also good to test the readiness of NATO's cutting-edge Response Force to carry out humanitarian missions anywhere required at very short notice. The first day of this exercise the level of volcanic alert was reached so that the SNPC, together with the three mayors of the Fogo Island, had to start to prepare the evacuation of the more than 900 inhabitants of Cha das Caldeiras. This exercise was an audit of the national emergency plan for volcanic eruptions and a major test of the ability of NATO's Response Force to undertake a wide range of missions when and where necessary, including responding to disasters. This exercise provided also NATO Civil Emergency Planning staff the opportunity to work together with the Cape Verde Civil Protection Organization to review their

plans and where possible give them advice on how to improve the readiness of the Cape Verdeans to deal with natural disasters. This joint effort opens possibilities for NATO civil emergency planners to play a role in future volcanic emergency simulation exercises.

Session 2.5

2.5-O-01

Uncertainty Under the Microscope: Deliberations, Scientific Advice and Expert Elicitation on Montserrat

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Discourses of risk assessment in volcanic crises and at persistently active volcanoes are permeated with precautionary approaches that reflect the relative youth of volcanology as a science, and the warnings of past eruptive crises. In volcanic emergencies, populations become very heavily dependent on scientists overnight, which can put huge strain on both sides. In addition, dealing with an ongoing eruption requires fundamentally different social structures within the scientific community – observatories focused on monitoring rather than universities focused on research, in the simplest formulation. On Montserrat, the Montserrat Volcano Observatory (MVO) and the Scientific Advisory Committee (SAC) have developed alongside one another in response to the volcanic activity since 1995. The MVO provides day-to-day monitoring, and the SAC carries out risk assessments every six months, applying expert elicitation and Bayesian statistical procedures (Aspinall, 2002; Aspinall, 2010). These require considerable discussion and debate among scientists, which is both helped and hindered by local knowledge and experience of the eruption. This paper will discuss the social implications of the expert elicitation procedure, and its importance in volcanic risk assessment. It will also consider social scientific questions about the role of scientific advice in policymaking more generally: the role of scientists during a volcanic crisis has been confused and confusing in some cases, with threat of litigation and the need to locate responsibility conflicting with the high levels of uncertainty involved. The role and remit of the SAC has been increasingly scrutinized, so this contribution will offer a timely overview of 15 years of expert elicitation for government advice. The nature of volcanic risk in relation to other types of risk (medical, biotechnological) will be discussed and related to the question of expert advice in volcanic eruptions.

2.5-O-02

Institutional Crisis Management vs. People's Response in Facing the 2007 Eruption of Mt Kelut (East Java, Indonesia)

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A new Plinian-type eruption had been expected, when Kelut volcano renewed rumblings in September 2007. Instead of pyroclastic flows and lahars, a lava dome appeared in the crater lake and grew up quickly, until the activity of this volcano seemed to be normal again in 2008. The Indonesian government prepared strategic management plans to protect the threatened populations living in the flanks of this volcano. This paper aims to understand what were the reactions of the threatened people and why. There was a kind of paradox between the good perception of the risk of the villagers, their good preparation to the worst case (determined by a work of questionnaires asked to a sample of population) and the reality of the evacuations, which shows certain malfunctions. This paradox laid principally on the interference of traditional knowledge and scientific observations, and on a lack of communication between the authorities and the people, which allowed the spreading of many common myths about the evacuations. Strategic crisis management can be disastrous and might increase populations' vulnerability if they are not taken in consideration in these plans.

2.5-O-03

Comparison and Evolution of the Volcanic Crisis Management at Piton de la Fournaise: Application to the 2007 and 2009-2010 Eruptive Cycles.

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In April 2007, a major distal eruption of Piton de la Fournaise volcano (Réunion Island) resulted in a 340m-deep collapse of the Dolomieu caldera. The eruption produced lava flows toward the sea, gas, vapour and ash, which affected the Tremblet village for one month. In 2008 - 2010, the activity resumed with two very similar cycles of short-lived volcanic eruptions around and inside the summit caldera. The summit activity did not affect populated areas but represented a major risk for visitors. The management and communication strategies adopted during these two eruptive scenarios will be compared and discussed.

In April 2007, a false alarm and ineffective communication between crisis management decision makers, led to the evacuation of Tremblet village. On the other side, scientists - mostly focused on understanding the eruption process, did not represent the only accepted source of information and advices. Access to the summit craters, which were one of the top tourist attractions, was forbidden for 32 months after the eruption.

A reopening program of the volcano summit began in early 2009, because of lobbying from local press, tourism operators and local organizations. The Piton de la

Fournaise Volcano Observatory and the recently created National Park supported this initiative. This long-term collaborative effort promotes a new access strategy to the volcano with a new communication approach. In that context, the secure access to the volcano summit was permitted to the public a few days after the beginning of both December 2009 and January 2010 summit eruptions.

These two case study's highlight the positive role of a) Identification and simplification of decision makers and decision making protocol during a volcanic crisis, b) Standardization of outgoing information to both the authorities and the press, c) concerted efforts to disseminate information effectively among the population and partners in the program.

2.5-O-04

A Multidisciplinary Approach to Improve Awareness, Communication and Understanding of Volcanic Risks Among Professionals and General Public: Galeras Volcano, Colombia.

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Galeras Volcano has been in episodic activity during modern historic times. Currently it is very active and a future large eruption within the next years to decades is possible. A culturally and ethnically heterogeneous population of approximately 400,000 people, including 10,000 within the Zone of High Volcanic Hazard (ZAVA), could suffer of potential harm from an eruption. The current management plan requires evacuation of the ZAVA when the risk rises to an elevated level. This regulation is a great discomfort for many of the affected groups including indigenous communities, farmers and urban dwellers. A workshop held in July 2009 (Sheridan et al., 2010, EOS) helped to improve the communication and understanding of risk perception and management among the various stakeholders (community members, scientists, politicians, and technicians). The sharing of Information during the workshop within a framework of full and frank communication, open listening to opposing arguments, and attempting to understand different points of view, facilitated the lowering of tensions and a movement towards moderation of opinions that had been becoming increasingly polarized.

Since the workshop there has been a facilitated process of continued dialogue between representatives of the communities and the major institutions. This has led to the formation of a core group called "Galeras Inter-sectional Network" who, by the end of 2009, had produced a mission statement, a list of objectives and a mutually agreed set of working practices. By November 2009, invitations had been extended to all stakeholders identified by the core group as instrumental to more participative collaboration in future risk management strategies and the group was operating with collective leadership and without facilitation. The latest outcomes of the group are the identification of new risk management options including establishment of different resettlements scenarios, definition of new communication strategies and work on human rights.

2.5-O-05
Exploring Risk Perception and Warning Effectiveness: The Case of Volcán de Colima, Mexico

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Studies of risk perception, social representation of risk, and response to warnings were applied the closest communities to Volcán de Colima. They indicate that the risk has been socially constructed. In most villages there has been a clear evolution of perception, with political, economic and historical factors defining the perception of volcanic risk and the response during emergencies. Increasing volcanic activity has a minor role on risk perception. Experience with the hazards and distance from the volcano was shown to not exert a direct influence. The inhabitants of La Yerbabuena, La Becerra and San Marcos have had the most direct experience with volcanic hazards and the highest perception of danger. However, many of their inhabitants maintain a resistance to evacuations and to the resettlement of one of those communities. Governmental risk management has played a decisive role on risk perception and its acceptability.

In general, people have a clear idea about the hazards. However, in some cases (lahars) their lethal potential has been questioned. Most people consider that a warning system is necessary, but they do not have clear information about how they work and the processes that trigger the alarms. Failures in the communication between the village's civil protection brigades, civil protection authorities, and public were identified. The situation is complicated by the belief of some scientists and authorities of some myths associated with warning systems. It is necessary to restore the credibility of both the authorities and volcanologists in order to ensure the public's participation. This could be obtained by considering social studies of the processes of risk-disaster within the design of emergency plans. It is clear that the different social actors (scientists-authorities: "experts", and villagers: "public"), can have different perceptions of risk, but for most of the time, all of them should be considered equally valid.

2.5-O-06
Perception of Volcanic Risk in Italy: Etna, Vesuvio and Campi Flegrei

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In risk mitigation strategies, communication and information have an important role, in particular during long lasting periods of volcanic inactivity. Many studies have shown that information will often be ignored or resisted, even during a volcanic crisis, if not placed into an appropriate social and cultural framework. In particular some researches focused on the public's understanding and perception of volcanic hazards and risks during volcanic crises or quiescence periods have highlighted on one side how important education and outreach programs are, and on the other the needing they were based on a real knowledge of the needs of the at-risk population. Our studies aim has been to evaluate the level of knowledge of hazard and risk related issues, the level of education and preparedness of residents, and the relationship of these factors to residents' sense of community. The researches, carried out in the last years, have investigated volcanic hazard and risk perception in population living, close to Etna, Vesuvio and Campi Flegrei caldera, in Southern Italy. Moreover local officials that gave some support to the surveys declared their interest in surveys' results, that could be useful to design more effective strategies in educating and motivating the public to take more in account the natural peculiarities of their territory, and the related volcanic hazards and risks.

2.5-O-07
Disaster mitigation and emergency management during large-scale eruptions in Japan.

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Japan Meteorological Agency has recently launched a new scheme of volcanic warnings and alert levels. The new scheme enables the civil defense authorities get in immediate action when the alert levels are as high as 4 or 5. When a large-scale volcanic eruption occurs it is inevitable that the alert levels will be 4 and 5 necessitating the immediate evacuation. The largeness of the eruption automatically requires involvement of the national level emergency operators such as Cabinet Office and the related ministries as well as prefectural governments and local municipalities. This naturally calls for complex and intricate planning of administrative operation among the governmental bodies but one of the most important topics seems the good communication between the specialists of volcanology (researchers included) and the administrators. Very infrequent occurrence of large-scale volcanic eruptions together with various and many different types of physical models of the volcanic eruptions make it extremely difficult for the ordinary civil defense specialists to understand and appreciate correct images of how volcanoes behave during major eruptions. It is proposed that one of the most urgent topics for the Japanese volcanologists would be to communicate well with the natural disaster mitigation specialists, both at national and local levels, in order to let them become firmly aware of the characteristic and special features of the volcanic disasters so that they can start creating specific emergency planning. Status quo of the volcanic disaster mitigation plans in Japan as well as the needs of creation of a well planned network of emergency action plans will be discussed.

2.5-O-08

Seismic Activity Index (SAI) as a communication Tool at Tungurahua Volcano

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Tungurahua volcano (5023 masl) is one of the most active volcanoes in the Northern Andes. During the last 500 years, Tungurahua experienced several important (VEI =3-4) pyroclastic flow-forming eruptions. The current eruptive period, initiated in mid 1999, includes periods of low to moderate explosive activity characterized by strombolian fountaining, canon-like explosions and light regional ash fallout. During these episodes of activity ash falls are the phenomenon that mostly affected people living around the volcano. In July and August 2006 and February 2008, major eruptions occurred at Tungurahua, generating tens of pyroclastic flows and strong ash emissions, extensively affecting communities around Tungurahua. Once that long enough seismicity time series have been collected and compared with the superficial volcanic products, the seismicity associated with the progression of these two diverse states of volcano activity could be clearly differentiated, and could be used to inform public officials and the media about the level of the ongoing activity and, more important, to make prognoses about future evolutions.

The Geophysical Institute has developed a seismic activity index (SAI) for Tungurahua Volcano that quantifies the mean seismic energy released day by day and reflects the level of volcanic activity. Our working hypothesis states that any significant change in internal physical processes of the magmatic system will be noticeable in our seismic recordings so will be the superficial evidences of those internal changes. Every seismic signal is classified, weighted and treated statistically to produce a unique daily index (DI) value. A weighted average is performed using previous days values, obtaining the trend of the seismic activity. This procedure also computes the variability of the DI to build activity levels that consider the weight of each type of event and the DI autocorrelation, which seems to reflect the physical evolution of the state of the volcano. SAI may be used as a valuable tool for more precise public communication of the state of activity of the volcano and has interesting perspectives for its usage as a short to medium term forecasting criterion.

2.5-P-01

Living with Katla – Rural Versus Urban Knowledge and Perception

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This research provides the first analysis of residents' knowledge and perception of the Katla volcano and emergency response procedures in all rural and urban

communities located in the eastern and southern Katla hazard zones. Using a questionnaire survey, we demonstrated that there is a difference between rural and urban community's knowledge and perceptions and we identified the contextual issues influencing residents' perspectives. All rural and most urban residents demonstrated accurate knowledge of Katla, the warning system and emergency response procedures. Urban residents believed the emergency response plan to be appropriate. In comparison, rural residents did not perceive the emergency response plan as appropriate and if conditions are bad they would personally assess the situation before deciding on a course of action. Livelihood connections and inherited knowledge affect rural residents' ability to comply with the recommended procedures. Factors such as hazard knowledge, sense of community and attachment to place indicate that rural residents are more resilient to volcanic hazards. Based on our findings we recommend that emergency management agencies use contextual issues, such as personal responsibility, neighbourliness, community involvement and cooperation, to develop and implement more appropriate volcanic risk mitigation strategies.

2.5-P-02

Web Based Communication At The Montserrat Volcano Observatory

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Efficient communication of information related to a volcano observatory is vital to both the population surrounding a volcano and to people further afield with an interest in current activity. At the Montserrat Volcano Observatory (MVO), most communication in the past has been via traditional methods such as radio, public meetings and printed material. In an increasingly Internet-oriented society, the Observatory's web-based media have become valuable communication and educational tools. The newly refurbished web site, which is updated several times per week, allows for indexed, informative material to be made available to residents and non-residents, while the use of social media such as Facebook, has enabled the rapid spread of critical information regarding recent activity and has fostered a greater degree of social interaction between MVO and the wider public.

Since MVO launched its Outreach and Education plan; "Living with our volcano", much progress has been made with the development of its Internet tools. A survey conducted at the end of 2009 entitled 'MVO online communication survey' has helped to measure progress and provide feedback on our new ventures into this form of communication. This recent work has shed light on not only what can be achieved via these media, but also some of the problems to overcome and the key decisions that need to be made.

2.5-P-03

Re-assessing Volcanic Hazard Maps for Improving Volcanic Risk Communication: Application to Stromboli Island, Italy of Volcanic Risk in Italy.

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Hazard and risk maps are both sources of information about hazards and different risk levels, and tool for risk management and planning and in informing and preparing the general public. Recent studies have highlighted that volcanic hazard and risk maps, usually used during emergencies, are often difficult to be interpreted. Our research had the aim of assessing the efficacy of currently available hazard and risk maps through testing map understanding and comprehension, understanding and perception of the volcanic hazards and to elicit opinion about existing maps and the information that this group would like to see on map, in order to produce new, innovative and more suitable maps.

The test area was Stromboli island, an active volcano characterised by a persistent low-to-moderate magnitude explosive activity, and by sporadic high magnitude explosive events and lava effusions. Landslides on the volcano North-Western flank have sometime generated tsunamis. The study has been developed in different phases, using semi-structured interviews conducted with local legislators, administrators and 'enforcers', in order to highlight common misconceptions and perceptions, and to get information about respondents' mental spatial maps. The maps to evaluate were respectively a contour, an aerial photo and a DEM maps, plus an innovative 3D tsunami risk map. On the basis of the obtained results two different volcanic hazard maps for both 'expert' and 'tourist' use, respectively using a contour map and a DEM and also a 3D map focused on the tsunami risk area have been produced.

2.5-P-04

An Interinstitutional Coordination Experience Of Disaster Risk Management In Metropolitan Area of San Salvador, El Salvador

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The Metropolitan Area of San Salvador (AMSS) faces a broad spectrum of threats of natural origin. Threats

include the volcanic eruptions posed by the San Salvador Volcanic Complex and Ilopango caldera, seismic events, flooding, and landslides among other potential hazards.

Around 1.6 million inhabitants dwell in the AMSS within its 14 municipalities including the capital, San Salvador. In the past 30 years, the AMSS has nearly doubled its size. During this rapid urbanization, the most vulnerable sectors of the population have tended to settle in areas with higher degrees of risk (rivers banks, mountain slopes, surrounding volcanoes, and others). Therefore, it is important for planning offices to have the right tools, standards, and skills to support decisionmaking processes and contribute to decrease risks regarding urban and regional planning.

The Integrating Participatory of Environmental and Risk Management in Development Plans and Regional Planning of the Metropolitan Area of San Salvador (IPGARAMSS) program, was created by the Council of Mayors of the

AMSS (COAMSS), the Planning Office of AMSS (OPAMSS), and the El Salvadoran office of Spanish NGO World Geologist. IPGARAMSS program aims to improve local capacities in disaster risk management, as well as, encourage AMSS landuse policies.

The IPGARAMSS promotes technical planning assistance of disaster risk management with multiple stakeholders. Participating stakeholders involved with disaster risk management include the multi-disciplinary staff of World Geologist, technicians from OPAMSS, municipal councils and departments, universities, community organizations, and interested individuals. Particularly important are the councils and their departments (environmental, legal, citizen participation).

IPGARAMSS is a platform of opportunity to disseminate hazard information and further provides a forum for scientists to share their experiences with other stakeholders involved in disaster risk management from geological and hydrometeorological hazards.

2.5-P-05

Roles For Geologists In Volcanic Crisis Communication

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During a volcanic crisis, geologists are frequently thrust into the media spotlight, expected to communicate everything about the emergency and to take responsibility for decisions taken—while continuing their physical volcanology work to better understand the volcano's behaviour. Yet geological studies rarely include communication training while geologists do not usually enter their field in order to be crisis managers. Diverting time and resources to communication during an emergent crisis can be particularly challenging, not least due to the different types of audience-dependent communication required (e.g. government, public, media, other scientists). Using examples such as eruptions from Guadeloupe (1976), Nevado del Ruiz, Colombia (1985), Montserrat (since 1995), and Mt. Pinatubo, the

Philippines (1991), lessons from social volcanology and communications science are summarised regarding the role of geologists in volcanic crisis communication. In particular, whilst communicating to different audiences often entails different skills and requirements, there are several responsibilities which are common to all forms of communication. Geologists need to consider practical matters including, but not limited to, use of terminology, conditional and absolute language, how hazard prediction is weighted, order of conclusions, definitions and perceptions of risk, and ethical implications and guidance. The latter includes codes of conduct, the power of information and how the recipient might use it, and constraints and responsibilities of geologists and hazard managers. At the forefront of these considerations should be the aim of serving the affected people first, above any political or professional gain. This research presents lessons learned from past eruptions and suggests how they can be adapted to aid better communication during future events.

2.5-P-06

The Importance of Understanding Local Social and Cultural Contexts in Reducing Risky Beliefs and Encouraging Risk-Reducing Behaviours

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In order to reduce the risk from a volcanic eruption the physical system is modelled, attempts are made to quantify uncertainties in predictions, and hazard maps to assist planning are drawn up. However, societal response also has a significant bearing on the outcome of a crisis and such responses can vary dramatically.

To investigate what factors may influence people's behaviours a comparative study was done on two Eastern Caribbean islands with contrasting eruptive histories. One island (St Vincent) has experienced activity within living memory whilst the other (Dominica) has not, but is showing signs of reawakening. Two phases of fieldwork – qualitative interviews followed by quantitative surveys – were used to draw out the respondents' mental models of processes that might occur during an eruption, their perceived impact and hazard for the surrounding environment, and the influence of this on likely behaviour in a crisis.

This revealed a number of 'risky beliefs' were prevalent in the surveyed sample; for example, 'the scent of sulphur is poisonous and can kill you', 'all earthquakes are linked to volcanic activity'. It is recommended that such beliefs are tackled as a matter of urgency, as they could result in risky decisions being made either in the lead up to, or during, a volcanic crisis. However, this is a complex problem as some misconceptions could encourage risk-reducing behaviour.

Survey data were also used to define characteristics of those more likely to hold these risky beliefs; island of residence, closely related to previous experience, was a significant predictor, as well as education level. Gender and age group were also useful

predictors in a few cases.

These findings have important implications for the communication of volcanic hazard and risk information. They illustrate the need to understand cultural and social contexts in order to effectively promote risk-reducing behaviour.

2.5-P-07

Some Perceptions of, and Attitudes and Responses to Volcanic Hazards with Special Reference to Tungurahua, Ecuador.

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Volcanic hazards kill or injure people and destroy or damage infrastructure. The skills of volcanologists and other people involved in hazard management are not necessarily sufficient in themselves to reduce risk to people. Vulnerable people's perceptions of, attitudes and responses to volcanic activity are considered a fundamental influence on their decision making processes. The study detailed in this paper examined monitoring and management of volcanic hazards and perceptions, attitudes and responses of those vulnerable to volcanic hazards. Each volcano is unique due to its location and economic, social and political conditions affecting the adjacent population. Research was carried out in Baños, a small town located on Tungurahua's slopes, an active volcano in Ecuador. In 1999 the entire population was evacuated due to a major eruption event predicted by volcanologists. Tungurahua did not erupt as catastrophically as expected and return of evacuees was affected by national government's political and economic problems. Low levels of volcanic activity continued at Tungurahua after the eventual return of the majority of the population. This scenario suggested potential for worthwhile research concerning perceptions of volcanic hazards. Ranking perceptions of places of relative danger and production of a contoured Mental Map superimposed on Tungurahua's hazard map, displayed the spatial perceptions of degree of danger felt by some of the people at risk from Tungurahua's hazards. Spatial perceptions demonstrated surprising uniformity of responses, and Semi-structured Interviews provided qualitative data to supplement spatial perceptions of hazards. The information gained from this study is considered to make a useful contribution towards further understanding of perceptions of hazards. In particular the use of Mental Maps could be utilized to inform those managing volcanic or other hazards of people's spatial perception of risk. People's perceptions of, attitudes and responses to volcanic hazards were found to be fundamental to effective hazard management strategies.

2.5-P-08

Media's Efforts Encouraging Volcano Safety Culture before the 2000 Mt. Usu Eruption, Japan

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The 2000 eruption of Mt. Usu, Japan was a successful case of eruption prediction, in terms of the view that nearly 15,000 local inhabitants had completed necessary evacuation before the eruption outbreak, as similar as that in the 1910 eruption just 100 years ago. One of the authors (SK) who was working at the time as an editor of Hokkaido Branch, Asahi News Paper Company had published 275 series of news stories focusing on the active volcanoes in Hokkaido, Japan over preceding 6 years (1994-1999) prior to the 2000 eruption. Those articles were later published also in a form of three popular books (total 643 pages) in 1995, 1998 and 1999. The efforts was very timely and played significant contribution creating volcano safety culture and positive behavior change toward close collaboration among people, officials, scientists and journalists. He had also offered a first face-to-face meeting opportunity between the director of volcano observatory (HO) and Mr. Okamura, the Abuta (presently Toyako) Mayor, only after 15 years since its 1977 Sub-Plinian eruption. It was well known that Abuta Town who operate Toyako Onsen Spa first ignored and later strongly refused an idea of volcano hazard map, at least until 1992, but later accepted a drastic mind change toward better utilization of a volcano hazard map. The Mayor's final declaration was announced on August 8, 1994, shortly after the Koike's news paper series on Mt. Usu. Mr. Okamura later insisted that the main factor of his behavior change was attributed to the impact of the 1993 Okushiri Tsunami Disaster. Major volcanic crises during the era such as 1985 Mt. Ruiz, 1988-1989 Mt. Tokachi and 1991 Mt. Unzen&Pinatubo, and also major earthquakes/tsunamis (ex. 1993 Kushiro/Okushiri, later 1995 Kobe) had provided timely cue for learning earth's activity and the way of better co-existence with them.

2.5-P-09

GUAYOTA: A Public Weekly Report of the seismo-volcanic activity in the Canary Islands

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Since 2003, the Environmental Division from ITER has been releasing a public, weekly briefing about the seismo-volcanic activity in the Canary Islands. In the very beginning, this graphic briefing was intended to provide an overview of the seismo-volcanic activity all along the archipelago. In that report, seismicity was plotted on a Canary Islands map, as well as geochemical information regarding to some of the geochemical stations that ITER has deployed in some of the islands. This report was freely distributed to Canarian newspapers to be published every weekend. Since the 2004 seismic-volcanic crisis, ITER volcano research group decided to bring out three additional, more specific Guayota reports. From that moment until present, Tenerife, La Palma and El Hierro islands have their own weekly report, in addition to the regional one. The hazards-warning system adopted in the Guayota is a Volcanic Traffic Light Alert System

(VTLAS), which is a basic communications protocol that translates volcano threat into only three levels of alert for the public (color coded green-yellow-red). This VTLAS is very important since population knows the meaning of a traffic light, what makes Guayota a comprehensive report, as well as a powerful tool to keep the population aware of any kind of unrest of the seismo-volcanic activity in the Canary Islands. With this VTLAS we intend to avoid confusion in the data interpretation, as some deviations in the normal values do not mean that any unresting is occurring at any of the three islands. Since this year 2010, Guayota will also take advantage of the social networks, going through some Facebook profiles to spread this informative and useful report.

2.5-P-10

IBEROAMERICAN Volcanological Network: A New Challenge for Reducing Volcanic Risk in the Iberoamerican Community

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The Iberoamerican Volcanological Network is a non-profit organization which is planning to promote and establish cooperation mechanisms to help reducing volcanic risk in the Iberoamerican community. This new organization was suggested by volcanologists from 13 Iberoamerican countries during a workshop at La Antigua (Guatemala) in February 2008 organized by ITER. The major goal of this 2008 meeting was to bring together experts on volcanology and volcanic risk management from Iberoamerican countries to evaluate the state of the art of reducing volcanic risk programs in Iberoamerica through a SWOT analysis as well as defining strategies to advance and strength the efforts for reducing volcanic risk in Iberoamerica. One of the strategies was to establish a network of Iberoamerican institutions which are willing to joint efforts for reducing volcanic risk in the Iberoamerican community. During the International Symposium of Volcanology Chinyero 2009, held at Puerto de la Cruz (Tenerife, Canary Islands) last November, the Iberoamerican Volcanological Network was established by 12 different institutions, which did act as founding partners, from Argentina, Cape Verde, México, Nicaragua, Portugal and Spain. May become members of this new partnership institutions and organizations (research and technological centers, universities, volcanological observatories,

professional societies, geological surveys, national civil protection services, companies, scientific and technical associations, municipalities, NGOs, international cooperation agencies, etc..) from Iberoamerican states meaning by Iberoamerican state which joined the Organization of Iberoamerican States (OEI). It may also be members of the Iberoamerican Volcanological Network institutions and organizations from the states which joined the Organization of American States (OAS) and those countries like the Philippines, Equatorial Guinea and Cape Verde have a close cultural and historical relationship with Spain and Portugal, respectively. The main purpose of the Iberoamerican Volcanological Network will be to encourage the exchange of knowledge and experience among the institutions working in the field of volcanology and volcanic risk management in the Iberoamerican community as well as enhance the cooperation as a working method.

2.5-P-11

Mass Media and Volcanic Risk in the Canary Islands

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In the framework of the International Volcanological Symposium CHINYERO 2009 held at Puerto de la Cruz (Tenerife, Canary Islands) on November 2009, a multidisciplinary group of professionals had the opportunity to discuss on "Mass media and volcanic risk in the Canary Islands". Journalists, volcanologists, educators and civil protection and emergency management experts gathered with the intention of bringing positions and discuss the role of the media on volcanic risk management in the Canary Islands. A SWOT analysis was the used tool to discuss on this subject. It was pointed out as weaknesses (i) a general poor training of scientists in communication as well as journalists in the volcano phenomenon and volcanic risk management, (ii) a tendency to prominence among some scientists and politicians who always remains strictly to any information, and (iii) a lack of an institution to centralize all information related to volcanic risk for the population in the Canary Islands. On the contrary, the observed strengths were (1) the existence of a large number of media, which is always positive when reporting, (2) the geographical proximity of the citizens to volcanoes, a factor that increases the interest for this natural phenomenon, and (3) the existence of a large number of international and national research groups working on this volcanic region. The major observed threats were (a) the recent significant reduction of journalists in mass

media, (b) the failure of scientists to use a single voice for public statements during volcanic crisis enhancing an informative chaos and discredit of the scientific community, and (c) the unprofessional conduct of some journalists by publishing information poorly contrasted and searching for headlines of their own interest. On the contrary the major observed opportunities were (I) the increasing interest of the society for this subject of scientific and social implications, (II) the Canary Islands' Government new tourist marketing challenge to use the volcanic phenomenon as a tourist attraction, and (III) the recent unanimous statements of the Spanish Senate and Congress as well as the Canary Islands' Parliament to establish urgently the Canarian Volcanological Institute (IVC).

The results achieved by this document come from the personal opinion of the co-author (Jorge Serra Llopart) and cannot, in any case, express the official statement of the Emergency Military Unit with regards to this subject.

Session 2.6

2.6-O-01

Cristobalite in a Rhyolitic Lava Dome: Evolution of Ash Hazard at Chaitén Volcano

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Prolonged exposure to fine, crystalline silica-rich volcanic ash could potentially cause disease in vulnerable individuals. Cristobalite is the silica polymorph of prime concern in andesitic/dacitic eruptions as it may crystallise in volcanic lava domes by vapour-phase deposition and devitrification of glass, becoming a major mineral phase (~ 10 wt. %). In rhyolitic, obsidian (glassy) domes, cristobalite is observed in spherulites which slowly nucleate from glass but it is not known whether rapid, large-scale cristobalite formation is also possible through vapour-phase deposition, as with their andesitic/dacitic counterparts. Rhyolitic eruptions are relatively rare and the eruption of Chaitén volcano, Chile (from 2 May 2008 to present) provides the first opportunity to determine whether active rhyolitic domes produce substantial cristobalite. Initial explosions, through a vent in an ancient (~ 9.3 ka B.P.) rhyolitic dome, generated ash which fell across Patagonian Chile and Argentina. By 21 May, lava dome growth had commenced. Here we show that the Chaitén rhyolitic ash contains substantial levels of cristobalite. The ash evolved in composition, and health hazard, with changing eruption conditions; ash erupted during the initial, explosive phase contained ~2 wt.% cristobalite whereas ash generated after dome growth began contains 13-19 wt.%. The work confirms that active obsidian domes crystallise substantial quantities of cristobalite on time-scales of days to months, probably through vapour-phase crystallisation on the walls of degassing pathways rather than through spherulitic growth in glassy obsidian. The ash is fine-grained

(9.7–17.7 vol.% < 4µm diameter) with the particles being mostly angular but sparse, fibre-like particles were confirmed to be feldspar or glass. This ash is sufficiently fine to have the potential to trigger asthma attacks in susceptible people and there is potential for chronic, silica-related disease if the population becomes exposed to high levels of ash over a prolonged period.

2.6-O-02

In Vitro Physiologically Based Extraction Tests of Volcanic Ash from Diverse Volcanoes

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A number of studies have correlated increased respiratory morbidity to exposures of volcanic emissions. Studies have also found that grazing livestock that ingest fluoride-rich volcanic ash (VA) with forage plants can develop fluorosis. Toxicity of inhaled or ingested VA is influenced strongly by chemical reactions with body fluids encountered along inhalation or ingestion pathways. VA can contain: 1) biodurable minerals such as crystalline silica (i.e., cristobalite) or other silicates, which do not readily dissolve; 2) potentially toxic bioaccessible species (i.e., F, Fe, Mn, Al, V, Mo, Zn, etc.) that are readily dissolved or desorbed from ash particles and would be available for absorption by the body; and, 3) potentially bioreactive components (such as acidic gas condensates) that might trigger tissue irritation or damage. We have utilized in vitro physiologically based extraction tests (PBETs) to examine the biodurability, bioreactivity, and bioaccessibility characteristics of ash from a number of volcanoes. Appropriately size-sieved samples were reacted for physiologically realistic times with simulated lung (SLF), gastric (SGF), and serum-based fluids (SBF). SLF tests suggest that in the lungs glass particles will preferentially dissolve relative to crystalline phases over time. A variety of redox-active elements (i.e., Fe, Mn, Cu, V, Mo) potentially linked to oxidative stress will also be released over time. SGF test results indicate that a wide variety of species (SiO₂, Fe, Al, Mn, Cu, Zn, As, etc.) can readily be leached from ingested VA in stomach acids. We have also modified a standard SGF PBET to assess bioaccessible fluoride. Initial results indicate that this PBET identifies VA with fluoride that is only sparingly soluble in water leaches, but that would likely be readily bioaccessible via ingestion.

2.6-O-03

Mineralogical Analyses And In Vitro Screening Tests For The Rapid Evaluation Of The Health Hazard Of Volcanic Ash At Rabaul Volcano, Papua New Guinea

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The continuous ash and gas emissions from the eruptive activity at the Tavurvur in the Rabaul caldera, Papua New Guinea, in 2007–08 impacted on nearby populations and the environment. As part of a formal evaluation of the effects of volcanic emissions on public health, we investigated the potential health hazard of the ash using a suite of selected mineralogical analyses.

The trachy-andesitic ash comprised 2.1–6.7 vol. % respirable (<4 µm diameter) particles. The crystalline silica content was 1.9–5.0 wt. % cristobalite (in the bulk sample) with trace amounts of quartz and/or tridymite. Scanning electron microscopy showed the ash particles were angular with sparse, fibre-like particles (~3–60 µm max. diameter) observed in some samples, which we confirmed to be CaSO₄ (gypsum) and not asbestiform fibres. The ash specific surface area was low (0.1–2.7 m² g⁻¹).

The results of our mineralogical analysis, combined with in vitro toxicity testing, suggest that acute exposure to the ash would have a limited potential to exacerbate pre-existing conditions such as asthma or chronic bronchitis, and the potential for chronic exposure to lead to silicosis was low. A direct outcome of this investigation has been the establishment of a comprehensive protocol, encompassing a range of mineralogical and toxicological testing techniques, to determine the potential health impacts from exposure to volcanic ash, at both persistently active volcanoes and sudden eruption scenarios.

2.6-O-04

Volcanic soils and health risks in the Neapolitan metropolitan and provincial area (Italy)

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The Neapolitan metropolitan and provincial area (1171 km²) is one of the most anthropized territory of the Italian peninsula. It is located in the southern Italy, in the central-western sector of the Campania region. Inside its administrative boundaries two active volcanic fields are located: Mt. Somma–Vesuvius and Campi Flegrei. Previous studies (Cicchella et al., 2005; De Vivo et al., 2006) carried on 982 soil samples collected over the whole provincial area, with a variable sampling density between 1 sample/250 m² (for the city of Napoli and for other urban areas) and 1 sample/5 Km² (for low anthropized and country areas), demonstrated that high geochemical baseline values for some metals (Pb, Zn, Sb, Hg, Cd, Cr, Cu) are dependent on both the long period of constant human activities in the province (anthropogenic) and the volcanic origin of soils (geogenic). Since Lima et al. (2005) and Albanese et al. (2008) high-

lighted a noticeable spatial correspondence between standard mortality rates (SMR) for cancers and high concentration values of some toxic metals and radioactivity (U, Th, K) in the Neapolitan province, a follow-up geochemical prospecting activity was planned to integrate the previous geochemical dataset. The new sampling activity aimed at achieving a minimum sampling density of 1 sample/km² for the whole provincial territory for a better definition of the spatial distribution of geochemical background and baseline values.

More than 520 new soil samples were collected in the northern-eastern and north-western (including the Campi Flegrei area) sectors of the provincial territory, and more than 300 soil samples were collected in the southern sector (S-SW of the Mt. Somma-Vesuvius) including both part of the Sarno river basin and the Sorrento Peninsula. Samples were analyzed by means of ICP-MS, after an aqua regia leaching, and concentration of 52 elements were determined. New geochemical background and baseline map were produced for the whole Neapolitan provincial area using a total amount of 1800 soil samples. New data confirm the relationship between toxic metal distribution of volcanic origin and health problems. References: Albanese et al., 2008. El-sevier; Cicchella et al., 2005. GEEA; De Vivo et al., 2006. Aracne Editrice; Lima et al., 2005. Appl. Geochem.)

2.6-O-05

Volcanic mercury (Hg) deposition around Mt Etna volcano (Sicily)

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Mercury (Hg) is a highly toxic metal and emissions from active volcanoes are a major source of Hg to the atmosphere. A key uncertainty in the potential for human health impacts from volcanic Hg is the extent of local deposition. This is likely controlled by the oxidation state of Hg compounds: Hg(0) is an inert, insoluble gas, while Hg(II) occurs as reactive gases and particles, which deposit rapidly and proximally. Using a new high temperature equilibrium model for the reactions occurring at Mt Etna's volcanic vents, we show that although the magmatic emissions are almost entirely Hg(0), significant quantities of Hg(II) are formed due to cooling and oxidation of the magmatic emissions by atmospheric gases. The model results explain recent crater-rim measurements of 1-2% Hg(II) (of total Hg) at Mt Etna. The model may also be applied more widely to explain the higher quantities of Hg(II) (e.g., 5% at Masaya volcano, Nicaragua) found elsewhere. The model results are supported by atomic absorption spectroscopy analyses of Hg in vegetation (*Castanea sativa*) growing on the flanks of Mt Etna collected over the period 2005-2008. Significant elevations in Hg in vegetation are found downwind of Mt Etna's summit (at distances of 7 - 13 km), particularly in the most proximal locations. By comparing biomonitoring results for Hg, As, Cd and Tl, we suggest that further oxidation of Hg(0) to Hg(II) occurs beyond the crater rim, at low temperature. These results suggest that the deposition of volcanic Hg is rapid and proximal,

and that, through bioaccumulation, volcanic Hg may have potential impacts on human health.

2.6-O-06

Health Impact of a Continuous Ash Emission Eruption: the example of Rabaul, Papua New Guinea, 2007-08.

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Continuous ash emission eruptions are uncommon, but may precede or follow large eruptions at explosive volcanoes. Unrest at Rabaul caldera continued after the Plinian event in 1994, and ash and gas emissions increased following the sub-Plinian event on 7 October 2006. For 6 months during each of the dry seasons of 2007 and 2008, the prevailing wind blew the plume from the Tavurvur crater (300m. asl) over the important port of Rabaul and its environs (pop. 40,000); conditions deteriorated in 2008 and temporary evacuation of the area was considered. A health risk assessment was undertaken, including a comprehensive study of the ash together with toxicity screening for its health hazard; ambient air measurements of ash particles, sulphur dioxide (SO₂) and radon; and a survey of rain water stored in catchments for drinking which was exposed to contamination by ash and gas. The respirable fraction of ash (<4 µm) and PM₁₀ comprised 4-6 wt% and 10-11 wt% respectively; cristobalite concentration was 2-5 wt%, and the ash contained numerous asbestos-like fibres we identified as gypsum. Toxicity testing of ash in vitro was negative for quartz-like activity. Ambient air levels of PM₁₀ and SO₂ were regularly in excess of WHO air quality guidelines. Increased respiratory and eye problems were widely reported: the hospital and its staff were affected and asthma attacks in children led to schools being closed during the worst pollution periods. Gastro-intestinal symptoms from drinking contaminated catchment water were compatible with its elevated zinc levels. People with pre-existing chronic respiratory diseases were advised to seek medical advice about leaving the area until conditions improved. Tuberculosis was common and sufferers were considered to be at increased risk of complications. Low altitude, continuous ash emissions are potentially highly disruptive for populated areas.

2.6-O-07

Recent Increase of Risk from Endogenous Gas Emission in the Urbanized Areas of Colli Albani Volcanic Complex (Rome, Italy)

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Colli Albani quiescent volcano is long known for its huge emission of endogenous gas (mostly CO₂ with minor H₂S). The related hazard has been hitherto neglected and urban development continued also in the proximity of strongly degassing sites, such as Cava dei Selci. The consequence is a relevant risk increase in the last ten years and only by chance no new human casualty has occurred. In February 2010 the indoor gas air concentration increased above the lethal threshold for both CO₂ (up to 24 vol.%) and H₂S (up to 500 ppm; the upper limit of the measurement device) in some houses of Cava dei Selci that had to be evacuated. Also indoor Rn (max 23,500 Bq/m³) was much higher than maximum permitted concentration (400 Bq/m³; yearly average). Another risk is related to gas blowout from wells drilled in urbanized Colli Albani zones, that frequently reach gas pressurized aquifers at shallow depth (10 to 350 m). These accidents killed many small animals and required complex and expensive remedy interventions. Six gas blowouts from wells occurred since 1986, two of which in 2008. Monitoring of CO₂ soil flux and of CO₂ and H₂S air concentration proved very useful in assessing the risk and in controlling the effectiveness of remedy operations.

2.6-O-08

Health Hazards From Endogenous Gas Emissions at Horizontal Drillings for Water Exploitation in Tenerife, Canary Islands

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Water has traditionally been considered a physically scarce resource in the Canary Islands. Due to agriculture, industrial and tourism demands during the 20th century, exploitation of groundwater resources in Tenerife became an important business turning water as a "private natural resource". To extract the water, traditional perforation methods have consisted on: (i) Galleries, horizontal drillings usually several kilometres long depending on the excavated distance needed to reach the general saturation level and (ii) wells. Conventional galleries measure 3 km on average, but many some of them can be longer than 6 km. Tenerife is riddled with 1051 horizontal galleries, totalling between them some 1700 km, and 393 wells. Volcanic rifts and dykes play an important role in the hydrodynamics of the island. Dikes and fractures are usually parallel to the ridges, facilitating longitudinal flow and considerably reducing transversal flow but at the same time allowing the rising of magmatic gases, mainly CO₂. This fact brings an important hazard when magmatic gases accumulate in the galleries, exposing workers, technicians, scientists and visitors to a great danger. Since exploitation of groundwater resources in Tenerife started, more than 20 people have died because the exposure to high concentrations of volcanic gases. After the last fatal accident occurred in the "Piedra de los Cochinos" gallery in February 10, 2007, where six walkers died when they entered in this unmarked water gallery, the Cabildo of Tenerife carried out a census reporting that at present

48% of the visited galleries (789) show a very low risk, 27% low, 16% medium, 7% high and 2% very high. Regarding to wells, of the visited wells (179), 79% show a very low risk, 8% low, 3% medium, 5% high and 5% very high. At the same time, The Government of Canary Islands decided to legislate exploitation of groundwater resources with a new decree, introducing additional security procedures in all wells and water galleries, regardless of whether work is ongoing or not, to try to avoid new tragedies can occur again.

2.6-P-01

Factors Affecting the Potential Toxicity of Volcanic Cristobalite

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Exposure to volcanic ash is known to trigger acute respiratory diseases, such as asthma and bronchitis, and has the potential to instigate chronic diseases if the particles are sufficiently fine to deposit in the alveolar region of the lungs. One suspected disease-causing mechanism arises from the existence of crystalline silica in volcanic ash, specifically as cristobalite, which is classed as a human carcinogen. Recently, we have established that the potential toxicity of volcanic ash is likely to vary depending on the type and style of eruption, particularly the amount of silica produced. However, little is known about the effects structure and composition have on the potential toxicity of volcanic cristobalite as toxicity has been sufficiently studied at only one location; Soufrière Hills volcano (SHV), Montserrat. It is therefore necessary to systematically characterize the mineralogical properties of cristobalite from different volcanic settings to further define the disease-causing potential of ash, and to elucidate properties responsible for adverse immunological responses.

Here we present results on the purity, abundance, crystallographic form, and crystal shape of volcanic cristobalite from the dacitic eruptions of Mt. St. Helens using XRD and SEM. As with SHV, the cristobalite is found in both euhedral and platy forms, growing within vugs in dome rock, and the composition is impure, containing traces of other cations such as aluminium. The quantity of cristobalite is reduced in comparison to SHV (4-8 wt. % compared with 12-15 wt. %). Future work will combine these preliminary results with mineralogical and toxicological data from other volcanoes (e.g. Merapi, Unzen, Santiaguito). As higher levels of cristobalite in respirable ash raise concerns about the onset of chronic, injurious disease following human exposure, it will be possible to recognize hazards based on volcanic settings; thereby significantly aiding the work of disaster managers when assessing health hazards during risk mitigation.

2.6-P-02

Tracking Multiple Pathways of Human Exposure to Volcanic Fluoride

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Excessive exposure to natural fluoride (F) in drinking water is a health concern in much of the world with numerous effects. Volcanoes emit F, constituting a source of deposition into the environment. Observations of volcanogenic F contamination in soils, water, air, and vegetation have prompted research on transport and environmental fate, as well as assessing human exposure. Intake estimates are made increasingly accurate by considering behavioural factors and bioaccessibility.

We've developed analytical methods designed to mimic the conditions of biological dissolution, in contrast to routine geochemical approaches which may not determine the bioaccessible F fraction. The multimedia exposure of residents potentially affected by volcanogenic F was assessed using air, rainwater, drinking water, soil, and vegetation/food sampling near Masaya, (F: 0.6 kg/s) and Ambrym, (F: 8-14 kg/s) volcanoes. Masaya residents are exposed to max. 36 $\mu\text{g}/\text{m}^3$ HF and Ambrym residents, max. 11 $\mu\text{g}/\text{m}^3$. However these atmospheric doses are not in excess of UK limits for HF occupational exposure. Drinking water F in excess of the WHO guideline of 1.5 mg/L were found in samples up to 1.82 mg/L at Masaya and 5.6 mg/L at Ambrym. Due to the strong retention of F in soil, it is not usually identified as a major F intake pathway. Interestingly, soils sampled near Masaya volcano and analysed for bioaccessible F provide 20-40% of a child's F daily reference dose (RfD) through incidental ingestion, Fluoride in Ambrym soil and food samples are not substantially above background concentrations. While drinking water is the major source of F leading to excessive exposure at Ambrym, F intake at Masaya is a contribution of drinking water and ingested soil. Finally, we have established that child residents at both locations have a daily volcanic F intake in excess of the NOAEL (0.06 mg F/kg/day) and are at risk of adverse health effects.

2.6-P-03

Health Hazard Associated With Popocatepetl Ash

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Popocatepetl has been producing ash from small eruptions since 1994. These ash eruptions have caused respiratory conditions in the state of Puebla, to the east of the volcano (Rojas et al, 2001), but because of the changing wind conditions in the summer mainly, some of these ash plumes go westward to towns in the State of Mexico and even Mexico City. Preliminary analyses of 20 of these eruptions indicate that some ash emissions produced increased respiratory noninfectious problems reported in local clinics in the state of Mexico. Weekly statistics were correlated with eruption plumes and ash characteristics.

We observed that the June 30 1997, 8 km high ash plume, produced respiratory disorders even 43 km away in Ixtapaluca, 39 km in Chalco as well as in Amecameca 18 Km from the volcano. On the other hand respira-

tory problems associated with smaller emissions were clearly identified only in Amecameca. Nonetheless, the July 19 and September 21, 2003 and July 21, 29 and September 21, 2005 also showed anomalies although they were camouflaged by other processes. When compared with years that did not produce ash clouds towards the west, the 3 towns showed lower respiratory problem incidence.

Ash fall samples from each emission were collected and analyzed with stereographic and petrographic microscopes as well as with a Jeol Scanning Electron Microscope. Ash contains a large amount of lithics from the crater domes which have been forming since 1996, plagioclase and pyroxene crystals and minor amounts of olivine and hornblende in some samples and vesiculated and nonvesiculated glass. Ash particles from June 30 1997 were more vesiculated. All of the samples associated with the studied eruptions contain more than 5% silicic dust which is largely between 0.5 to 2 μ .

2.6-P-04

The Laki Fissure Eruption And UK Mortality Crises 1783-1784

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It is well established that the Laki fissure eruption acted as an environmental causing mechanism for the UK mortality crises of 1783-84. Causes of death were not commonly recorded in the 18th century, making it difficult to establish which diseases contributed to the crises. By exploring the diseases endemic at the time and the relationship between their vectors and environmental conditions, it is possible to discern to an extent, the origin of the crises. Here, an investigation of environmental, nutritional, economic and health conditions reveals how these factors impacted upon mortality in the 18th century. Weather records, grain prices, burial records and contemporary writings are utilised in exploration of four counties in England and several major UK cities. Endemic diseases included smallpox, typhus, dysentery, measles and in certain areas malaria. People living in urban areas often lived in cramped and badly ventilated housing with little sanitation, which facilitated the transmission of disease. Climatic perturbations following the eruption led to highly anomalous weather conditions; extremes of temperature can have a direct impact upon morbidity in the elderly or vulnerable, anomalous temperatures can also affect both microbial and parasitic disease vectors, and poor harvests resulting from unseasonable weather can contribute to nutritional deficiency which in turn makes individuals more susceptible to disease. Under certain environmental, economic and social conditions these endemic diseases reached epidemic proportions; had there not been widespread mortality at the turn of the century which reduced the number of vulnerable people in the population, the Laki eruption may have caused even greater crises. The findings presented here give a very nuanced picture of the crises, reflecting the differing levels of sensitivity of both the environment and the population in different parts of

the UK at that time.

2.6-P-05

Hydroxyl Radical Generation As An Indicator Of The Potential Respiratory Health Hazard Of Dust Produced By Quarrying Volcanic Deposits

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The potential respiratory health hazard of volcanic ash is routinely studied but little is known about the respiratory hazard of quarried volcanic deposits, either as loose, clastic deposits or freshly blasted lavas. Quarrying of both deposit types, may expose workers to fine volcanic particulate and subsequent processing of material may reactivate particle surfaces thereby affecting their potential toxicity. An assessment of whether quarried volcanic particulate can potentially cause respiratory disease has never been undertaken and is urgently required to assess whether re-activated, aged deposits could be harmful and whether formation of new particulate from blasted lava poses a similar hazard as ash generated from fragmentation during eruptions. Two areas where such quarrying is of economic importance are Montserrat where material is quarried from loose pyroclastic deposits and mud flows, and New Zealand by blasting basaltic lava rock faces (Auckland Volcanic Field) and extracting rhyolitic pumice deposits (Taupo Volcanic Zone). Here, results are presented from samples obtained in New Zealand. Grain size analyses of samples from six quarries showed that the finest particles were produced as a result of drilling (carried out prior to blasting), however, finished product also contained significant quantities of respirable material. Surface reactivity tests showed a clear correlation between the quantity of available iron on particle surfaces and the quantity of hydroxyl radicals produced, indicating that iron-rich samples produce greater numbers of hydroxyl radicals than iron-poor ones. There is a strong relationship between magma type and potential toxicity; with iron rich magma types such as basalt, generating greater quantities of hydroxyl radicals than the iron-poor rhyolitic samples. Morphological (SEM) and compositional (XRD) tests are in progress. This trans-disciplinary research will incorporate mineralogical characterisation with in vitro toxicological assays and risk assessment of the occupational impact, the results potentially contributing to improved policy on exposure standards.

2.6-P-06

Ambient Air Quality And Other Environmental Effects Of The Ongoing Summit And East Rift Eruptions Of Kilauea Volcano On The Island Of Hawai'i

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The effects of Kilauea's volcanic emissions on air and water quality have been a concern for residents, health officials, and land managers on the island of Hawai'i for over two decades of the ongoing eruption. The onset of the Halema'uma'u eruption in March 2008 added disproportionately large impacts due to the location of the vent and the plume dispersal pattern to downwind communities. Beginning in early 2008, the combined SO₂ emissions from the east rift zone (ERZ) and summit of Kilauea increased by ~40% as compared to the 2003-2007 long-term average, notably though, emissions from Kilauea's summit increased ~6-fold, averaging 850 t/d during 2008-2009. While ash production from the summit vent has been limited, the ash contains elevated fluoride, and ongoing research regarding water quality and livestock health is examining these impacts. Ambient air quality data show that federal gas and particle standards have been exceeded frequently in various communities on the south half of the island. Pahala, located 30 km downwind of Kilauea's summit eruptive vent under prevailing trade wind conditions, exceeded the SO₂ annual standard for 2008 and 2009. No communities outside of Hawai'i Volcanoes National Park recorded an exceedance of standards prior to the opening of this vent in March 2008. The increase in volcanic pollution has enhanced health concerns. A rise in respiratory emergencies for visitors to Kilauea caldera in early 2008 led Hawai'i Volcanoes National Park to close areas downwind of the vent. Two recent health studies on the Island of Hawai'i conducted prior to the 2008-2009 activity noted increased upper respiratory symptom prevalence in areas of persistent volcanic pollution. The current activity and exposure provides further opportunity to examine thresholds of human response.

2.6-P-07

Selenium Around Etna Volcano, Italy

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Humans are attracted by the fertile properties of volcanic soils and currently around 10% of the world population lives within active volcanic areas. Volcanoes emit significantly amounts of potentially toxic elements such as selenium (Se), even in the absence of obvious volcanic activity. Although Se is an essential element for humans, ingestion of an excess amount of Se can produce adverse effects. Mt. Etna, the biggest volcano in Europe, is persistently active for the last 200,000 years and one of the most intensely monitored volcanoes. We have studied selenium in rainwater and soils from Mt Etna volcano. Bulk depositions were collected from April 2006 to December 2007, using a network of five rain gauges, located at various altitudes around the summit craters. Highest Se concentrations (up to 13 µg/L) have been found close to the emission vent, con-

firming the prevailing volcanic contribution to rainwater composition close to the summit craters. The deposition rate for Se was estimated to be 1.7 $\mu\text{g m}^{-2} \text{ day}^{-1}$ nearby to the summit vents, to 0.5 $\mu\text{g m}^{-2} \text{ day}^{-1}$ at the local background site on the upwind western sector. Thirty soils collected at the flanks of the volcano show total concentrations between 0.1 and 2.2 ppm. Lab-controlled experiments with these soils and synthetic rainwater show that up to 5% of the Se is mobilized during soil-rain water interaction. The trace element deposition of the plume cannot explain the observed spatial trends. However, the stage of soil development plays an important role in the behaviour of Se within the soils. Our results have implications for the chemical composition of the Etnean aquifer. Additional, the mobility of soil Se influences the bioavailability and potential toxicity through agricultural activities, essential to the local economy.

2.6-P-08

Study Of The Impact of Nyamulagira And Nyiragongo Volcanic Plumes On Population Health In The Kivu provinces; Democratic Republic of Congo.

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Nyamulagira and Nyiragongo are two volcanoes located in a densely populated area near the border between DR Congo and Rwanda. The two very active volcanoes belong to the Virunga Volcanic Province (VVP) and are located in the western branch of the east African rift. Historic eruptions of Nyiragongo (outside the main crater) are restricted to 1977 and the devastating 2002 eruption whereas nearby Nyamulagira has produced more than 30 reported eruptions in the last century. Nyiragongo is characterized by a semi-permanent lava lake and is among the world's largest point sources of sulfur dioxide (SO_2) gas. Under the influence of the dominant easterly winds, the volcanic plume typically disperses west of the VVP. The impact of volcanic gas and particle emissions on the local population either directly (respiratory or skin diseases) or indirectly through contamination of crops has been strongly suggested. The DRC health program includes a national health information system (SNIS) that is used to detect disease prevalence anomalies in long-term epidemiological data that could be linked to volcanic activity. The long-term impact of persistent emissions from Nyiragongo is studied and compared with the impacts of the sporadic Nyamulagira eruptive plumes. More specific and daily observations were systematically performed in four health structures in the Kirotshe – Sake area during the recent January 2010 Nyamulagira eruption. Those data will be compared to the SNIS data of that period and to those of previous eruptions –in particular 2006. The selection of the health structures where data are collected is based on systematic satellite measurements made under the NSF-VISOR project. They are also compared to the analysis of water samples collected in the area

where low PH and high Fluor content have been detected.

2.6-P-09

Health Hazard from Gas Emissions in the Quaternary Volcanic Province of Latium (Italy)

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The Quaternary Volcanic Province of Central Italy is characterized by zones with a huge endogenous degassing where frequent, sometimes lethal, accidents occur to people and animals. The emitted gas has a deep origin (volcanic or mantle) and is mainly composed by CO_2 (up to 98%) and H_2S (1-4%), which may reach dangerous concentrations both in open air and indoor. Here we present the results of a multiparametric geochemical study carried out in 2007-2009 in the Provinces of Rome and Viterbo (Latium), with the aim of assessing the health hazard of their main gas emission sites (GES). Three types of GES were investigated: 1. natural, open-air thermal pools, 2. within natural reserves, 3. near to inhabited zones. More than 15 GES have been studied, and here we will illustrate some of the cases with the highest hazard. Results are presented for the sites of Vejano and Mola di Oriolo (Viterbo), Caldara di Manziana, Tor Caldara and Solforata di Pomezia (Rome). Cava dei Selci is a well-known inhabited area of the volcanic complex of Colli Albani (Rome). In each site, multi-technique surveys have been carried out to estimate the total gas output and its concentration in air, by measuring: CO_2 and H_2S viscous and diffuse flux (the latter by accumulation chamber), CO_2 and H_2S concentration in air (by TDL profiles and punctual Draeger measurements); moreover, the chemical and isotopic composition of the gas was determined in each site. In all these zones, lethal air concentrations may be reached by both H_2S and CO_2 , but more frequently by the first. Recommendations for risk reduction were given to Civil Protection authorities.

Session 2.7

2.7-O-01

Modeling the tephra fall out hazard associated with sustained Hawaiian fountaining eruptions.

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Most impact assessments for natural hazards assume a short duration for the event such that the studies model the impact of say a flood, earthquake or tsunami in its entirety. The generalization is valid for many volcanic eruptions, however eruptions of moderate intensity and cone-building style are often protracted. High Hawaiian fountaining eruptions with their combinations of moderate discharge rate (10^4 to 10^6 kg s⁻¹) with prolonged duration (2-300 hours) and high proximal accumulation rates (1-25 cm h⁻¹) thus have the potential for exceptionally high impacts on adjacent communities. Cone-building phases of such eruptions are typically protracted, i.e., of weeks to months in duration, prolonging the period during which emergency managers will have to fine tune mitigation for numerous parameters such as fluctuations in intensity and wind shifts. Historical data suggests that rapid cone growth during future eruptions will each define a region of some 30 to 100 hectares where complete destruction will occur on a time scale of hours..

Here we contrast the eruption and accumulation rates for the three classical high fountaining eruptions of the late 20th century (Kīlauea Iki 1959, Mauna Ulu 1969, Pu'u O'o 1983-986) with the accumulation patterns for transient impulsive pyroclastic eruptions from Kīlauea in 2008-2010.

2.7-O-02

Quantifying the economic impacts from thin tephra-falls

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Many cities face their highest volcanic hazard not from devastating local events but rather widespread tephra-falls. The expected thickness of these falls is typically less than what would result in damage to structures but nonetheless may have significant impacts on the built environment, transport systems, health, utility supply and agriculture. Clean-up operations will likely be necessary even when only small volumes of tephra are deposited in built-up areas. Although many of these impacts have been observed, attempting to quantify their probability has proved to be much more difficult.

Surrounded by at least six potentially active volcanoes, Tokyo is one such city. Tephra-falls exceeding 1 mm in central Tokyo are expected to occur only on the order of every 1000 years; however, thinner more localised dustings of tephra, such as that from Mount Asama in February 2009, may occur more frequently. Quantifying the economic impacts of future events and applying probabilities will assist in determining the benefits and feasibility of preparation measures.

We use a catalogue of 60,000 simulated tephra-fall scenarios and a detailed land-usage database to investigate two of the largest problems that Tokyo is likely to face from future tephra-fall events – the necessity for clean-up activities and the adverse effects to agriculture and crops. For each cell in a 1 km resolution grid covering the Greater Tokyo area, we are able to calculate the probability of any given tephra load and the total

amount of tephra falling on various land types including residential, non-residential, agriculture, forestry and roads.

Functions have been created from analogous events that relate the volume and mass loading of tephra to the costs and resources needed for clean-up activities and the damages to agricultural/horticultural production and the asset base. We will present these results and discuss data that will aid in future volcanic impact modelling.

2.7-O-03

Characterization Of Tephra Deposits And Implications For Hazard Assessments

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Quantitative hazard assessments of active volcanoes rely on a comprehensive characterization of past, current and future volcanic activity, which is typically based on the determination of eruptive parameters. Even though recent eruptions are typically easier to characterize because they can be described through visual observations and satellite retrievals, eruptive parameters are typically difficult to constrain. In particular, tephra deposits retain crucial information on plume height, erupted volume, mass discharge rate, duration and grain size. In fact, the distribution of tephra thickness and mass per unit area around the volcano (isopach and isomass maps) is necessary for the estimate of erupted volume, whereas the distribution of the largest clasts (isopleth maps) is typically used for the estimate of column height. Both isopach/isomass maps and isopleth maps can also be used for the determination of the eruptive vent location and the eruption classification. The mass eruption rate and the duration of the sustained phase can be calculated from a combination of these parameters. However, the accuracy of the information derived from tephra deposits strongly depends on the quality of exposure and, as a result, is typically inversely correlated with deposit age. An important challenge for modern volcanology is an efficient and careful investigation of all types of tephra deposits, as they often represent the only open window on past volcanic activity. As a result, systematic protocols for the study of tephra deposits should be built on a deep understanding of tephra sedimentation, careful analysis of different types of tephra deposits and a broad comprehension of empirical, analytical and numerical models typically used to derive eruptive parameters. Finally, strategies considered for the compilation of tephra hazard assessments should also account for the complexities associated with the identification of eruptive scenarios and designed to deal with epistemic uncertainty (e.g. fully probabilistic strategies).

2.7-O-04

Recovery From Small Basaltic Eruptions: Lessons From The 1973 Heimaey Eruption, Iceland

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The 1973 basaltic eruption on the island of Heimaey in Vestmannaeyjar, Iceland, produced a cinder cone and lava flows in the middle of a populated area. The immediate and long term recovery issues associated with tephra produced during this eruption provide useful insight for communities at risk from similar eruptions. We carried out an assessment of the eruption impacts by reviewing published work and conducting interviews with local experts (including scientists, civil authorities, medical personnel and decision makers), most of whom were directly involved in the 1973 eruption response and recovery. During the eruption almost the entire population of Heimaey (c. 5,300) was evacuated to the mainland. At the end of the six month long eruption, 417 houses were buried under lava and tephra, and ~400 more damaged by tephra alone. Although many structures collapsed from the weight of the tephra, dozens were saved by crews of volunteers who cleared roofs during the eruption and tacked corrugated shutters over windows to prevent fires. There were very few injuries during the eruption; falls from roofs were cushioned by the coarse ash and lapilli, and helmets worn by first responders prevented major damage from ballistic ejecta. After the eruption a major clean-up effort was undertaken to rebuild the town; this was funded by all Icelanders through a special surtax and by foreign aid. The post-eruption clearing of tephra, carried out by local and foreign volunteers, took two years and was centrally coordinated by a local fire chief. Tephra was used for aggregate and for leveling the ground for new housing developments. Remobilised wind-blown tephra ("scoria storms") proved a major nuisance, causing damage to homes, morale, and recovering vegetation. A year-long re-vegetation programme in 1976 successfully stabilised the scoria, and provided important psycho-social benefits for the returning population.

2.7-O-05

The Alaska Volcano Observatory Citizen Network Ash Collection and Observation Program.

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The remoteness of many of Alaska's 52 historically active volcanoes makes direct eruption observations and real time ash-fall collection challenging. As a result, scientists at the Alaska Volcano Observatory (AVO) ask citizens positioned both near active volcanoes and under the path of eruption clouds to make voluntary observations and collect ash samples during eruptions. Scientists at AVO make these requests to individuals by phone, postal and electronic mailings, and advertise the need more broadly on the AVO website. AVO provides detailed instructions for making observations and collecting samples as on-line documents and as a video;

both can be mailed to communities without internet access. In addition, AVO has held community workshops to educate volunteer observers and provide collection materials (tools, and mailers). Because of the varied abilities and interests of the general public, and environmental conditions, AVO provides instructions for a variety of acceptable collection procedures. Observations can be submitted directly to AVO's database-driven website, or by phone, mail, or hand delivery. A recently developed web-based geographic interface helps scientists to visualize the locations of ash fall activity in near-real time. During the 2009 eruption of Redoubt volcano, AVO received approximately 250 written or verbal observations and 55 physical samples from the public including time-incremental collections during prolonged ash fall events; measured-area samples, and bulk samples. Timely posting of eruption and ash-fall information improves the accuracy of official warning messages and thus the effectiveness of communicating volcano hazards information to the public. Observations of ash-fall events including timing, location, and amount are communicated directly to the National Weather Service so that public Ash Fall Advisory statements can be updated. Scientists use ash-fall samples and observations to understand the composition, volume, and dispersal pattern of the ash clouds.

2.7-O-06

Chaitén 2008 Rhyolite Eruption, Southern Andes: Indirect Impact Of Volcanic Ash Fall

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Chaitén volcano (Southern Andes; 900 masl) erupted unexpectedly on May 2 2008 (Carn et al., 2009; Lara, 2009; Castro and Dingwell, 2009). Sustained ash emission lasted for a week with at least three stratospheric ash injections on May 2, 4 and 6. After the explosive phase, the eruption transitioned into a rapid dome growing stage (> 20m³/sec) that built a ca. 0.5 km³ dome complex, still active as February 2010. Volume estimate of erupted ash is still controversial because the lack of proximal data but ranges from 0,2 km³ to < 6 km³. Grain size distribution of fallout deposits have been reported to be extremely fine (Reich et al., 2009, Watt et al., 2009) which could pose serious risks on long-term human health. On May 12, Chaitén town (12 km away from the volcano along the Chaitén River) was severely disrupted by floods and lahars that remobilized the proximal ash accumulation. Despite the direct short-term effect of ash fallout on the downwind area (mostly eastwards), long-term statistical analysis based on ash sedimentation and transport models (e.g. Bonnadonna et al., 2005) and wind field datasets (Kanamitsu et al., 2002), we estimate that populated areas would have <10% probability of reaching 10 cm thick ash cover, derived from VEI 5 events occurred in the volcanoes nearby. However, indirect impact of ash accumulation in the watershed basins poses an unparallel hazard which is local but intensive as demonstrated by the 2008 eruption when more than 5,000 inhabitants were displaced with the subsequent large-scale social impact. References: Carn et al., 1999, EOS; Lara, 2009, Andean Geology; Watt et al., 2009, JVGR; Bonnadonna et

al., 2005, *J Geophys Res*; Kanamitsu et al., 2002, *Bull Am Meteor Soc.*; Reich et al., 2009, *Geology*; Castro and Dingwell, 2009, *Nature*.

2.7-O-07

Ash Falls at Tungurahua Volcano: Implementation of Systematic Ash Collection for Quantifying Accumulated Volumes

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Since the beginning of Tungurahua's eruptive process—starting in 1999 until the present, the volcanic phenomena of most persistence and an overall level of affectation has been that of ash fall. During strong Strombolian activity such as in 2001 and the July and August eruptions in 2006—in which the greatest areas were affected, the calculation of volumes was achieved by occasionally measuring the ash thickness around the volcano. Starting in 2007 about 30 ash collecting bins were deployed to cover the areas of major to marginal ashfalls. Ash collection has allowed us to have systematic control of the accumulated thickness, which then is employed to elaborate isopachs and volumes of fallen ash. Using the method of Pyle (1989) with the interpolation of only one segment, it has been possible to calculate the volumes of the February, 2008 eruption (1.5 million M³), as well as for other ashfalls during 2008/2009. In the recent eruptive period between January to February, 2010 systematic ash collecting has permitted the calibration of volumes that have accumulated—1.2 and 1.6 million M³, respectively, with the level of seismic activity, the height of ash clouds, calculation of magma volumes using tiltmeter and GPS data and the reduced displacement of explosions, etc. Volumes calculated using the methods of Feirstein and Nathenson (1992) and Legros (2000) give similar values.

2.7-O-08

Ashfall impacts: Mount St Helens to Vesuvius

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The impacts of volcanic ashfalls can range from apocalyptic visions of the burial of whole communities and asphyxiation of their inhabitants, to the growing realisation that even light ashfalls can cause major disruption and consequences to health and safety. The dynamics of the impacts of ash falls depends upon a range of factors, beginning with the type of eruption, the prevailing meteorological and climatic conditions, and a wide range of characteristics and socio-economic activities of the settlements and populations at risk. The cataclysmic eruption of Mount St Helens, 1980, was the first opportunity for the extensive cataloguing and study of ash fall impacts and it was undertaken by US federal agencies with advice during the crisis period communicated to the public by the Federal Emergency Management Agency. The eruption of Mount Pinatubo, 1991, in the Philippines, showed for the first time the major loss of life that could be incurred from roof collapses due to tephra loading. This presentation is an analytical survey

of the fallout impacts from notable past eruptive events, beginning with the consequences of the AD 79 eruption of Vesuvius and ending with the most recent planning for a future sub-Plinian eruption at Vesuvius, including real time modelling of fallout for assisting with evacuation decisions.

2.7-O-09

Volcanic Ash in the Environment

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The entry of volcanic ash in the environment may instigate a range of physical and chemical impacts. These may be direct or indirect, and their magnitude depends on a combination of intrinsic and extrinsic factors. Intrinsic factors refer primarily to the size distribution, specific surface area, bulk and surface compositions of the ash. Extrinsic factors denote the physical, chemical and biological conditions of the environmental media exposed to the ash material. Ash may be deposited in permanent sinks, such as soil or aquatic sediment; temporary sinks, such as vegetation surfaces; or may be transported through the atmosphere or a water body. The significance of the ash surface properties for eliciting effects in the environment increases as the residence time of ash in that environment decreases. Conversely, the bulk properties of ash become more important when the environment serves as a permanent sink. However, there remain many uncertainties surrounding the interactions which occur at the ash-environment interface, many of which stem from a limited understanding of the chemical reactivity of the ash surfaces. This paper will review current knowledge on how the surface properties of ash influence the type and magnitude of environmental effects. In light of these findings, suggestions for developing improved ash analysis and ash impact data collection protocols will be made.

2.7-O-10

The Impact of Ash Fall On Visibility

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During volcanic eruptions fine ash particles act as scatterers of sunlight. This can produce a serious reduction in visibility if the concentration of suspended particles becomes sufficiently great. As a consequence, the safety of transport of all forms and airport operations is easily compromised and the economy impacted. Revisiting theories of aerosol science, we performed a first study on the role of the finer portion of volcanic ash in causing deterioration in visibility during an on-going

eruption at Mt. Etna. Using the VOL-CALPUFF dispersal code (Barsotti et al., 2008), we modelled the dynamics of 10-micron particles, and smaller, from their release in the ascending plume to their fall to the ground and quantified their concentration in free atmosphere and close to the ground. In particular we estimated 2 m height concentration at pertinent sites, such as airports, main roads, and in densely populated cities. We performed this analysis for an episode of long-lasting weak plume activity both for a single deterministic event and adopting a Monte-Carlo approach for taking into account uncertainty on eruptive intensity and on the duration of a hypothetical event of this type. Results quantify the spatial distribution of critical fine ash amounts around the volcano and the probability of exceedance of specific particle concentration values, and the corresponding reduction in visual range. The adoption of a simple re-suspension model, based on an empirical correlation between tephra deposit thickness and the amount of fine ash remobilized by various causes, also demonstrates the importance of remobilization in further attenuating visibility.

2.7-O-11

Health, Agriculture And Water-Supply Impacts Of Long-Term Volcanic Ash And Gas Eruptions In Vanuatu – Perception Vs. Reality

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Recent research has demonstrated that ongoing ashfall on Ambrym Island, Vanuatu, has generated chronic human health and agricultural problems, and that dental (and possibly skeletal) fluorosis is endemic to parts of the Island. Following recognition of this since 2001, a succession of high-profile volcanological and agricultural/health studies have taken place on the island by local government officials and external scientists. This has resulted in a higher public perception of the issue, but has also given rise to a number of misconceptions of the level of volcanic ashfall threat and its indicators. During a volcanic crisis in 2005, no major eruption took place, but higher than normal ashfall levels were associated with up to 20,000 tonnes/day of SO₂ release. During this period, local roof-fed water supplies contained over 10 times the WHO safe limit of fluoride, and some rainfall with volcanic ash contained acutely toxic levels. The combined ash and acid rain devastated agriculture across many parts of the island. A recent upsurge in activity in early 2009, led to emergency requests to WHO for a survey to determine the volcanic health threat. The associated field visit and follow-up workshops with governmental agencies and local communities showed that the level of volcanic threat was within its “normal” range experienced for at least the last 80 years. Only 33% of tested water supplies were higher than the WHO recommended limits. The health alarm in 2009 was triggered by measurement of low pH drinking water following ashfall, from which it was assumed toxic levels of F were present. In this study it was shown that except for the most extreme eruption cases (e.g. 2005), pH is NOT a good indicator of fluoride levels in drinking waters. The latest health crisis on Ambrym reflected both an underlying misunderstanding of volcanic health

impacts of by authorities and local communities and a delayed response to evaluating impacts from the Jan-Feb 09 surge in volcanic activity. Through many different assessment teams and scientific groups a fractured picture of information regarding volcanic health was developed. This must be addressed by a coordinated inter-agency (and inter-scientist) plan for the monitoring, assessment and communication of volcanic health and impact information to local communities.

2.7-O-12

Ash Fall Impacts Before, During and After an Intense Lava Dome Collapse on 20 May 2006 at Soufrière Hills Volcano, Montserrat.

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An intense lava dome collapse and at least two vulcanian explosions at Soufrière Hills Volcano on 20 May 2006 removed 86 Mm³ DRE of andesite lava in two distinct pulses over 35 minutes. The maximum ashfall in inhabited areas was 30 mm but farmland and forest inside the exclusion zone was affected by up to 600 mm of ash. About 7 km from the volcano, doves were reported falling to the ground covered in mud and fish in a pool died. Lizards and frogs were reported in the exclusion zone with white opacities to the eyes. A flock of 65 sheep was penned 2 km downwind of the dome. Forty died by being buried under ash and 15 were dug out alive but ash had to be removed from their eyes as they were rescued, of these, 5 had permanently damaged eyes. Untethered livestock had not died during the event but many died of starvation in the following weeks as vegetation showed little sign of recovery one month after the collapse. Some livestock began to wander through inhabited areas in search of food causing a hazard to people.

Vegetation damage in the exclusion zone was extensive with large trees left leafless and many broken branches. This was more extensive damage than that seen after the much bigger dome collapse on 12 July 2003, which had a heavier and more extensive ash fall.

Increased lava extrusion rates from February 2006 resulted in high hydrogen chloride - sulphur dioxide ratios and regular fine ash fall, which, when combined with unfavourable wind directions led to several months of prolonged vegetation damage before the dome collapse. This damage, combined with the intensity of ash fall on 20 May 2006 resulted in the generation of the most voluminous lahars yet seen during the ongoing eruption.

2.7-O-13

Forecasting Distal Impacts From Volcanic Crises

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As one of the furthest reaching volcanic processes, tephra fall has the potential to affect the greatest number of communities and incur significant social and economic disruption. Assessment of tephra fall hazards commonly involves just immediate physical impacts, with the long-term influence of volcanic ash on communities and the associated implications for community recovery only a more recent consideration. As part of the ongoing development of the emergency management plan at Vesuvius volcano in Italy, we have investigated the consequences of tephra falls for distal communities and management of the crisis. Around Vesuvius, more than 1 million people could be directly exposed to the effects of tephra fall and associated hazards, such as lahars. We present potential crisis scenarios for Vesuvius that may result in challenging physical, social or economic conditions for communities and adversely affect their capacity to cope during the crisis or to recover post-crisis. A rapid escalation of unrest activity over a few weeks culminating in a definite climactic explosive event and subsequent punctual decline in activity would be the least complicated future scenario at Vesuvius for crisis management, and for planning to cope with the psychological and actual reactions of the threatened population. However, the precursory timeline that develops in the next crisis is unlikely to be so straightforward. Drawing on experience of past eruption crises elsewhere, we focus here on the hypothetical response of the communities at Vesuvius to a more prolonged crisis period, including a protracted and varying unrest phase, and on the effects of continued ash emission following the eruption climax. The consequences of these more complex eruption scenarios for economic sustainability and community resilience at Vesuvius are discussed and suggestions provided for mitigating the impact.

2.7-O-14

Impacts on critical infrastructure following the May 2008 Chaitén eruption in Patagonia

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On 2 May 2008 a rhyolitic eruption from Chaitén volcano in southern Chile led to extensive ashfalls over

>200,000 km² of Chile and Argentina. Lahars were also generated in drainages surrounding the volcano. Our team visited the affected region between 23 January and 12 February 2009 and assessed impacts to critical infrastructure.

Several high and low voltage electrical distribution networks suffered flashover damage to insulators and damage to lines from treefall, resulting in outages to some communities and prompting cleaning and insulator replacement programmes. The Futaleufú hydroelectric power dam (Argentina) received heavy ashfalls but these did not cause immediate damage. However, ash-induced flashovers on transformer insulators in the step-up yard disrupted electricity supply to the Argentinian national grid. Municipal water supplies in the towns of Chaitén and Futaleufú (Chile) and Esquel (Argentina) were disrupted by the eruption.

In Futaleufú, the original snowmelt-fed source was disconnected on a precautionary basis, and a groundwater-fed system developed. In Esquel, a timely and well-designed monitoring programme helped allay public fears about a metallic taste in the water supply, which remained continuous. Authorities did however experience other problems with the water supply as a consequence of the ashfall; suspended ash increased turbidity levels in the intake water and to prevent terminal disinfection from being compromised it was necessary to increase the chlorination dosage. In addition, residential cleanup operations came close to exhausting the town supply.

Ground transportation networks suffered disruption with ash reducing visibility both during the primary ashfall and as a result of remobilisation. Some bridges have been damaged or destroyed by lahars. Most electromagnetic transmission systems proved resilient to ashfall, at least in the short term. The only reported problems occurred when ash penetrated telecommunication devices causing failure to electronic componentary, also overloading of local exchanges due to excessive call traffic.

2.7-O-15

State Of The Art Review Of The Impacts Of Volcanic Ash Fall On Urban Environments

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A state of the art review has been undertaken to assess the extent of current knowledge on the impact of volcanic ash on urban environments. A systems engineering framework is applied to the topic in order to assess strengths and gaps in the state-of-the-art. It is found that existing studies are limited but do provide some insight into the impacts of volcanic ash on: health, structures, water and contamination, electrical appliances, agriculture and emergency management. This paper presents these findings and identifies knowledge gaps in the assessment of ash fall impact on whole urban areas, which compromise assessment of urban vulner-

ability to this hazard. The literature is complemented by a recent field study, undertaken by the author on Montserrat. Observations are made both on physical and social elements of vulnerability, and on soft system functionality in the context of an eruption that has spanned over two decades.

2.7-O-16

Ash fall impacts in New Zealand: mitigation strategies developed through New Zealand and international case studies

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The 1995-1996 eruption of Ruapehu brought home to New Zealanders the disruptive nature of volcanic ash fall on society, especially air traffic, infrastructure, agriculture and tourism. New Zealand is at risk from ash fall from a range of potentially active of basaltic fields (Auckland), andesitic volcanoes (Taranaki, Ruapehu, Tongariro, White Island) and rhyolitic calderas (Okataina and Taupo). Observations of impacts across many sectors were collected from the 1995-1996 eruptions, and subsequently on collaborative projects studying Mount St Helens, Mt Spurr, Kagoshima, Merapi, Hudson, Pinatubo, Heimaey, Chaitén and most recently Redoubt. Studies have focussed on various aspects of critical infrastructure including electricity and water supplies, wastewater, land and air transport, telecommunications; on ash cleanup and disposal; and agriculture, including impacts on livestock, crops, soil fertility and rural communities. In New Zealand these have led the establishment of a "Volcanic Impacts Study Group", an annual volcanic hazard management short courses for the emergency management sector, and industry-specific reference resources including reference posters and reports (<http://www.aelg.org.nz/aelg/index.cfm?F96A5BF4-1279-D5EC-EDA9-01B2268C93DE> and <http://www.maf.govt.nz/mafnet/rural-nz/emergency-management/volcanoes/volcano-0609.pdf>). Collaboration with the US Geological Survey has helped to populate and grow the 'Volcanic Ash' impacts and mitigation web resource (<http://volcanoes.usgs.gov/ash>).

Despite these efforts, and recognition of volcanic risk by potentially affected agencies, it remains difficult to maintain a high level of preparedness by many sectors in New Zealand. This is due in part to other training and planning commitments and in part to the infrequent (decadal) nature of ash fall episodes. Compounded by regular staff turnover, this has led to a difficulty in maintaining - let alone enhancing - organisational knowledge

and readiness. Continued effort is required by both the volcanological and emergency management communities - working together to enhance capacity and capability.

2.7-O-17

Emerging Ash Fall Impacts and Management Lessons from the 2010 Eyjafjallajökull Eruption - from Iceland to Europe

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Unusual seismic activity near Eyjafjallajökull in southern Iceland began in late 2009 and continued to March 2010, preceding a 20 March onset of eruption. The initial fissure eruption on the NE flank of the volcano was effusive, attracting significant volcano tourism. A more-explosive (hydromagmatic) phase of eruption began on 14 April from the summit crater beneath a thin ice cap. It has produced volcanic ash plumes that significantly interfered with air travel in Europe with global economic consequences. In Iceland, ash fall has caused disruption and impacted on rural communities, air travel, farming and land transport.

This talk will present emerging ash fall impacts and management lessons from the hydrovolcanic phase of eruption. It is intended to include data collected by a range of workers up to the start of the Cities and Volcanoes 6 conference on 31 May, 2010. It may include an update on plume dispersion and grain size distribution work.

2.7-P-01

Manual on Ashfall Contingency Procedures: a Work Project with the Community

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In the Andes there are several active volcanoes, most of them are located in Chilean territory. Prevailing winds from the west transport volcanic ash to Argentine territory. There is no record of the proceedings during and after the fallout that affected our area in the recent past to provide experience for future events. The recent eruption of Chaitén volcano, exposed the lack of information on how to act quickly under this situation. This paper presents a model program designed to create in Argentina a manual of procedures before the ash fall. The project was carried out in the Patagonia region in three emblematic locations affected by this danger: Los Antiguos-Perito Moreno (Santa Cruz Province), Cavia-

hue (Neuquén Province) and Esquel-Trevelin (Chubut province), including the villages around these cities that have been affected by ash fall. These villages on which we develop our study have been recently affected by ashfall from the eruption of Hudson volcano (Chile) in 1991, Copahue volcano (Argentina) in 1992, 1993 and 2000 and Chaitén volcano (Chile) 2008-2009, respectively. From the experience of people and incorporating scientific knowledge of professionals on how to act before, during and after an ashfall this manual on contingency procedure was obtained to prepare communities before the eruption. This material is focused on municipal authorities and local agencies that act directly against such an event. Another achievement was to bring near was to bring scientists into the community, resulting in an exchange of knowledge between both groups, particularly learning from the experiences of these groups (successes and mistakes) before and after this phenomenon occurred.

2.7-P-02

A New Operational Ash Forecasting System For Chilean Volcanoes

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According to the tectonic segmentation model of the Andean margin, four discrete zones with widespread Holocene volcanism do exist. In the particular case of the Chilean Andes, the volcanic zones present are the Central (18-27S), Southern (33-46S) and Austral (49-56S), where in more than 50 volcanoes have been recorded historic activity. It is worth noting that between 33-42S around 90% of the Chilean population is concentrated. Although explosive activity has occurred in all of these segments, tephra fall hazard studies are limited. In addition, significant differences in atmospheric circulation occur between 18-56S (more than 4000 km), resulting in non-uniform patterns of tephra dispersion and transport. As a consequence, the development of an operative ash forecasting system is highly relevant for both civil authorities and decision makers. The aim of this contribution is to present advances in the implementation of such system for selected Andean volcanoes. Eruptive conditions are considered in models such as advection-diffusion and particle tracking. Meteorological data come from analyzed wind fields, which were interpolated to regional domains using the Weather Research and Forecasting model (WRF) in order to improve their resolution.

2.7-P-03

CENIZA: An Latino-American Network for Modelling and Monitoring Volcanic Ash and Aerosols and its Impact on Infrastructures and Air Quality

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Volcanic eruptions can inject large quantities of ash and aerosols that at transported hundreds of kilometres downwind by the prevailing winds. On the other hand, many volcanoes show diffuse emission of gases and aerosols during intra-eruptive periods. Both phenomena have consequences at regional and local scales and influence the quality of air of the surrounding areas. CENIZA is a networking project (2010-2012) funded by the Ibero-American Development Programme for Science and Technology (CYTED), a Programme aimed at combining different perspectives and visions to promote cooperation in Research and Innovation for the development of the Latin America region. The CENIZA network gathers institutions from six different Latin-American countries (Argentina, Colombia, Ecuador, Mexico, Nicaragua, and Spain) and is devoted to monitoring, modelling and forecasting volcanic ash and aerosol dispersion. Focussing on large urban areas located nearby active volcanoes, the network aims at developing and implementing the necessary tools for a daily forecast of ash fallout during eruptions and airborne gas/aerosol concentration from diffuse emissions. A second goal is to investigate the role of volcanic emissions on local atmospheric pollution and its effects on air quality and human health at short and mid-term. Here we review the network goals, working plan, implementation and outreach strategies.

2.7-P-04

An Active Volcano, Tatun Volcanic Group, in Metropolitan Taipei, Northern Taiwan: Inferred From ~6 ka Juvenile Volcanic Clasts in the Dream Lake

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Tatun Volcanic Group (TVG) in metropolitan Taipei, northern Taiwan is located in one of the most densely populated areas in the world, which has over 6 million inhabitants. One fifth of them just lived at the foot of the TVG hill. Effective and reliable volcanic hazard mitigation is absolutely mandatory. However, hazard mitigation can be achieved by applying numerous techniques, based on reliable data base. How to understand the most recent eruption of the TVG will be much important hint for prediction the future activity of eruption. The core was collected from the Dream Lake at the eastern slope of Cising Mt.. Total 21 samples from depth 190 cm to 231.5 cm have been tested. The volcanic ashes in the core with the identical morphology were firstly identified as juvenile materials. The glass matrix in these clasts

showed the medium K₂O (~4%) and Na₂O (~3%) with SiO₂ (~80%) contents. Comparison of chemical compositions of glass and minerals in the juvenile clasts with those of lava around TVG, they clearly showed that the volcanic ashes can be correlated with the eruption of the closest Cising Mt. It was notable that a kind of high silica (above 95% SiO₂ contents) crystalline like the hydrothermal gel was also found in some clasts. It will probably represent which are the products of phreatic eruption. According to the radiocarbon (C-14) age of core sample at the depth 225 cm, the age was extrapolated around 6150 yrs ca. C-14 age. This new founding directly demonstrated that there had been re-active in the TVG in the last 6 kyrs and also strongly sustained that Belousov et al. (2010) and Chen and Lin, (2006 and 2007) claimed that the most recent explosive activities of the TVG were identified from weak phreatic to highly explosive plinian eruptions within the last 6000 to 20000 yrs.

2.7-P-05

Ash Fall Impacts From Recent Eruptions in Alaska: Lessons Learned From Trace to Minor Ash Fall Events

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Between 2006 and 2009, 4 significant explosive eruptions in Alaska generated trace to minor ash fall on waterways, infrastructure, and communities. Fortunately, all 4 eruptions were sufficiently remote such that ash accumulation on permanently inhabited areas did not exceed about 2 mm for any one fallout event. Principal impacts of anticipated and actual ash fall included: (1) expenditure of resources to purchase preparedness supplies (masks, spare air filters, plastic sheeting, etc.) and implement a variety of mitigation measures (planning and education, nightly computer system shut-downs, etc.); (2) brief interruptions of airport operations, marine traffic in adjacent waters, and other activities; (3) anxiety about health impacts and minor respiratory and eye complaints following exposure to ash both during fallout and re-suspension. Two eruptions were preceded by weeks to months of precursory activity allowing local authorities and the Alaska Volcano Observatory (AVO) to conduct an extensive preparedness campaign that used existing printed and web-based resources, local media, and presentations. Two eruptions occurred very suddenly. Most events prompted formal ash fall warnings from the National Weather Service (NWS), a text message usually prepared in collaboration with AVO. Derivative warning messages focusing on air quality impacts were issued on some occasions by the State of Alaska's Department of Environmental Quality (and also the Municipality of Anchorage). NWS also issued specific ash fall warning products for mariners. Warning message content improved through time as language became more consistent and 'call to action' statements were refined. The lack of an operational ash fall forecast model to estimate expected thickness rapidly remains a challenge to providing the public with more accurate

guidance. Misinformation about how much ash to expect and overly-severe concerns for potential impacts of trace to minor ash fallout remain education challenges for all agencies involved in eruption response and ash fall warnings.

2.7-P-06

Economic Impact of Volcanic Eruptions: Evaluation Model

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One volcanic event may produce much more economic damage of what is normally perceived. In order to evaluate the possible economic damage of the expected volcanic eruption (subplinian) in the Vesuvius area, we developed a conceptual model that has been implemented through a computer based simulation model. The first issue for the evaluation is the definition of the "Timeline" of the entire volcanic cycle starting from the rest phase through the Unrest phase, the Event, the Ante-Normalization and the Normalization up to the Rest phase again. Along the Timeline we have identified all the possible "direct costs" and the "factors" (indirect costs) that will impact the economic growth, such as costs for mitigation, evacuation, emergency assistance and management, ash cleaning up, rehabilitation and reconstruction, human health interventions, changes in Gross Local Product or Local value added due to the emergency, etc. The costs which have been identified can be referred to one or more temporal phases of the phenomenon and can vary according to the reference damage scenario and strategic policies assumed during emergency phases.

Each cost is built up through a specific algorithm that is fed by various providers, in order to run a software that will calculate the global amount of economic damage produced by a volcanic event.

2.7-P-08

Adapting a Rapid Analysis Ash Leachate Method to a Volcano Observatory Setting.

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Mount Redoubt, a volcano in south-central Alaska, erupted in March 2009 producing more than 19 explosions that sent ash clouds downwind in all directions from the volcano. The Alaska Volcano Observatory (AVO) received several inquiries about Redoubt volcanic ash impacts on open water reservoirs. It is well known that when volcanic ash falls onto open water, including rivers, lakes, and reservoirs, leaching of constituents from the ash particles into the water does occur, forming volcanic ash leachates. The AVO has long been concerned

with potential health and environmental hazards associated with volcanoes, including the impacts of volcanic ash leachates. Since 2004, the USGS Field Leach Test (FLT) has been used by USGS volcanologists for the rapid assessment of volcanic ash from twelve different eruptions. AVO has now adapted this leach test as a standard protocol during Alaskan eruptions. Adaptation of the FLT to a volcano observatory setting requires use of local resources and interagency collaboration. Basic water quality measures can be performed in the field or in a laboratory with readily available equipment and supplies. In Alaska, chemical analysis of the leachate solution using ion chromatography will be performed at a local University laboratory thus facilitating rapid acquisition of results. Ion-specific probes can also be used for chemical analysis for in-situ operations or in developing countries. Coordination and collaboration with local health agencies to understand and communicate results of FLT and the presence or absence of any related public health impact is important to a successful eruption response. We will present our methods for adapting the FLT to an observatory setting including utilization of local resources, development of communication plans, and rapid assessment of ash leachates in remote locations. We will also show how the FLT results correlate with those of other published ash leaching protocols.

2.7-P-09

Pyroclastics and Power – Quantitative Testing of High-Voltage Transmission Systems to Volcanic Ashfall Hazards.

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High voltage electrical transmission networks are vulnerable to interruption due to volcanic ash-fall contamination. Depending on variable conditions, the most common problems arise from supply outages due to insulator 'flashover', controlled outages during ash cleaning, line breakage and tower collapse and the breakdown of air conditioning/ cooling systems/ diesel generators in substations and other types of housing caused by air intake blockage and corrosion.

While ample anecdotal accounts and information exists, little quantitative data has been gained from research of this kind. Research at the University of Canterbury has identified the properties most significant in causing electrical breakdown of insulators, a phenomenon better known as 'flashover.'

Dry volcanic ash is highly resistant to the flow of electricity, however this resistance drops rapidly with increasing input from influential parameters. The major parameters being explored include grain size, surface ionic content (soluble volcanogenic salts), moisture content, and compaction. Preliminary results show that under testing conditions electrical resistance reduces with increasing grain size, ionic content, moisture content and compaction rates. Contamination testing has shown that dry ash does not compromise the integrity of insulators however a preliminary exercise demonstrated how the flashover voltage for an insulator coat-

ed with 2mm of fine-grained (105µm) 0.18M NaCl basalt wetted with a hand sprayer was reduced by nearly four hundred percent.

Current research includes live testing of high voltage insulators exposed to volcanic ash-fall and characterising the adherence of a range of volcanic ash types to insulators under different environmental conditions. This project will ultimately look to resolve some of the uncertainty involved in identifying the parameters most significant in causing ash-induced flashover on high voltage transmission systems.

2.7-P-10

Mitigating Tephrafall Damage: Lessons from the 1991 Pinatubo Eruption, Philippines

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Most of the 847 fatalities of the climactic, VEI 6 Pinatubo eruption on 15 June 1991 were killed by roofs collapsing under accumulating tephra. Many of the fatalities could have been prevented. Government volcanologists and meteorologists could have coordinated more closely before the eruption. A tephrafall hazard assessment did not take into account the possible effect of passing typhoons; one fortuitously passed nearby during the climactic eruption. It greatly modified the tephrafall distribution, and its rainfall soaked the accumulating tephra on roofs, greatly adding to its weight. Intimidated by continuous dramatic but harmless cloud-to-cloud lightning and thunder, most civilian and military personnel did not clear roofs of accumulating tephra. Damage was especially severe in the U.S. Naval base in Subic Bay, despite the presence there of thousands of military personnel, who could have saved all the buildings and the billions of dollars of materiel they contained. Only in Olongapo City during the eruption were people actively advised by a contingent of volcanologists to ignore the lightning and sweep the tephra off their roofs. Even there, however, most public buildings such as hospitals, schools and markets were wrecked; better community planning could have assigned the duty of saving them to families with a surplus of the able-bodied. At the village level, roof sweepers should also be assigned to help people living alone, especially the elderly and the infirm.

2.7-P-11

Building Technologies For The Mitigation Of Volcanic Risk

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The object of the present paper is the definition of basic strategies and technical solutions for the mitigation of volcanic risk on buildings and infrastructures. The goal is to reduce vulnerability (and expected damages) on the built environment, considering both retrofitting ac-

tions and new buildings construction.

The destructive effects of eruptive phenomena as earthquakes, pyroclastic flows, ash fall and lahars can be strongly reduced by specific intervention on buildings structure and envelope.

The study proposes a design approach for the mitigation of risk, considering the cumulative effects given by the eruptive scenario and highlighting both technical and economical implications, through the definition of performance indicators for the effectiveness of each technical option and a cost-benefit evaluation.

Conventional solutions and innovative technologies, which include the use of advanced materials, must meet specific requirements of safety, reliability, durability and integrability. A specific attention is given to building site issues related to logistics and on-site operations, taking into account the need to make widespread interventions in risk-prone areas and preferring solutions – with equal performance levels – characterized by quickness and easiness of installation or by low operating costs.

2.7-P-12

Lessons from the 2008 Chaiten eruption on the early assessment of ash impacts

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The 2008 Chaiten eruption offered an unprecedented opportunity to assess the extent and impacts of volcanic ashfall from a large explosive eruption. A team of UK scientists arrived in Argentina within four weeks of the eruption, to map and sample the ash deposit and to collect environmental samples (e.g., vegetation, water and air quality samples) for the purposes of constraining eruption parameters and making an early assessment of ash impacts. We produced detailed maps of the deposit across Argentina (40°S-46°S) illustrating wide and complex dispersal patterns of fine-grained (<100 micron) ash, strongly controlled by variable wind fields. We further showed that ashfall resulted in an immediate measurable environmental impact, in terms of increased trace metal inputs to the environment. High levels of respirable ash, resuspended by vehicle activity and wind, were found to be persistent for at least several weeks following deposition. These early results have been useful to scientists working on the 2008 Chaiten eruption and to local agencies charged with management of subsequent ash impacts and hazards. To maximise the usefulness of these early assessments to understanding and managing the impact of fine-grained ashfall, we suggest that a standardised approach be followed in sampling. Furthermore, sampling information should be shared between groups (with priority) such that time-series can be established to better investigate the integration and degradation of the deposit within the surrounding environment.

2.7-P-13

Extracting Palaeo-Volcanological Reconstructions Of Explosive Eruptions From Limited Outcrops

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Many of the world's volcanoes are found in areas where limited outcrops of previous volcanic events are preserved (e.g. tropical rainforests and deserts). Hazard assessments in these areas require a new and different methodology compared to eruptions where there is a substantial record. The aim of this study is to determine optimum field measurement and sampling strategies in order to calibrate tephra dispersal models when there are few outcrops. The Minoan fall deposit of Santorini, Greece has been used as a focus for this study. Information on the grain size distribution and maximum clast size was collected from 2 proximal outcrops. The uncertainties in the field practices used have been evaluated in an attempt to constrain the most representative way of collecting data from a single outcrop. Maximum clast size has been determined by measuring the 5 largest clasts in different sized areas to determine the effect of area sampled on the largest particle measurement. The methodology for measuring maximum particle size has also been assessed. Uncertainty in field data can lead to discrepancies in the reconstructed plume dynamics, e.g. column height. The relationship between data from the two outcrops has been studied to extract the maximum information available for the reconstruction of the paleo eruption from a limited data set.

2.7-P-14

Estimating The Vulnerability Of Buildings And Occupants To Volcanic Ash Fall

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The damage to buildings from the accumulation of tephra on their roofs during major eruptions can constitute a large proportion of the impact and the cost of recovery. Human casualties can also result from collapse of roofs. The estimation of such impacts for scenario eruptions can be an important element of the planning for an emergency. The collapse load for an individual building depends on the accumulated tephra thickness, its density, water content, the form of construction of the roof and to an extent on the roof shape (roof slope etc). Previously reported work has proposed estimates of probable mean collapse rates for European building classes as a function of tephra load, based on the relatively small amount of post-event damage data available, supplemented by structural engineering calculations of expected roof resistance. Estimates of likely levels of human casualties from roof collapse have also been proposed. However, for risk calculations it is important to know the uncertainty of the estimated vulnerability. In two recent projects (MIA-VITA, 2008-2011) and SPeeD (2007-2009) the previously published vulnerability functions have been reviewed, and an approach to the definition of uncertainty for both collapse vulnerability and human vulnerability proposed, while the range of building types has been extended to those found around a

number of non-European volcanoes. These revised vulnerabilities are presented and the implications of these findings for mitigation and emergency management strategies are discussed.

2.7-P-15

Rehabilitation of Pasture following a Large Volcanic Eruption

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Volcanic eruptions produce unique, potentially severe, and often poorly understood impacts to agriculture. This study used laboratory, tunnel-house and field trials to quantitatively analyse the impact of moderate to thick deposits of ashfall and lahar debris to pasture and soils, and to measure the effectiveness of different rehabilitation techniques including tillage and fertiliser treatments.

Impact of variable ash thicknesses on pasture: Pastures were treated with 0, 10, 50, 100, 150, 200 mm of high-silica rhyolitic ash, and fine- to coarse-grained andesitic ash from the 2007 Ruapehu lahar sediment (chemically and physically analogous to 1995-96 Ruapehu ash). With >100 mm of ash the pasture was smothered; only at desiccation cracks was ryegrass able to grow through. Pastures benefited from 10 mm of lahar sediment with significantly increased growth compared to control pastures. However, at larger thicknesses (50-150 mm) pastures took-up very high levels of sulphur, selenium and manganese. These reached levels toxic to livestock and pastures in many cases. The Ruapehu lahar sediment also contained high soluble volcanic-derived salts (sulphates, chlorides, fluorides), which caused yellowing of all pastures for 2-4 weeks. No noticeable chemical changes occurred in soil or herbage samples from pastures treated with rhyolitic ash.

Germination of common pastoral seeds in volcanic media: Eight diverse but commonly used pastoral seeds were tested in germination trials to examine their performance in highly acidic fine and coarse 2007 Ruapehu lahar sediment and 1996 Ruapehu ash. Many seeds failed to germinate at all (despite control test giving >90% germination counts), but rape, annual ryegrass, and white and red clover varieties germinated successfully. However after 10-20 days, root development was inhibited in all varieties. A second round of testing found germination was improved by the application of lime to the sample.

Testing rehabilitation strategies: A field trial was carried out on an established pasture (clover and ryegrass mix) impacted by the 2007 Ruapehu lahar on the southern banks of the Whangaehu River in the Tangiwai/Ohakune area, New Zealand. Different rehabilitation treatments were tested, using a combination of re-seeding, mechanical cultivation and/or fertiliser regimes. The greatest value treatments were cultivation, which broke up the hard surface crust and provided good mixing of the lahar deposit, and high lime addition. Ryegrass, clover and rape could be successfully germinated, along with better soil fertility. Rainfall was an extremely important but uncontrolled factor. A further liming 4 weeks

after initial treatment significantly increased the soil fertility indicators and increased plant development. Without cultivation, there was nil germination, despite heavy liming and fertilisation. The highly acidic conditions had the same effect as in the laboratory germination trials, retarding initial root development during germination. Chemical analysis of rape plants from the field plot area below show very high sulphur, iron and selenium levels compared to those from a control plot 20 metres away. The high levels of these elements could be potentially toxic for ruminant consumption and are the focus of future work.

2.7-P-16

Protecting Water Supplies From Volcanic Activity: Lessons Learned

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It has been estimated that nine percent of the world's population lives within 100 km of a historically active volcano. Volcanic hazards (e.g. ashfall, pyroclastic flows and surges, lahars, lava flows and gas emissions) can cause damage and disruption to critical infrastructure such as water supplies, electricity distribution networks and transport and communications networks. Here we examine volcanic hazard impacts on water supplies, with a particular focus on volcanic ashfall as it is the most widely-distributed product of explosive volcanic eruptions, and areas hundreds of kilometres distant from an erupting volcano can receive ashfalls.

Many water supply managers have rarely, if ever, considered volcanic hazard impacts and thus there is limited knowledge about potential impacts and appropriate mitigation options. Volcanic hazards can lead to water shortages by: contaminating water supplies so that they are not fit for purpose (for instance, if they violate drinking water standards), increasing water demand for cleanup purposes and physically damaging components of water extraction, storage, treatment or distribution systems.

Impacts of water shortages can include health consequences such as infectious disease outbreaks caused by a lack of water for hygiene and sanitation problems. The security of water supplies can be a major factor in evacuation decisions. Water shortages are also likely to have consequences for the agricultural sector, as modern farming operations are critically dependent on water supplies. We draw on a wide range of case studies to illustrate volcanic hazard impacts on water supplies. The vulnerability of small, open water supplies to contamination from volcanic ashfall or aerosol deposition can be predicted on the basis of the dimensions of the system and its pre-existing water quality characteristics. We emphasise 'lessons learned' from the diverse case studies, and it concludes with a discussion of mitigation options available to water supply managers.

Session 3.1

3.1-O-01

Geological Mapping of the Andahua-Orcopampa's Volcanoes Valley, Peru

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The Valley of the Volcanoes of Andahua-Orcopampa is located in southern Peru. The volcanic field has been caused by a monogenetic volcanism type, which overlies a substrate composed of sedimentary and volcanic rocks of Pliocene to Jurassic age. This monogenetic field is emplaced over a graben valley type of 57 km long slightly sloping to the Andean address and controlled by NNW-SSE faults.

The Valley of the Volcanoes of Andahua-Orcopampa consists of cinder and lava cones, ash and cinder cones and extensive lava flows. These products are andesitic, basaltic andesite and basaltic composition. It has identified 21 cones, some of one symmetric conical and others partially destroyed by lava emplacement and erosion. The smaller cones with less than 400 m in diameter and 150 m high (Kallana Mauras, Jenchaña and Chilcayoc), while the larger cones are between 1,000 and 1,300 m in diameter and between 200 and 250 m high (Puca Mauras, Yana Mauras and Mauras). The lava flows travel mostly between 4 and 6 km away and have been expelled from fissure-type emission and central centers (craters). Lavas have been identified type "aa" lava blocks and a transitional range between the two types. The lavas have needle structures, disjunctions columnar and spheroidal, and minor cordate structures.

Based on geological mapping, geomorphological characteristics, as well as previous works (Delacour, et al., 2007, Sorensen and Holm, 2008, Cabrera & Thouret, 2000), it have been identified up to 7 generations of lava flows, emplaced between Late Pliocene and the Holocene. They also take 4 generations of cones from the Upper Pleistocene (10 cones), early Holocene and half (3 cones), Late Holocene (3 cones) and historical time (4 cones).

3.1-O-02

Volcanoes, Touristic Attraction

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Situated on the island of Tenerife, Teide National Park features the Teide-Pico Viejo stratovolcano that, at 3,718 m, is the highest peak on Spanish soil. Rising 7,500 m above the ocean floor, it is regarded as the world's third-tallest volcanic structure and stands in a spectacular environment Teide was in 2008 the most visited National Park in the Canary Islands and Spain, with a total of 2.8 million visitors, according to the Instituto Canario de Estadística (ISTAC). For this reason Teide National Park is a big touristic attraction. Beyond the basic objectives of facilitating and regulating protection, research, recreation and public education, the national Park aims to promote sustainable economic development programs

to benefit the surrounding communities. The park has an area of 18900 hectares and was named a World Heritage Site by UNESCO on June 29, 2007. Since the end of 2007, it has also been one of the Twelve Treasures of Spain. Teide is the most famous natural icon not only of Tenerife but also of all the Canary Islands. The visual impact of the site is all the greater due to atmospheric conditions that create constantly changing textures and tones in the landscape and a 'sea of clouds' that forms a visually impressive backdrop to the mountain. Teide is of global importance in providing evidence of the geological processes that underpin the evolution of oceanic islands.

3.1-O-03

The Kemenes Volcano Park, Hungary: from the Initial Plans to the Realization.

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This year, the Kemenes Volcano Park project has been approved and the realization of the plans could start soon. This will be the first thematic volcano park in Central Europe and as far as we know the third one in Europe. The initial plan goes back to the early 1990's, when the volcanological studies of the Ság hill revealed the complex history of the 5.5 Ma basaltic volcano. It is situated at the western part of the Pannonian basin (Hungary) and belong to the extensive alkaline basaltic volcanism of this region occurred between 11 Ma and 0.13 Ma. The remarkable volcanological features of the Ság hill as well as of the nearby extinct volcanoes provide a strong background for the volcano park. A detailed realization plan has been worked out in 2003 and this was the basis of the proposal of the Council of Celldömölk, the town next to the Ság hill. The plan involves a Volcano House at the foot of the Ság hill, where the visitors could get a general picture about the volcanic processes and the 20 Ma long history of volcanic activity in the Carpathian-Pannonian region. There is going to be an opportunity to take a journey into the interior of the Earth and to have a short visit in a magma chamber. The volcano-horror room will show the destructive force of the volcanoes and gives place for a memorial of the destroyed settlements from Pompeii to Plymouth. An important part of the volcano park will be construction of the Volcano path, which leads to the Ság hill and shows the main volcanological features. An open-air volcano-playground and rock exhibition could provide further opportunities to science education. The Kemenes Volcano Park as a touristic attraction could initiate the recovery of economy in this otherwise poor region.

3.1-O-04

A movement by the citizen of the Shimabara City after COV5 and a future vision of Unzen Volcanic Area Geopark

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The conference of "Cities on Volcanoes 5th" held on 2007 in the Shimabara City became one of the big advantage for the beginning as the geopark. The international conference accepted several hundreds of participates from abroad. It was successful by hard works of scientists and administrations, local volunteers. It became a chance of discover the local charms. We are making full use of original experiences of the volcanic eruption and the international conference to the geopark. The promoting office for the approval of a member of Global Geopark Network was formed in Feb., 2008. It consist of members from lacial governments and tourism facilities, museums and guide organizations etc.. The office was done preparation of the information guide and preservation of the geosites. And also, The making courses of geotours was done. Training for guides also is continuing. After the judge by GGN, We became a member of GGN and was got out the same assignments. Members of GGN are checked about the level of geoperk once during four years. If the geopark will not have a sufficient level, the geopark will not be a member. It is not sufficient of making a simple network in present. There are many geosites and museums for example, Mt.Unzen Dasaster Memiril Holl and Mt.Unzen vistor centor in our geopark. The gopark may be a good tool connected many institutions in future. We believe that the geoprk will be a big force for continual development in our region. We are also thinking that the aim of geopark is the education and preservation for the nature, and next sightseeing. We would like to make efforts that the big wave from the education of elementary and junior school will be generated. And we hope that the waves will move a wheel with continual developments.

3.1-O-05

The Xitle Lava Tubes in Mexico City, Conservation or Destruction?

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Southern Mexico City is built on the Xitle lava flows which were fed by a complex system of large multiple level lava tubes. The lava flows covered the pyramids of the Pre-Colombian City of Cuicuilco 2000YBP. The area is also home to a series of endangered species which include several cacti and agaves as well as small mammals. The area where the lava tubes are found is referred to as a protected area even on published topographic maps, but a new development is planned because of recent changes in land use. Landscape management in Mexico City has been very difficult due to the rapidly expanding urban area and a population of over 20 million people.

Tubes are found from 1 to 17 below the surface and at least 7 levees can be seen inside; stalactites, coalesced tubes, galleries more than 10m in diameter are some of the features which we are hoping to preserve. Resistivity tomography was carried out with Dipole-Dipole, Wenner-Schlumberger and Wenner-Wenner geometries with an Iris Syscal Pro Switch resistivimeter.

Electrodes were placed at a 3m distance on 125 m lines in a parallel array 25m apart. Inversion results confirmed the presence of new segments and tubes at depths of 5m thought to have been destroyed. Presently several conservation strategies are being attempted to reduce the impact of new constructions.

3.1-O-06

The Chaîne des Puys : A Rich, Unique Volcanic Heritage Environment

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The Chaîne des Puys is a unique alignment of 90 small volcanoes near Clermont-Ferrand, the Auvergne capital (French Massif Central). This potentially active volcanic landscape is an exceptional environmental, economic, cultural and educational resource. Such impressive variability of volcanic forms in a compact, perfectly-preserved alignment is an ensemble not seen anywhere else. Magmas vary from basalt to trachyte, and there are maars, tuff rings, scoria cones, domes, and different lavas. Ash layers blankets Clermont-Ferrand, and eruptions destroyed local prehistoric settlements. The ash is spread over Europe, making vital markers for archaeology and climate research. This intra-continental monogenetic field presents some complex volcanoes, best seen at the Lemptégy 'open-air' volcano that reveals a tortuous growth history, or at the Vulcania science park, an internationally acclaimed educational resource. The rich volcanic terrain is perfect for educational excursions. Volcanology research began in 1751, and the Chaîne hosted many major 19th century geological debates. Brunhes made his famous magnetic reversal discovery here. The Chaîne des Puys continues to provide scientific debate and, coupled with a rich interaction between landscape, human activity and the environment, this makes it a world-class volcanic heritage site, developing several innovative projects such as an ecological cog railway.

3.1-O-07

Fogo's Natural Park: Present and Future

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The existence of an active volcano in the park poses to all a feeling of uncertainty. In the 1995's eruption approximately 26% of agricultural land in Chã gave way little by little, the mantles of lava that destroyed everything that was on its way. This destruction of natural land, forces people to seek new areas for agricultural practices pressing the established habitats, the endemic species that exist as well as a geological diversity with great recreational and scientific interest. The geological diversity has great potential for the development of geoscientific scripts, which can enlarge the paleontological knowledge, with the priority given to the interac-

tion among the scientific community, the government and the population. So it's the responsibility of the park to develop educational, social and scientific projects in order for the people to understand the importance of conservation and what is being studied and preserved and why. In this way, we are encouraging eco-tourism, leading to the involvement of local people through economic activities that are not exploratory as well as to facilitate its use for studies of the schools by enabling multidisciplinary approaches. We believe that we will achieve these objectives by the creations of "geosítios" inside the Natural Park. With these "geosítios" is intended primarily to protect, educate and enhance the geological value of the Park, is expected also to recognize the importance of research and protection of the natural and cultural aspects of development as the park and the adjacent localities. In order for this to happen we have to bet on a number of drivers such as the certification of the communities products, the accommodation with all the genuine hospitality of the region, improving quality in tourism linked to nature and cultural heritage and ethnographic display mode of traditional products, rehabilitation and strengthening of traditions, recovery, signs and interpretation of a unique geological heritage in Cape Verde.

3.1-O-08

Volcanic Galapagos

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At the primary view one would like to share the description of the islands' most famous visitor, Charles Darwin, a biologist and geologist by profession, who stated that "Nothing could be less inviting than the first appearance. A broken field of black basaltic lava, thrown into the most rugged waves and crossed by great fissures which shows little signs of life". But Galapagos offers much more and not only on the second view. Above a restless hot spot, magma supply gives birth to new land to these islands, which fight against sea and land erosion for survival, providing simultaneously home for life in general and rare species in particular. Bizarre lava flows and several hundreds of smaller volcanoes above some of the biggest volcanoes on Earth are just a few of the many spectacular volcanic features the Galapagos have to offer. Closer examination reveals much more. An explanatory book, which will be presented at the COV6 gives many insights about how the Earth works, what kind of rocks we are stepping on, how volcanic explosions occur, how lava flows move, which volcanic hazards may threaten life in the Galapagos, how the volcanic islands emerged, what is the individual geologic development of each volcano, who discovered the island and who left a legacy, what role plays flora, fauna, humans and conservation on the islands, what is the importance of climate and weather for the archipelago. The actual and the past geodynamic situation of the Islands, their closest plate boundaries, and the types of volcanoes that exist are explored. The different life stages of the volcanoes in Galapagos are presented from their initial stage until their disappearance. Later the most plausible explanations are given about how life

originated, became preserved, and evolved differently on the Galapagos based on geodynamic explanations.

3.1-P-01

Valley of Volcanoes in Andahua, Geopark in Southern Peru Project.

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The Instituto Geológico Minero y Metalúrgico – INGEMMET has developing studies in areas of geological significance to promote the establishment of Geoparks. Some of these areas stand out for their geodiversity and volcanic landscape. One of them was denominated a natural wonder of Perú and is the Volcanoes's Valley of Andahua.

The Volcanoes's Valley of Andahua, is located 135 km from Arequipa, the second most important city of Perú. The geopark's area has altitudes between 1350 masl (Colca Canyon) and 5450 masl (Chila's Mountains). Here are located five districts of Castilla province with 13 000 people approximately. Its economy is based on agriculture, cattle, mining and fishing activities.

Volcanic activity developed during Pliocene, Pleistocene and Holocene, originated in the valley floor and hillsides, volcanic emissions and fissure-type products and Strombolian eruption. Fields of andesitic-basaltic lavas, 24 cinder/scoria cones, are superposed on alluvial fans of Upper Pleistocene, and a complex geological history comes from Jurassic.

Geomofologic, tectonic and hydrogeologic sceneries, sedimentary and igneous rocks and important epithermal deposits, are so important in the area because they had given the economic life for decades. Lakes or natural dams caused by lavas, canyons and waterfalls, resurgence of water and hot springs, mountains and structural hills, ancient strato-volcanoes and in general a domain of volcanic landscape. Increase the potential of the geopark, some pre-hispanic occupation remains, pre-Inca and Inca's agricultural production centers, diversity flora and fauna, ancestral ways and customs of their communities.

This majestic valley offers us their geodiversity, fertile grounds, culture and allows us to understand the volcanic hazards. To know, protect and do it sustainable with the help of the people from Alto Castilla, allow in a short time its postulation as Geopark, its geoconservation and convert Andahua into an important tourist destination.

3.1-P-02

Volcanic Geomorphosites and Sustainable Tourism: The Example of the La Corona del Lajal Volcanic Complex, El Hierro Island, Canary, Spain

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Geomorphosite as a form of the landscape with peculiar and significant geomorphological attributes, which qualifies it as a component of the cultural patrimony of a territory (Panizza, 2001). The volcanic forms constitute a component of the cultural heritage of a territory (historical monuments, works of art, spiritual places, etc.). In the volcanic regions people visit volcanoes for a variety of reasons, for example the fascination of being close to the power of nature. The aim of this paper is to illustrate the volcanic geomorphologic heritage of a monogenetic volcano based on the geomorphological and geomorphosite maps (Dóniz-Páez, 2009) and their natural, cultural and use values (Serrano and Trueba, 2005) and its possible relationship with the sustainable tourism. Mafic monogenetic volcanoes constitute the most common eruptive forms produced subaerial volcanism in the El Hierro island. 174 cinder cones are still well preserved on El Hierro contained in three volcanic rifts. La Corona del Lajial Volcanic Complex (CLVC) is a cinder cone located in the south rift of El Hierro island (UTM: 204117-3064424) and formed by a monogenetic basaltic volcano, several small scoria cones, local lava collapses, pond of lava and a spectacular lava field (pahoehoe, aa and blocks). In general, the CLVC is a volcanic paradise rich in spectacular geosites. The major economic resources of the volcanoes is tourism (Sigurdsson and Lopes-Gautier, 2000). La Restinga is the most important tourist zone of the El Hierro and it has the marine reservation (Punta Restinga-Mar Calmas). The tourists come to the La Restinga for diving tourism. Therefore it is possible to combine the diving tourism with that geotourism. In this sense, they can propose a several geomorphological itineraries for the different geosites of the CLVC. References: Panizza, 2001, SCB; Dóniz-Páez, 2009, Nimbus; Serrano and Trueba, 2005, Géomorphologie; Sigurdsson and Lopes-Gautier, 2000, EV.

3.1-P-03

Lava Trees and Tree Molds (“Cannon Stones”) at Mt Etna Volcano, Sicily

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Peculiar volcanic formations, known as “lava trees” and “tree molds”, form when a fluid lava flow runs over a tree, wraps around it and, while the wood burns out, solidifies forming a sort of external cast of the trunk that rests to testify this event. These formations are observed worldwide, even though the scientific literature is scarce on this subject. Basaltic lava flows, especially of pahoehoe type, produce the best lava tree molds, as testified by the abundant observations on the Hawaiian volcanoes. In the present work we point out that lava trees and tree molds can be observed also in Italy, on Mt. Etna, and that Etna is the only Italian volcano where they have been observed so far, and one of the few in Europe. Moreover, the formation of lava trees during the 1865 Etna eruption is among the first documented cases (Reclus, 1865; Silvestri, 1867). The sites where lava tree molds are exposed are located within the protected area of the regional Etna Park. They are named “pietre

cannone” (“cannon stones”) by the local inhabitants because of their cylindrical shape. Our aim is also to call the attention of the scientific community about their occurrence to encourage botanic and absolute dating studies on the burnt tree rests that frequently are found within them. These studies are important to give new insights to a better comprehension of the paleobotanic aspects of the Etna vegetation and to date eruptive events that were not eyewitnessed. Moreover, we are aware that these formations need to be protected and enhanced as part of the local natural heritage and, since they are reachable by walking trails, they have a high potential for geotourism. References: Reclus E., 1865, *Revue des Deux Mondes*; Silvestri O., 1867, *Atti dell’Accademia Gioenia di Scienze Naturali di Catania*.

3.1-P-04

The Volcanic Heritages in the Proposed Novohrad-Nógrád Geopark, Hungary-Slovakia.

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Devastating pumiceous ash-flows, submarine and subaerial lava flows, one of Europe’s largest coherent lava plateau, exposed subvolcanic bodies and volcanic vents, maars, diatremes, “petrified” gas bubbles, lava spatters, platy and columnar jointed basalts and andesites including a unique “andesite-slide”, garnet in the volcanic rocks and fragments from the upper mantle! The area of the planned Novohrad-Nógrád Geopark presents various volcanological phenomena, strongly associating with cultural and historical heritages: it is indeed a paradise for volcanologists, but also for visitors, who are looking for the exceptional relationships of nature and culture. Here, remnants of a 20 million-year long volcanic activity can be found on a relatively small area: basalts, andesites, rhyolites formed both by effusive and explosive volcanic eruptions. Due to the strong erosion, the deep structure of the volcanoes is now nicely exposed. The Geopark is - without doubt - an excellent place to have a unique insight into the nature of one of the Earth’s most important processes. The proposal of the Novohrad-Nógrád Geopark crossing the border between Hungary and Slovakia is under consideration by the Committee of the European Geopark Network and has a good chance to be approved soon.

3.1-P-05

The Morphological Features of the Abeque Volcanic Rift (Tenerife, Canary Islands) as Major Determinants of the Natural Dynamics and Present-Day Landscape of the Historical Volcanoes Garachico and Chinyero.

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The Abeque volcanic rift is one of the main relief units of Tenerife, situated to the northwest of the island, forming a long alignment of mountains over 1,500 m in al-

itude. This imposing ridge includes a large number of recent volcanoes concentrated in the higher sections of its wide slopes descending toward the sea. From these emission points, the lava flows spilled down the mountainsides as spectacular cascades of fire penetrating the ocean, or otherwise merely circulated around the summit areas, stopping after only a few km.

The morphological features of this rift have conditioned the location, local morphology and spatial arrangement of its most recent eruptive events, the historical volcanoes Chinyero (1909) and Garachico (1706). These are the result of fissure eruptions of basic magma with Strombolian eruptive behaviour, giving rise to pyroclastic edifices at their mouths and predominantly aa lava flows.

This study first establishes the geographic units of the present-day landscape of Chinyero, confined to the summit, and Garachico, located on the northern slope. The aim was then to demonstrate that the general morphostructural factors of this rift were also essential in regulating the spatial articulation of the transformative processes acting on their original appearance (plant colonization, rock weathering and modelling of eruptive forms), now that respectively 100 and 300 years have passed after the original eruptions. The age of the volcanoes has only a minor influence on the final result of this major natural geosystem.

3.1-P-06

Chinyero Special Nature Reserve (Tenerife, Canary Islands). Contributions from the geographical study of the landscape to its management and conservation.

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Chinyero Special Nature Reserve is located in the north-western summit of the island of Tenerife and covers an area of 2379.4 ha. This protected area includes Chinyero volcano, caused by the last eruption on the island in 1909, and also part of other zones visibly affected by eruptions, such as the historical volcano of Garachico (1706), the subhistorical Montaña Reventada (900 a 1200 AD), interesting examples of Canary summit scrub and some particularly beautiful *Pinus canariensis* forest. The reserve thus constitutes an area of great scientific interest, as it contains unspoilt landscapes representative of the original volcanic mountain environment of the Canaries.

The work presented here applies the results of an intense period of research examining the landscape geography of this sector of the Abeque mountain area. The landscape of a territory is the physiognomy resulting from a unique interaction in space of its constituent elements: vegetation, landforms, soil; and their use as natural resources by man. From this perspective, we present basic considerations on the spatial delimitation of the reserve and innovative ways of evaluating the landscape. These highlight the exceptional heritage value of this reserve and form the basis of this study method as an effective analytical perspective, essential for the proper management and conservation of a protected area.

3.1-P-07

The Geodiversity Map Of Vico And Cimino Volcanic Districts, Central Italy

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The Geodiversity Map of the Vico and Cimino Volcanic Districts (sc. 1:75000) has been realized by the Regional Agency for natural Parks (ARP-Lazio) in collaboration with the University of Roma Tre in the frame of a wider national and international project aimed at the conservation and management of the geological heritage. Within the project particular care has been devoted to the valorization of the "geological factor" as a fundamental contributor, in addition to the biological ones, to the landscape geodiversity of a given protected area. The preservation of the geological heritage is carried out through the institution of sites of particular geological interest (geotopes) where significant geological features are preserved and constitute key elements to the comprehension of the geological evolution of that particular area. The Geodiversity Map of the Vico and Cimino Volcanic Districts has been conceived with a twofold aim: i) create the first Italian prototype of geodiversity map in volcanic areas and ii) the promotion of geotourism as a sustainable resource for local economies resident in the Vico-Cimino area. The map has been designed to be easily accessible to non specialists and its legend has been structured in a versatile fashion in order to be applied also to areas characterised by different geovolcanological features. Nonetheless the map still preserves first order information such as lithology, geomorphology, stratigraphy of the volcanic products and the underlying sedimentary basement and the location and classification of geothermal features that may serve as basic tools for landscape/administrative planners and managers.

3.1-P-08

Toya-Usu Global Geopark, Japan - A Changing World of Lava Domes in Front of Us

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In August, 2009, "Toya Caldera and Usu Volcano Geopark" was designated as one of the first three Global Geoparks in Japan together with Shimabara and Itoigawa. It is the first Global Geopark of active subduction volcanism. The area covers ca. 1180 m² consist of four municipalities (Date/Toyako/Sobetsu/Toyoura). Most area is inside the Shikotsu-Toya National Park.

General geology consists of pre-Toya basement, 0.11 Ma old Toya caldera, 50 Ka old Nakajima, and ca. 20 Ka old truncated strato volcano Usu with young domes which grew up by the recent 9 eruptions since 1663. Volcanism gave us a prosperous land covered by the forests, cultivated lands & farms, rivers & lakes, good scenery, and even hot springs. Toyako Spa was originated from the Meiji-Shinzan crypto-dome intrusion 100 years ago. Recent eruptions also offer us an inevitable challenge living safely with the potentially hazardous volcano. Luckily, scientific research on volcano originated here even before the 1910 eruption, and had achieved significant development. 15,000 inhabitants successfully evacuated even before the onset of the 1910 eruption, and Prof. Omori proposed a promising idea of future eruption forecasting through the monitoring and basic research. The area offers a unique disaster park with many memorials such as "Great Graben Road", collapsed hospital, tilting/distorting houses, upheaved railway bridge basements, abandoned apartment invaded by hot mud flows. Visitors can stay here with a beautiful panoramic caldera view, hot springs, local farming/fishing products. Taking trails, ropeway, ferry boat, buses and rent car, you can enjoy visiting various stage of recovering process of recent lava domes and compare them with the original scenery and accumulated knowledge. This global geopark offers you a unique opportunities, how to become a friends of active volcanoes, and live together with their prosperous blessings towards less hazardous future.

3.1-P-09

A Geographical Information System model for developing countries

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Geographical Information Systems (GIS) have become recognized as one of the most beneficial ways to planning and management resources. Some applications of GIS are water distribution, electric, agriculture, transportation, environmental management, ecology and conservation, urban planning, emergency management and public safe, health care, education, commerce, tourism, industry, forestry or real state. A GIS can provide a spatial framework to support decisions but needs an accurate and updated knowledge of the territory. To satisfy this requirement GRAFCAN offers a solution set adapted to developing countries that includes basic geographical information production (maps, orthophotos and digital elevation maps), integration and normalization services, standard and interoperable data services startup, web viewers developing and hosting. A description of this solution and the successfully experiences in Mexico and Cape Verde will be the contents of this paper.

3.1-P-10

Canary Islands Spatial Data Infrastructure (IDECanarias)

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IDECanarias is the Canary Islands Spatial Data Infrastructure (SDI) according to INSPIRE, the Directive 2007/2/CE of the European Parliament and the Council. IDECanarias is a framework for planning and management in Canary Islands; a global, accurate and updated reference to know de territory. This Spatial Data Infrastructure allow users access to public free information via several services. IDECanarias web portal (<http://www.idecan.grafcan.es>) has system general information, news, documentation, tutorials, links and access to main services: IDECanarias viewer (<http://visor.grafcan.es>) and OGC services. IDECanarias offers Orthophotos, Topographic Maps, Streemaps, Digital Terrain Models, Historic Aerial photos (more than 150.000 since 1959) and a lot of Thematic Maps. IDECanarias was presented on May 26th 2008. At the end of 2009 more than 247 million WMS requests had been received. The system has received more than 1.600.000 request in a single day but the average response time remains 0,2 seconds per image. Daily users exceeds 1000.

3.1-P-11

Providing a Geo Tourism's Data Bank and Describing the Volcanic Potentials of Iran

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We are describing the volcanic geosites of Iran and examining the geotouristic potentials with the volcanic point of view. We have produced the geosites' data bank of Iran with the volcanic base and have described and examined the areas that they have the ability of the expansion and making a geopark. According to the geological specifications and tectonic complications and existence of the different geological periods, Iran is a good place for doing volcanic studies and it can be successful in geotourism industry by having geosites as Damavand, Taftan and Sabalan volcanoes, mud volcanoes, gas volcanoes and the other geologic specifications. Provided data bank of Iran's volcanic geosites is created by applying GIS and includes suitable information about sites such as geographical situations, geological information, geosites' specifications, photos and satellite's photos. This data bank can be applied to plan for Geosites' development and Geoparks' formation.

Session 3.2

3.2-O-01

Some Volcano-hosted Geothermal Systems in Western Pacific Belt

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Settings and hydrothermal activities of five high-temperature geothermal systems namely Kamojang, Karaha-Telaga Bodas (both in West Java), Ulumbu (Flores), Lahendong (North Sulawesi), and Tiwi (Luzon) are reported. They are located in topographically steep andesitic volcanic complexes which have not been active during historic time but nearby (5 – 20 km) are some presently active volcanic centers. The systems are expressed at the surface by fumarolic and steam-heated-type manifestations sitting within or in the vicinity of poorly-defined caldera structures, or craters, or flanks of an inactive volcano.

Thermal activity in Lahendong may have begun after 2.2 Ma, or as late as 0.5 Ma (Utami et al., 2007). Tiwi system started at 0.3 Ma (Moore et al., 2000) whereas Karaha-Telaga Bodas system began later than 6 ka (Moore et al., 2002). Kamojang and Ulumbu systems are not yet dated. The heat sources of all systems are likely magmatic. There are indications that the Lahendong and Tiwi systems are sustained by more than a single heat source emerging in different times.

The hydrothermal fluid is mainly of meteoric origin, but Karaha-Telaga Bodas which is located above an active magmatic vapor chimney, receives a considerable amount of magmatic fluids (Moore et al., 2004). Tiwi which is situated near the sea got an influx of sea water in the past (Moore et al., 2000). Hydrothermal alteration studies show that 1) variation in the systems's alteration mineralogy is independent of their original rock types; 2) distributions of their hydrothermal minerals are controlled by prevailing and past hydrology; 3) tectonic and volcanic activities control the changes of the characteristics of the system as indicated by mineralogical textures and other evidences. References: Moore et al., 2000, *Econ. Geol.*; Moore et al., 2002, *Proc. NZGW*; Moore et al. 2004, *Can. Min.*; Utami et al. 2007., *Proc. NZGW*.

3.2-O-02 - Keynote lecture

Utilization of Geothermal Energy at Kuju Volcano, Central Kyushu, Southwestern Japan

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Kuju volcano, which is a typical island arc volcano, is situated in central Kyushu, southwestern Japan. It has active fumarolic fields in the central part and also has many geothermal fields including hot springs around the volcano. We have four geothermal power stations in the Kuju volcanic region. They are Hatchobaru ge-

othermal power station (Installed capacity: 110MW), Otake geothermal power station (12.5MW), Takigami geothermal power station (25MW) and Kuju geothermal power station (2MW). They have been continuing stable generation of geothermal power. Otake geothermal power station, which was constructed in 1967, is the oldest "liquid dominated type" geothermal power station in Japan. Hatchobaru geothermal power station is the largest geothermal power station in Japan which was constructed in 1977. Takigami geothermal power station started in 1996. The geothermal reservoirs of Hatchobaru and Takigami have been well monitoring by repeat gravity measurements and they show good examples of sustainable development of geothermal energy. Kuju geothermal power station started in 1998 and it is owned by a private hotel. Geothermal hot waters are also used for rose-growing, cooking and space heating in the Kuju region. In addition, we have many hot spas in the region. Therefore the Kuju volcanic region is a good example of symbiotic relationship between volcano and geothermal energy utilization. Furthermore a large amount of volcanic heat is estimated in the deeper part of Kuju volcano and a method to extract such deep volcanic heat is proposed by using Downhole Coaxial Heat Exchanger. We have a future plan to extract such deep volcano energy not only for geothermal utilization but also for mitigation of volcanic eruption.

3.2-O-03

Magmatism and Geothermal System at Ungaran Volcano Central Java, Indonesia

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One of geothermal prospectus areas in Java Island is Ungaran geothermal field. Until now its status is still in preliminary exploration and is not developed yet. The potential of the geothermal energy at Ungaran is inferred about 50 MWe and is high temperature of liquid dominated system. It is featured by the occurrence of surface manifestation such as fumaroles, hot spring and hydrothermally altered rocks at the southern, eastern and northern flanks of dormant Ungaran volcano. Among those locations Gedongsongo area at the southern flank is the most active area. A lateral up flow was deduced due to the occurrence of travertine surrounding hot spring located about 10 km east of Ungaran volcano. Soil air gas survey indicated that the occurrence of manifestation is controlled by geological structure. Oxygen and hydrogen stable isotopes confirmed that the geothermal water is originally atmospheric water.

This paper reports the petrogenetic evolution of magmatism at Ungaran volcano and relate it with the geothermal occurrence at that volcano. The Ungaran volcano is divided into Young- and Old-Ungaran hav-

ing distinctive mineral assemblage and chemical composition. The Young-Ungaran is characterized by occurrence of sanidine phenocryst and higher potassium content than Old-Ungaran that is characterized by large hornblende xenocryst up to 2 cm long. Both Young- and Old-Ungaran magmas are categorized as high-K magma typical of back arc side magma in island arc. K-Ar dating confirm the age of Young- and Old-Ungaran of about 0.3 and 0.4 Ma respectively. This age of volcano is comparable to the age of volcano having geothermal system such as Wayang Windu, Karaha Bodas and Gunung Salak.

3.2-O-04

Carbon Dioxide Diffuse Soil Degassing: A Precious Tool For Identifying Productive Geothermal Reservoirs

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In geothermal exploration it happens rather frequently that deep wells find high temperatures but are not productive because they don't cross any permeable fractured reservoir. Because of the high cost of deep drillings, this aspect represents one of the main economic risk of geothermal exploration. The aim of this paper is to show that a detailed survey of diffuse CO₂ soil flux allows to identify from the surface the permeable portions of a deep-seated actively degassing geothermal reservoir, drastically reducing that risk. The first application of the method has been made in the Quaternary Latera caldera, North of Rome. We will show that productive wells were all located on high CO₂ flux zones, whereas the not-productive wells were sited on low flux areas. In addition the survey allows to identify some as yet unexplored portions of the geothermal reservoir where future wells should be conveniently located. The same technique has been applied in the geothermal exploration of Platanares and Azacualpa, Honduras and of Las Pailas, Costa Rica. Obviously, CO₂ flux cannot provide any estimate of temperature at depth, which has to be assessed with other geochemical or geophysical exploration techniques.

3.2-O-05

The Campi Flegrei Deep Drilling Project 'CFDDP': from volcanic risk mitigation to geothermal energy exploitation.

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Campi Flegrei caldera is a good example of the most explosive volcanism on the Earth, a potential source of global catastrophes. Alike several similar volcanic areas (Yellowstone and Long Valley, USA; Santorini, Greece; Iwo Jima, Japan, etc.) its volcanic activity is dominated by physical mechanisms involving the strict interaction

between shallow magma sources and geothermal systems. Furthermore, just like similar areas, it should be characterised by very large shallow magma chambers, filled by residual magma left after the ignimbritic caldera forming eruptions. However, neither the physical mechanisms of magma-water interaction, nor the evidence for such large magma chamber, are actually clear enough to be used for detailed volcanological interpretation and eruption forecast. Campi Flegrei caldera, with respect to many similar area, has the advantage that the most interesting structural details and main volcanic features appear located at shallower depth, making it a natural candidate for a deep drilling project aimed to understand the volcanic structure of calderas. The CFDDP project aims to understand, for the first time in a direct way by deep drilling, the location and rehology of large residual magma chambers and the mechanisms of interaction between magma and aquifer systems to generate eruptions and unrests. Furthermore, the direct, detailed study of the geothermal system for its whole length, will allow to extract crucial information about the geothermal potential and about the most fruitful strategies for geothermal energy exploitation in such a densely urbanised area. Just like the Icelandic Deep Drilling Project, in addition, Campi Flegrei deep hole will reach temperatures up to 500°C-600°C in layers where supercritical fluids are expected. Supercritical fluids exploitation can be considered the most powerful geothermal energy of the future, in hot volcanic areas. CFDDP is then also aimed to raise new interest in Italy for geothermal energy exploitation, which can become the real clean and sustainable alternative to fossil fuels.

3.2-O-06

Geothermal Development in Kenya

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Kenya currently has an interconnected installed electric power capacity of about 1143 MW_e which comprises a mix of hydro, geothermal, thermal, wind, gas turbines and diesel power generators. Out of this, geothermal energy currently provides 167 MW_e representing about 14% of the total installed capacity and 22% of power dispatched. The Least Cost Power Development Plan (2008-2028) prepared by the Government of Kenya indicates that geothermal plants have the lowest unit cost and suitable as base load and thus, recommended for additional expansion. The Geothermal Development Company which is a wholly Government owned company that was formed to fast-track geothermal energy development in the country targets to produce steam equivalent to 2,200 MW_e by 2020 and 4,000 MW_e by 2030 from the estimated available resource potential of 7,000 MW_e in the Kenya rift valley. All the high temperature geothermal prospects are associated with large Quaternary volcanoes most of which had last eruptions during early Holocene. The volcanoes are typified by eruptions of transitional basalt – trachyte – rhyolite alkaline suite. Studies using petrochemistry, gravity, micro-seismics and InSAR remote sensing techniques revealed that the volcanoes are underlain by shallow,

large, evolved active magma chambers. It has been interpreted that these magma chambers are the heat sources for the volcano hosted geothermal systems of the Kenya rift. Plans are underway to set up and maintain volcanic hazard monitoring systems at the volcanic fields.

3.2-O-07

Geothermal Energy Development, an Strategic Challenge for Canary Islands

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The world oil crisis of the 1970's led to the Spanish federal government to look for new energy sources to reduce external energy dependency. Geological Survey of Spain (IGME) was commissioned by the Energy Ministry to study the geothermal potential of the country. From the very beginning, Canary Islands were considered as one of the areas with higher potential for the development of geothermal energy due to the recent volcanic activity and the presence of surface manifestations. Several geothermal exploration activities were undertaken from 1970's to 1990's comprising geochemistry, geophysics and drilling; providing with a lot of scientific data and defining significant geothermal anomalies in several islands.

The growing interest of the private initiative for the geothermal energy caused the birth of the new high enthalpy section of APPA (Spanish renewable energy association). The main objective of this APPA section is to promote the development of geothermal energy within Spain and during the last years it is working on the definition of the geothermal potential of the country. This paper will be focused on presenting the results of this APPA study for Canary Islands. The document considers that Canary Islands have the highest potential within Spain to develop high enthalpy resources and it would be in a position to develop up to 250 MW of installed geothermal electric power by 2020. The report also shows that geothermal power generation could compete in price with power generation from fossil fuels or even be cheaper. This technology in contrary to another renewable is base load; this fact together with reduction of carbon emissions and external energy dependency makes geothermal development a strategic topic for Canary Islands.

3.2-O-08

Surface Geothermal Exploration in Different Volcanic Settings in the Central and Southern Andes of Chile

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Chile is located on the southeastern edge of the Pacific Ring of Fire and has three active volcanic chains along the Andes, from north to south: the Central, Southern

and Austral Andes. Volcanic centers and complexes have different eruptive histories, as well as tectonic and hidrogeological settings. Geothermal exploration therefore in Chile has an "extra" challenge related to these important differences on the settings of geothermal reservoirs. Here we present the preliminary results of surface exploration (geology, geochemistry and geophysics) in two volcanic areas: Pampa Lirima located in the Central Andes and Tinguiririca, located in the Southern Andes, ca. 1600 km north and 150 km south of Santiago, respectively.

Pampa Lirima is a small basin located in the Altiplano with a basal elevation of 4.000 m asl. Surface manifestations consist of a series of hot springs on the southwestern edge of the basin, where boiling waters (ca. 83°C) crop out through silica sinter deposits within a major alluvial/fluvioglacial fan. The closest "young" volcanic centers are located some 12 km to the northeast and consist of an oblique chain of Plio-Pleistocene dacitic volcanoes, from which there are no records of historic or even Holocene eruptions. Chemical geothermometers from chloride thermal waters indicate subsurface equilibrium temperatures of ca. 240°C.

Tinguiririca volcano (ca. 3.000, asl) is an andesitic edifice, which shows periodically fumarolic emissions in its crater. There is a historical record of at least one eruption in the XXth Century. Surface manifestations consist mainly on a series of mud pools, solfatara gas emissions and sulfate rich hot springs, most of them located on its western lower flank, strongly controlled by major NS striking faults. These major fault systems also control the basement structure, in this are formed by Upper Cenozoic volcanoclastic sequences. Geochemical data show subsurface equilibrium temperatures of ca. 260°C.

3.2-O-09

GEOFAR Project – Geothermal Finance and Awareness in European Regions

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The EU-funded project GEOFAR – Geothermal Finance and Awareness in European Regions, which comprises a consortium of institutes and companies from 5 different European countries, is being carried out within the framework of EU's "Intelligent Energy Europe" (IEE) program, which is part of the Competitiveness and Innovation Framework Program. The project GEOFAR aims to unveil the non technical difficulties and barriers which hinder the initial stages of geothermal energy projects and are responsible for the lack of this kind of investments in Europe. One of the main goals of GEOFAR is to propose workable solutions and to raise awareness on geothermal energy among decision makers, especially at regional level, in order to help boost new investments. Although many countries in Europe have a great geothermal potential and latest technological innovations now permit a much more efficient use of geothermal energy, the exploitation of this potential is still inadequate. This is mainly due to a lack of information among decision makers and investors, but also because of inappropriate funding schemes. GEOFAR

develops and proposes appropriate and innovative financing and funding schemes, raises awareness and disseminates knowledge and information among the different target groups. The GEOFAR project is divided in two parts: one part included the analysis, the findings and descriptions of the technologies and financing methods, while the second one deal with information dissemination. The results of the first part will be several reports on geothermal activities in selected countries, case studies, proposals for financial instruments, fact sheets about innovative geothermal technologies and the main outcome, financial schemes validated by experts. The second part is related to dissemination activities as a video documentary film, a website (www.geofar.eu) and a series of awareness seminars in four European countries and a major conference. With this broad dissemination GEOFAR aims at updating on a regular basis the various target groups in the different European countries. With the first part of the project almost finished, the obtained results will be presented looking to next steps and outcomes of the project.

3.2-P-01

Mapa Geotérmico del Perú

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The Andes Cordillera resulted from the interaction of the Nazca and the South American Plates. The subduction process occurring between both plates has controlled all geological evolution of such territory since Mesozoic to present time. In this context, magmatic and tectonic processes have allowed development geothermal environments with great resources to be evaluated and subsequently developed making a sustainable exploitation. Perú has a vast geothermal potential with many manifestations at the surface as hot springs, fumaroles, steam, all over the country. First geothermal studies began in 70's with the first inventory of mineral and thermal springs. In this work the Geothermal Map of Perú is presented in order to geographically define zones of the country where geothermal resources are located. Currently six important geothermic regions have been identified: Cajamarca – La Libertad; Callejón de Huaylas; Churín; Central; Eje Volcánico Sur and Cuzco – Puno. From the analysis of bibliographic information and field studies, it was concluded that in both, in northern and central Peru high temperature manifestations are product of the geothermic gradient, where the water flows across deep faults. Whereas in southern part geothermal manifestations are related to active volcanism. In this zone the hot springs are of mixed origin. Until now, most of the studies to characterize geothermal resources in Perú have been focused on the Eje Volcánico Sur zone, located in southern part where several locations with different geothermal importance have been recognized. High: Tutupaca, Calacoa, Maure, Laguna Salinas, Chachani and Chivay. Medium: Puquio, Parinacochas and Orcopampa. Low: Catahuasi, Coropuna, Caylloma and Mazo Cruz. Finally, it is important to mention the present status of investigation of geothermal resources in Perú is in the exploration stage. At this point the geothermal map developed constitutes a tool to follow

investigations and a contribution in the development of this environmentally friendly resource.

3.2-P-02

Surface Geochemical Survey for Geothermal Exploration in the South-East Zone of Tenerife, Canary Islands

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Water and gas sampling of natural discharges are the most common type of geochemical surveys for geothermal exploration. However, these natural discharges are generally scarce at geothermal exploration areas where the extent of the field is not known. Therefore, soil-volatile and soil-gas are becoming a useful geochemical tool to identify permeable areas and potential upflow or boiling zones. These surveys can also help to delineate the margins of a geothermal system, and often complement geophysical surveys particularly where their interpretation shows some difficulties. Recently, a surface geochemical survey of 577 sampling sites was undertaken in a ~120 km² area at the south-east slope of Tenerife Island. In-situ measurements of radon (²²²Rn) and thoron (²²⁰Rn) activities together with Hg⁰ and H₂S gas concentration as well as soil CO₂ and H₂S effluxes were performed at each sampling site. In addition, gas samples were taken from the soil atmosphere at 40 cm depth for subsequent chemical analysis by means of microGC and QMS (He, H₂, Ne, N₂, CO₂, CH₄, Ar and CO₂). At least two geochemical anomalous zones have been identified: (A) one close to Siete Fuentes-Fasnía historical vents (1704-1705 AD) and (B) located on the southwestern limit of the study area. Relatively high concentrations of H₂ and ΔHe as well as high H₂/Ar and He/CO₂ ratios were observed at both zones, indicating a clear evidence of the existence of an upflow zone with an important contribution of endogenous gases. Although both zones have significant geochemical anomalies at the soil environment, zone (A) shows a good spatial agreement with observed physical-chemical anomalies in the groundwater system below. The existence of a volcanic-hydrothermal system coupled with a vertical permeability structures could explain these geochemical anomalies observed in the surface environment.

3.2-P-03

CO₂ Flux and Soil Gas CO₂ and He Concentrations In The Reykjanes Geothermal System, SW-Iceland

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In summer 2007 a soil gas chemistry survey was carried out in the Reykjanes geothermal field, SW Iceland, which included measurements of diffuse CO₂ soil degassing and chemical analyses of the soil gas in more than 300 points in an area of about 0.25 km². The study had three main objectives: 1) to assess the effect of a 100

MW₆ geothermal power plant, commissioned in 2006, on CO₂ emissions through soil in the geothermal field; 2) to evaluate the applicability of soil gas measurements as a geothermal exploration tool; 3) to use the CO₂/He molar ratio to constrain fractionation of these gases on their way to the surface. The assumption was that calcite precipitation in the subsurface would decrease the CO₂/He ratio. Due to increased boiling in the reservoir as a result of sharp pressure drop in the reservoir, the diffuse CO₂ degassing through soil in 2007 had increased by ~40% compared to two surveys conducted before the commissioning to the 100 MW power plant. Fuzzy correlation was observed between CO₂ flux and CO₂ and He concentrations in soil gas. However, CO₂ flux and CO₂ and He soil gas anomalies on maps generated by sequential Gaussian simulations of the survey results are in good agreement with each other. Interpretation of CO₂/He ratios in soil gas was complicated by the fact that CO₂ has three sources in this environment (biologic, atmospheric, and geothermal) but He only two (atmospheric and geothermal). Several samples, collected on the margins of the geothermal anomalies had atmospheric He concentrations but elevated CO₂ levels. The CO₂/He ratio of most soil gas samples collected within the geothermal anomalies was scattered around the CO₂/He ratio of deep geothermal solution (~19,000) suggesting that CO₂ fractionation by calcite precipitation had not significantly affected the gas on its way from the reservoir.

3.2-P-04

Surface Geochemical Survey for Geothermal Exploration in the South Zone of Tenerife Island, Canary Islands

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Soil gases and volatiles studies have become an important tool to identify vertical permeability areas for the rise of hydrothermal gases in geothermal exploration in areas where no obvious surface geothermal manifestations are present. These surveys can also help to delineate the geothermal system margins, particularly where the interpretation and application of geophysical data is difficult. During July and August, 2009, a geochemical survey of soil gases and volatiles was carried out in the south rift zone of Tenerife Island, Spain, covering an area of about 100 km². In the 557 sampling site that were selected, soil CO₂ efflux, ²²²Rn and ²²⁰Rn activities and Hg⁰ and H₂S concentrations were measured in situ. Soil gas samples were collected at 40 cm depth for chemical (He, H₂, N₂, CO₂, CH₄, Ar and CO₂) and isotopic (d¹³C-CO₂) analysis. Soil temperature measurements

at a depth of 30-50 cm completed the survey. Spatial distribution maps of the analyzed chemical and isotopic species were constructed by means of conditional sequential Gaussian simulations (sGs). The observed geochemical anomalies at the soil environment have allowed the identification of areas with vertical permeability where a significant contribution of endogenous gases is observed. The main soil gas and volatiles anomalies were measured in the north and central zone of study area. Locations of these areas are in good agreement with the main volcano-structural characteristics of the study area. Geophysical and other geochemical studies are necessary to determine the existence of a volcanic-hydrothermal system, with a potential for geothermal exploration.

3.2-P-05

Surface Geochemical Survey for Geothermal Exploration at Virunga Volcanic Field, Rwanda

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Rwanda is one of the countries in Africa with potential for geothermal resources utilization. This is confirmed by the occurrences of surface geothermal manifestations such as hot springs in North-west Rwanda. In order to test and utilize the resource, the Rwanda Government in partnership with the German Government through the Federal Institute for Geosciences and Natural Resources (BGR) decided to explore and develop the geothermal resources in the volcanic zone in the northern part of Rwanda. During March-April, 2009, a geochemical survey of soil gas and volatile was carried out at Virunga Volcanic Field, Rwanda, covering an area of about 467 km². In the 877 sampling sites that were selected, soil CO₂ efflux and ²²²Rn and ²²⁰Rn activities were measured in situ. Soil gas samples were collected at 40 cm depth for chemical (He, H₂, N₂, CO₂, CH₄, Ar and CO₂) and isotopic (d¹³C-CO₂) analysis. Soil temperature measurements at a depth of 15 and 40 cm completed the survey. Spatial distribution maps of the analyzed chemical and isotopic species were constructed by means of conditional sequential Gaussian simulations (sGs). The observed geochemical anomalies at the soil environment have allowed the identification of vertical permeability areas where a significant contribution of endogenous gases is observed. The main soil gas and volatiles anomalies were measured in two main linear structures, one with a SW-NE direction and a secondary one with a NW-SE direction and perpendicular to the first one. These areas are located in good agreement with the main volcano-structural characteristics of the study area. A more detailed study at those areas showing surface geochemical anomalies might be desirable to constrain the existence of a volcanic-hydrothermal system, with a potential for use geothermal resources.

3.2-P-06

State of The Art of Geothermal Exploration in Chile, One Decade after the New Geothermal Law Enacted in 2000

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Geothermal energy is well-known worldwide, especially associated to volcanic chains or systems. Several countries located around the Pacific Ring of Fire are amongst those that generate more clean energy from geothermal sources, such as USA, Mexico, Indonesia, New Zealand. Despite this fact, there are currently no geothermal power plants in operation in South America. In the 60's and 70's, funded by UN and local governmental agencies, a series of exploration programs were carried out in several countries in South America; with different degrees of advances; however no power plants were built. Chile, a country located on the southeastern part of this Ring of Fire and being the second country worldwide with more active volcanoes, geothermal energy has a great potential, which has been estimated to be in the order of 3.500 MW to 12.000 MW. A new geothermal law was enacted in Chile in 2000 for encouraging local and international companies to develop geothermal energy. Due mainly to economic reasons (cheap gas coming from Argentina for generating electricity) no major development on geothermal exploration occurred until 2005. However, the decrease in gas supply from Argentina, together with the oil crisis and new governmental incentives, several companies, both national and international, started to develop geothermal exploration in 2006. Today, at least 10 exploration companies own some 20 geothermal exploration concessions and 4 geothermal exploitation concessions, given by the Government through application or bidding processes. Two projects have drilled deep geothermal exploration wells, and three others have drilled slim holes. Surface geothermal exploration has increased enormously in 2009 and seems to be the beginning of geothermal power generation in Chile.

3.2-P-07

Geothermal Development in Rwanda: Karisimbi Geothermal Prospect

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Given the frequent drought that affect the national hydropower, variation of fossil fuel prices in the world and the increasing demand for more power, geothermal energy offers an indigenous environmental friendly alternative to Rwanda today. According to the US Geological Energy Association (GEA, 1999), Rwanda's geothermal resources may be sufficient to provide 100 percent electrification of the country. Geothermal activity in Rwanda occurs as few widespread hot and warm springs and gas release in some springs. Previous geoscientific investigations indicate the Karisimbi volcano surroundings as zone of prime interest for geothermal exploration.

The Karisimbi volcano is part of the Virunga volcanic

complex which is located at the triple junction between the Republic of Rwanda, the Democratic Republic of Congo and the Republic of Uganda within the western branch of the East African Rift. Resistivity measurements detected a low resistivity anomaly along the SW flank of the Karisimbi volcano and gas geochemistry suggested structural controls as pathway for up flows of geothermal fluids. Subsurface temperatures above 100°C may be expected.

Session 3.3

3.3-O-01

Sabalan Volcano Lake: An example of Geotourism Potential in Iran

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Iran is one of a few countries in the world that due to its geographically superior statues enjoys a wide variety of beautiful natural and geological graces and Sabalan volcano can be considered as the gate to Iran's geotourism.

Sabalan volcano is a point type volcano bearing stratovolcan cone. Its height is 4800 m from sea level located in the western part of Iran. There is beautiful lake within its conical crater whose contents are ice and snow. Ice pillars around this lake are a great source of attraction. Sabalan lake volcano is one of the most attraction mountains regions of Iran and perhaps Asia. The slopes of this mountain in central part are related to Meshkin Shahr and Ahar cities in the north, Tabriz on the west, Sarab on the south and Ardebil on the west. Sabalan is like a beautiful volcanic cone which now its extinct volcano opening has changed to a lake. Hopefully the presence of geothermal power plant development produces a new tourist attraction in the Sabalan area and for this reason the natural recovery is extremely important over the vegetation and over the fauna to achieve the positive impacts.

3.3-O-02

The San Venanzo Volcano Park and Museum in the Frame of the Volcano Tourism in Italy

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Italy has about a million of people visiting its volcanoes due to their special concourse of Natural and archaeological resources. Notable examples are Pozzuoli Solfatara and Campi Flegrei, Vesuvius, Etna and Stromboli active volcanoes. The two latter pose questions about safety of tourists due to the casualties occurred in the past. Also the volcanic field of Northern Latium and Southern Tuscany, located in an area of large-calderas, are suitable for tourism purposes but present risks for large-volume releases of CO₂ and H₂S. Mefite vent in

Irpinia (Campania) is the largest localised emission of CO₂ and H₂S worldwide. Others volcanoes, such as Vulture and Pantelleria deserve more attention to a sustainable touristic developments. In addition, there are several smaller indoor and outdoor museums scattered throughout Italy. In the Umbria Region there are the Polino and San Venanzo (SV) museums. SV volcano has been famous since the XIX century for its kamafugitic lavas and for rare minerals. At SV, scientific and environmental information is facilitated by a open-air path and a museum. They shows both volcanological and mineralogical aspects as well as the peculiar flora. Some archaeological spots are also depicted. To facilitate the understanding of the SV park complex aspects, a volcanological museum has been created with laboratories, local and general naturalistic collections and several models which illustrate the nature of volcanic phenomena and their importance for the environment, wildlife and people living on a volcano. Eventually, economic interests conflicting with the park have been reconverted to sustainable activities and an increasing numbers of visitors has been recorded. SV attracts investors by mean of fine arts exhibitions, library and conferences, as well. A main effort for the networking of Italian volcano-related touristic centres is now ongoing and led by SV museum.

3.3-O-03

The Volcano, a risk of tourist attraction: example of cases in the Islands Canaries

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In the same way as the legal figures on preservation and conservation of natural spaces foment that these are used as resources of attraction of natural tourism, also the so called spaces "of Risk " are being formed as source of income in the area of the sustainable development. This one is the case of some volcanoes in the Canary Isles which presence, not only she identifies as spaces of danger, but it she helps to contribute important economic benefits. In this communication that I present, I want to announce three examples of volcanoes. The first one of them constitutes it the National Park of the Teide, which is formed as one of the most beautiful forms of the landscape tinerfeño. The construction of the National Inn of the Glens, the existence of Altavista's refuge to 3420m. of altitude, and the presence of a wide and varied offer for the accommodations in the localities placed in her proximities, more attractions make him be one local for his visit, in spite of being one of the places of major eruptive activity. The second example of volcanic space of risk demonstrates in Taburiente's Boiler, in the north sector of The Palm's island. Also declared as National Park, she spreads over a surface of more than 10.000 hectares and in the same way as in the Teide, she constitutes one of the zones of major attraction for the tourism in that island. The third example of space of analysis in our study, it shapes Timanfaya placed in the coast west of Lanzarote's island, with a surface of 5.107 hectares, and also declared as National Park, raises as one of the most spectacular volcanic and recent constructions, since

it was constructed from the eruptions that happened among 1730 and 1736.

3.3-O-04

Tourism and Volcanic Risk During Eruption - A Challenge Between Security and Local Economy

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Recent spectacular eruptions of the volcanoes Chaiten (Chile), Mayon (Philippines) and Soufriere Hills (Montserrat) have highlighted problems for tourism management during volcanic activity. More and more people are considering volcanic eruption as an attraction and for some of them even the associated danger has become an attraction while normally most people try to get as far away as possible when a volcano erupts. During the recent eruption of Mayon volcano, officials in the Philippines have expressed their amazement at the stupidity of tourists who were flocking in their thousands to fields around the dangerous volcano in order to take photographs of the spectacular lava flows. Specific security measures have been taken in order to mitigate the risk for tourists during this eruption. Montserrat also offers a very rare opportunity for volcano watchers to witness an active volcano from a safe distance, but sometimes tourists and photographers go to within the danger zone. The same problem exists for Chaiten volcano in Chile, where the Chilean state emergencies office ONEMI has felt the need to remind everyone that Chaitén volcano in southern Chile is still dangerous and kept the alert level at red, but more tourists are flooding the area. However, touristic business is very important in these countries. Due to growing numbers of tourists attracted by volcanic eruptions, it has become an increasing problem for the authorities how to combine tourism with security. It will be advisable to design special international guidelines and recommendations for visitors, tourism organisations and tour operators. Tour guides should have sufficient knowledge about Volcanology and should have emergency training.

3.3-O-05

Volcanoes & Stars: an Emotional Experience for Tourism at Teide National Park

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In recent decades tourism has become a major business. Tourist activity affects, in one way or another, hundreds of millions of people, and is part of the quality of life for many people in many different countries. Its good "health" is one of the indications of the economy overall. Noting the trends in recent years along with continued growth in visitors to the National Park, as well as overcrowding and other intervening factors such as the various seasons and weather conditions (snow for example), visitor awareness to avoid "the masses" of visitors, is why as tourism professionals we are obligated to seek other alternatives that will achieve a better approach in environmental education. As a result, in the

summer of 1997 the idea of a new route to the volcanoes in the National Park evolved. In the beginning it was only mildly accepted (there were only 795 visitors who opted for it at the time) but, gradually grew during the following years. The year 2009 (with about 25,000 visitors) became a reference point for some of the tour operators entering the program, as well as specialized firms in the sector, and even some sections of governments (municipalities, etc.). The TeideAstro objectives are: i) a more direct approach to the environment outside the overcrowded noontime activities; ii) perform field work about the volcano and the Parks nature in whole; iii) discover the differences in climate and landscape during the afternoon and evening; iv) explain the unique characteristics of the Canary Skies and their global importance with classes on astronomy and ethno-astronomy; v) stay longer than five (5) hours at the Park, being the only one who do this in Tenerife, and emphasizing the importance to the natural environment.

3.3-O-06

Volcanic experience: An innovation project for the touristic promotion of a volcanic area

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Abstract: Volcanic experience is a promotional movie for touristic attraction in Canary Islands, a volcanic area whose main economic resource is this industry. There are a large variety of volcanic formations and structures which form spectacular and impressive landscapes at these islands, also worldwide known by the quality of the sky for astronomical observations. This two key strengths have been used to design this promotional project that have been funded by the Consejería de Turismo del Gobierno de Canarias. In Volcanic Experience the volcanic phenomena in the Solar System is used as the conducting line for this film. Made with a documental stile and based on scientific information, it shows how in the Canary Islands we can find several volcanic features that are common at other planets of our Solar System. Volcanic experience combine art (an original musical work, poetry, photography) with scientific information coming from volcanological studies of the Canarian Archipelago and from discoveries obtained during the last NASA exploratory missions, Cassini and Mars Odyssey orbiter. A flight simulation over each one of the seven islands have been performed by rendering aerial views taken from an helicopter. Also a simulation of the Volcan del Medio, the active submarine volcano located between Gran Canaria and Tenerife islands have been performed. Finally, a comparison of several volcanic features such as giant shield volcanoes, volcanic alignments, deep valleys and canyons, or fumarolic activity of volcanoes are compared to similar features at other planets and moons of our Solar System. The final claim – The Universe is here – summarise the argument of the movie.

3.3-O-07

Volcanoes for the Non-Professional: Encouraging Tourism and Education

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The increase in popularity of adventure travel has made active volcanoes an attractive destination for the general public. Professional volcanologists are often divided when it comes to encouraging tourism on active volcanoes, however, national parks such as the Hawaii Volcanoes National Park have shown that it is possible to manage tourism in a way that is educational and relatively safe. In my book “The Volcano Adventure Guide” I chose to encourage the general public to visit volcanoes active and dormant, but emphasized the importance of understanding the general behavior patterns of volcanoes and of familiarization with potential hazards. Reception to the book, and to the concept of encouraging the general public to visit active volcanoes, has been strongly positive. Alternative ways of encouraging visitors include providing more detailed and up to date information about field areas on either books or websites. Websites are particularly useful for active volcanoes where information may become quickly outdated. Encouraging volcano tourism is a strong educational and outreach tool for volcanologists and visitors can at times provide useful information to professionals, particularly in remote places that are seldom visited. This talk will discuss the reception to the book, ways in which professional volcanologists may wish to encourage the visiting public, and ideas on making information available to a large number of potential visitors.

3.3-O-08 - Keynote lecture

Volcano Tourism: A Growing Demand for Active Volcanic and Geothermal Destinations

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Volcano tourism is becoming increasingly popular in many countries, as the fascination of people with active volcanoes has created a growing demand for this particular tourism sector. Destination promotion and information exchange via the Internet is contributing to a raised awareness about volcanic and geothermal environments. However, the academic literature rarely mentions tourism in volcanic regions, despite the fact that every year millions of people travel to volcanic and geothermal areas. With between 1300 and 1500 volcanoes currently classed as active, part of the attraction is the possibility of viewing volcanic activity, and it is not uncommon that some tourists are planning their travels around active volcanoes.

A large number of these fascinating landforms have gained in popularity on a global basis for a variety of reasons. Firstly, volcano tourism generally synergizes well with other forms of tourism such as hot spring tourism, geotourism, ecotourism and adventure tourism as well as cultural tourism. Secondly, volcano tourism includes leisure and recreational activities such as skiing, hiking and trekking, mountaineering and camping - a

perfect combination with the exploration of adventurous destinations. A third reason for the growing numbers of volcano tourists is the ease of access to remote destinations and the affordability for budget travellers, and a fourth reason is the growing interest in the natural environment, which includes the geosphere with its extraordinary natural heritage.

Specially organized volcano tours and expeditions reflect the sheer determination of a growing number of people to visit active volcanic or geothermal areas. To attract visitors of different interest groups, tour operators offer their customers what these are looking for - a diversity of adventurous trips with varying degrees of difficulty and risk factors - activity guaranteed under the guidance of trained volcanologists. Many active volcanoes are increasingly protected in national parks and world heritage sites, as well as in national and global geoparks, therefore volcano tourism comes in many different guises. In some cases people are not even aware that they are close to active volcanism, or they are touring active volcanic and geothermal environments as part of their trip agenda.

The fusion of tourism, geography/geology, the tourist quest for knowledge about the environment and the diversity of complementary landscape features make volcanic landforms very attractive to a broad spectrum of visitors. The coexistence of volcanic and hot springs is a common occurrence in many countries, even where volcanic activity has long ceased. As a result many areas are specializing in catering exclusively for volcano tourists, with accommodation being made available as close to volcanic and geothermal activity as possible. Whether active, dormant or extinct - volcanoes are major tourist magnets, because for many countries the revenue from volcano tourism means a substantial contribution to the economy. However, the main objective is to make volcano tourism as safe as possible by developing international safety guidelines for temporary visitors in active volcanic and geothermal regions.

This presentation is based research findings from our book about volcano tourism (Title: Volcano and Geothermal Tourism - Sustainable Geo-Resources for Leisure and Recreation) which is available in April 2010.

3.3-O-09

The Significance of Volcanoes for Tourism in Japan

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Volcanic and geothermal areas are becoming increasingly popular for travellers who are looking for unique experiences in unusual natural environments. Often located within protected areas such as national parks, geoparks or world heritage sites, volcanoes and their related features such as hot springs, geysers, sinter terraces and boiling mud ponds are integrated in the tourism sector in many countries worldwide. In Japan active and dormant volcanoes are part of everyday life in most regions and have their place in cultural festivals and ceremonies directly related to the volcanic environment and are attracting large numbers of tourist every year. For example since the eruption period of Mt Unzen (1990 - 1995) several tourism sites, including volcano

museums and memorial halls, have been established for the busloads of tourists who arrive on a daily basis. Education about potential hazards near active volcanoes is one of the objectives, but also the opportunity to talk with local residents about the disastrous events during the eruption period. Many active volcanoes are included in trip agendas in Japan - Mt Usu on Hokkaido is another example where tourists enjoy crater rim walks and the local volcanic hot spring spas, which are possibly the most important tourism drawcard all over Japan. This paper is based on years of research of volcano tourism in Japan.

3.3-P-01

The Salvatierra and Calatrava la Nueva castles: Two Remarkable Examples in the Use of the Eruptive Material in the Iberian Peninsula (Campo de Calatrava Volcanic Region, Ciudad Real, Spain)

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The presence of volcanic material from Campo de Calatrava has always been present in the daily lives of the inhabitants of this area, has been present from unmemorable times. Not only have taken advantage of its own landscape settings but have benefited from specific conditions given to them by volcanoes. In the eruptive history of Calatrava volcanism have created a series of distinct volcanic deposits, according mainly to their chemical composition and mineralogical, but also the type of eruptions that have generated. This continental volcanism is characterized by alkaline magmas very rich in CO₂.

Salvatierra Castle-38°39'57"N/3°49'17"W.

Located on the flank of Sierra de Calatrava, is an imposing fortified complex built by Muslims around the X century. Strategically built on a steep hill of quartzite, covering one of the most important natural routes that cross the Sierra Morena. It was adapted to the morphology of the terrain and using rocks for defense. On the southwest side of the castle is located the homenaje tower, about 12 meters high and built of quartzite, limiting the use of volcanic stone ashlar (spatter) to the most noble parts like door and window jambs.

Calatrava la Nueva Castle-38°39'57"N/3°50'42"W

This is an impressive fortress on a hill framed quartzite. Built between 1212 and 1217 is occupied by the Military Order of Calatrava. In 1931 it was declared National Historical Monument. Is a complex compound consisting of church, monastery, guest house, and external enclosure, all heavily fortified. The arches of the doors of the premises of the castle were made with red welded scorias (spatter); at the convent are interspersed with other welded lapilli cemented with carbonates, are bicolor arcs, alternating red and white. In the Church, the bow and rosette abroad were also made with welded lapilli. The interior is constructed entirely with blocks of basalt.

3.3-P-02

An Analysis of Visitors to Santa Pau Village and Volcanic Garrotxa Area (NE Iberian Peninsula)

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The Santa Pau village, with 1335 inhabitants and with an important number of tourist, is located in the Garrotxa Volcanic Area (NE Iberian Peninsula) and includes some of the main attractions of the area, as the volcano Santa Margarida or the Fageda d'en Jorda. It is a village with an interesting medieval historical center, which highlight the castle and the arcaded square. The study of the visitors to this village has allowed obtaining a clear image of the characteristics and visiting forms of the Garrotxa Volcanic Area. We analyzed the characteristics of the visitors, as well as the visited routes and the affluence flows in the different year seasons. We also examined the activities developed for the visitors during the stay in the volcanic zone, both for individual visitors as well as for group visits. All this allows obtaining a better knowledge of the use of this natural heritage and this will contribute to the better management of this volcanic area.

3.3-P-03

Volcanic Caves in the Galapagos

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Speleologically, Galapagos is one of the most important volcanic regions of the world. Almost one hundred volcanic caves are accessible in the island of Santa Cruz on the Galapagos Islands, Ecuador. Inside of most of the volcanic caves studied reigns absolute darkness and absolute silence with a fascinating, endemic living world of its own below the marvelous and charming world of the Galapagos. The importance of volcanic caves at Galapagos is therefore more than evident. Besides their geologic mysteries, deep inner parts of subterranean cracks and caverns open the view to an underground universe where plenty living, in a capricious lava-tube formed environment, cave-adapted creatures, mostly blind, colorless, and flightless, have discovered many unique ways of finding their food and finding their way. In this amazing ecosystem life is developed in constant evolution. The study of such cave-organisms has already brought curious examples of insular evolution into light, but their biological fragility remain to be extremely sensitive to human activities as shown by past and present insular activity. Some tube-trapped animals can be preserved and may serve for the reconstruction of past animal evolution even long after their extinction. The caves have comprised frequently paleontological deposits, due to their physical and climatic characteristics that have preserved bones up to present days. Some Holocene aged fossils are witnessing the extinction occurring by the arrival of man, such as in the case of the species *Megaoryzomys* (rodent), known only by preserved bones within the caves. It is speculated that

some time ago, the lava tubes constituted part of the animal habitat, some of them today extinct. Most of the paleontological sites at the Galapagos correspond per se to lava tubes. A systematic study of these lava tubes leaded recently to a volcanic guide, which will be presented at COV6.

3.3-P-04

Volcanic Caldera Lake Cuicocha in Ecuador and Associated Scientific Tourism

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The volcanic caldera Cuicocha in Ecuador is part of the extreme southeastern edge of the Ecological Reserve "Cotacachi-Cayapas". The reserve located in the Provinces of Imbabura and Esmeraldas represents one of the biggest (243.638 ha) protected areas in Ecuador and was created on the 29th of August 1968. The 3.2 km long elliptic shaped lake, which is originally known as Tsui-Cocha, the lagoon of the Gods, is located some 110 km north of Ecuador's capital Quito and some two dozens of km west of Ibarra, the capital of the Province of Imbabura. As this volcano represents today one of the most dangerous active volcano in Ecuador, it is still visited yearly by more than 150.000 tourists (up to 35% foreigners). Currently, the volcanic activity is represented by the upheating of its waters and a severe sublagunar fumarolic activity expressed by the gas bubbles in the lake and some dead vegetation due to the emission of CO₂ through the soils. However, the volcano can reactivate at any time. A unique flora and some extraordinary animals can be observed in Cuicocha's environment. There are more than 400 plant species between the lakeshore and the islands' mountaintops. The predominant varieties are medicinal, utilitarian and decorative plants and wildlife is abundant. Due to this environmental and volcanic circumstances, we decided to write a bilingual (English-Spanish) book entitled "Cuicocha - Lake of the Gods", which finally is more than a simple Geo- Volcanic-Biologic guide as it shall help to understand this fragile bio-diversity within one of the most dangerous volcanic areas in South America. This book, which will be presented at the COV6, is part of a "Geo-series of the CGVG" and was written because of the need for a simple, modern, comprehensive text with explanatory photos and graphics about the volcanology and biology of Cuicocha.

3.3-P-05

Natural Areas in Volcanic Islands: A Path to Sustainable Development.

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Volcanic landscapes constitute a strong claim for visitors from the old Europe. In addition, to its singular geomorphology, they have an important biodiversity and ethnographic original values, consequence of the adaptation of the population to such a hard reality.

All these ingredients conform an opportunity to carry out sustainable development strategies, which allow integrating economic, social and environmental aspects in a local scale. The application of measures directed to this type of development in such a fragile territory supposes a challenge, but also a responsibility of its managers.

The project that is being implemented in Tenerife Island has a global approach, based in stimulating the creation of a network of infrastructures of leisure associated with the natural areas. This net of equipments, which is sustainable, diversified, sure, attractive and with high quality standards, includes homologated trails, housings, biking and horsing itineraries, climbing routes and rappelling ravines, accessible routes and other complementary infrastructures. This network, under the umbrella of a responsible tourism, tries to revalue these volcanic territories, little-known by our visitors, and to generate new opportunities for the local development.

At present the first phase, which is being concluded, includes 7 Short Trails, 1 Local Trail, 1 Accessible Trail and 1 Long Trail, as well as communication and divulgation actions. In addition, several refuges and mountain lodgings are in project, as well as the conditioning of the rest of infrastructures.

3.3-P-06

TRANSVULCANIA II Ultra Mountain Trail, La Palma Island

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TRANSVULCANIA, II Ultra Mountain Trail – La Palma Island, is considered by many as the toughest mountain Ultramarathon in Canary Islands and will be held On June 5. Just after the conclusion of the first edition, 25 July 2009, the organization of the Ultra Trail du Mont Blanc (UTMB) has considered TRANSVULCANIA, II Ultra Mountain Trail – La Palma Island as a career, with a score of 2, of the 4 required. This distinction confirms the great potential that La Palma Island has, in terms of Landscape and Active Leisure. Spanish Tourism Institute - Tourespaña consider the island as one of the 5 most important mountain destinations nationwide. Four hundred participants participated in the first edition. They had to ignore the climatic conditions in the holding of the first edition, with winds over 50 km/h and temperatures over 35 degrees centigrade, and challenge the distance of over 83 kms and their own physical conditions to complete the 1st edition of this Ultramarathon. The tour deserved it, because the participants could enjoy a full morning in Volcano Route, traverse the boundaries of the National Park Caldera de Taburiente, enjoy the fabulous view of points higher elevations of the island, next to the Astrophysical Observatory of the Roque de Los Muchachos and appreciate the scenic

prints that offers a route from south to north along the ridge of the island.

3.3-P-07

Cueva del Viento Geological Park

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The Cueva del Viento is a lava tube located in the district of Icod de los Vinos that takes the same name (Tenerife, Canary Islands). In his more than 17 kilometers long (fifth in the world), three levels of different passages and beautiful geomorphological phenomena can be observed, such as pits, terraces and other lava formations. The Cabildo de Tenerife, through the Museo de Ciencias Naturales de Tenerife, acquired the surroundings areas in El Sobrado cave mouths. In the whole territory a path was established in which, more than a cave-show which also is, a guided tour is offered in which shows and explains what is a lava tube, as well as other geological phenomena and ethnographic aspects along the route. In the tour there are two geological units: 1) A thick phonolite lava flow (Lava channel), with lateral lobes. It belongs to Roques Blanco's eruptions that departs from the slopes of Pico Viejo and has about 1800 years old; 2) Outcrops of basalt plagioclase pahoehoe morphology in that the volcanicity cavity was formed. It corresponds to the first phase of Pico Viejo stratovolcano formation, and is dated in $27,030 \pm 430$ years. The opened section is located between two natural mouths of the cavity, so it is drafty and the risk of radon (Rn222) accumulation is minimized, related to the repeated exposure of the guides. The sector contains the sufficient variety of geomorphological phenomena to make it interesting if they are interpreted correctly and exposed by the guide (<http://www.cuevadelviento.net/>).

3.3-P-08

Islas Canarias Volcanic Experience: A Tourist Marketing Challenge for the Canary Islands

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The power of volcanoes has fascinated humanity for thousands of years, and it is no different today. Tourists flock to sites with particularly spectacular displays of volcanic activity despite the potential danger they pose. Therefore, an efficient volcano tourist marketing for any active volcanic region should consider not only to improve continuously the attraction efforts for the beauty of the volcanic landscape but also the safety program of the volcano destination. It is evident that the visitors' attraction will increase with a better knowledge on how volcanoes work to create these marvellous volcanic landforms. The effort to enhance and build up a volcanological cultural for the visitors, using quite attractive methods, will be always a big plus for the volcano tourist destination because it will help the visitor to read "the book" of the volcanic landscape. On the other hand, all visitors to volcanic environments need

to be made aware of the potential and individual dangers relating to a particular volcanic area regardless of the level of volcanic activity since they are usually not informed about the current risk management strategies for the local residents. Hence, the combination of Volcano Knowledge + Safety should be the best tourist marketing challenge for volcanic destinations. The poor volcano knowledge and the lack of information on volcanic risk management in the Canary Islands for tour operators and tour guides, travel agents, tourist organizations,...are the major weakness of the Islas Canarias Volcanic Experience product, and their can generate potential threats and reduce great opportunities for the Canary Islands as tourist destination.

Session 3.4

3.4-P-01

Sculpture In the Canary Islands. The Vacuolar Basalt as a Resource.

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Studying the pieces made by sculptors who have worked in the Canaries in different periods, we find very interesting examples of vacuolar basalt sculptures.

An overview allows us to realize that the use of vacuolar basalt in sculpture does not occur until the second half of the twentieth century. Prior to that, in sculpture and ornamental work, ignimbrites were used mostly from quarries of Arucas or Arico and trachytes from quarries of Granadilla, Santa Ursula and other places. However, the fine pore basalts (preferring because of it's high quality those extracted in Granadilla) are one of favourite rocks of sculptors in last decades. This change has been determined by the fact of the availability of Vidia tipped tools and tools covered by diamond dust, wich has made working with the material easier, a task that was very difficult to accomplish with the traditional tools.

Comparing the shape of pieces made of trachytes and ignimbrites with those made of porous basalt, we realize that the use of the basalt has led to the incorporation of hollows and thin or linear surfaces agreeing with the current aesthetics.

Photographs and comments of vacuolar basalt sculptures made by the following authors have been included: Plácido Fleitas, Tony Gallardo, Manolo Bethencourt, Roberto Martín, Paco Curbelo, Maribel Sánchez, Fernando Mena, Tomás Oropesa, Guillermo Batista, Manuel Cipelly and Ana Ruíz. Interesting examples of Canarian sculptors who have worked this kind of basaltic materials sporadically are Eduardo Gregorio and Enrique Cejas. Other foreign sculptors who have produced interesting pieces in this material are Ann Carlson and Hagbart Sóllos. Some emerging sculptors are also producing pieces in vacuolar basalt, including Isabel de Miguel and Máximo Magro.

3.4-P-02

Biodeterioration of the Volcanic Stones of Casa de Los Capitanes, San Cristobal de La Laguna

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In the Casa de los Capitanes of S. C. de La Laguna, a building that responds to the best Canarian style, with a Cultural Monument category with since 1981, we are conducting the study of biodeterioration, produced by fungal organisms in the main doorway and the window openings companions as well as the columns of the courtyard, all made of volcanic stone, red Toba removed from the quarry called Bishop's Quarry located in the space of the Mercedes. Once collected the samples, both the cover and the window openings of the facade and the columns of the courtyard have been taken to the laboratory where he has sown the seed of those on PDA, with the collection and isolation species of fungi: Cladosporium sp, Alternaria sp and others are under study. We are also studying which type of volcanic rock shows deterioration of this building, besides being produced by the human mishandling and environmental agents has been fueled by the performance of these pathogens. Therefore, our work contributes to value the importance of studying fungal in-volcanic stone materials and in particular Canary island of Tenerife, considering the vital importance within the field of conservation and restoration of heritage properties.

Session 3.5

3.5-O-01

Volcanoes Geotourism Potential, A Case Study: Hot water Springs of Sabalan Volcanoes (Northwest of Iran)

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Tourism sector is among the most successful industries in the world. In the world today, tourism has adopted a broad approach towards the issue of ecotourism. Geotourism as one of the specialized branches of ecotourism enjoys so much attraction not only for the experts in the earth sciences, but also for all those interested in nature.

Sabalan is large andesite stratovolcano, the second highest volcano in Iranian (4810 m) after mount Damavand. Sabalan volcano is higher than mount Balcin in the Alps, with many lakes & volcanic crater. The Mt. Sabalan region lies on the South Caspian plate, which under thrusts the Eurasian plate to the north. It is in turn under thrust by the Iranian plate, which produces compression in northwestern direction.

The volcano is quite old, as its rocks have been dated to 5.6-1.4 million years. Some references state that volcanic activity continued into the Holocene, less than 10000 years ago.

There are over 400 mineral and hot water springs in Iran. The majority and also the most important mineral and hot springs in Iran are in Azerbaijan province, especially Sarein region.

In Sarein area, there are eight hot springs: "Sabalan, Gav Mish Goli, Sari So, Hamam-e-Shagha, Ghareh Soo, Jeneral, Besh, Machilar and Ghahvehkhaneh". Kind of this water is hot Chlorine Bicarbonate and have high amount of Silica. Studying of mineral amounts in these springs show similar origin for them. Water temperature in these springs verify between 40 – 47 C°. According to its temperature, these waters are hypothermal water. Also Ph for this water changes in neutral range (5.8-6.2). Water flow from this spring is 5 – 80 liter per second.

This springs use for relaxation and could have alleviated nervous, rheum and orthopedic pain too. This subject caused to tourist attraction to this area. This improves the economic potential of this area.

3.5-O-02

Clay Minerals Reserve In Volcanic Rocks Of South East Gonabad (East of Iran)

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In south east of Gonabad town there is a small part of Eocene volcanic rocks . Petrographic and geochemical studies showed that their compositions are generally intermediate and are of Latite to Andesite rocks type that have changed into clay minerals. Volcanic rocks are origin clay minerals.

The XRD and XRF chemical and mineralogical studies on the Clay minerals indicated that their main clay minerals are Kaolinite, Illite, Allonite and Dickite. Pyrophyllite is minor clay mineral. They are identified with light color in the filed. Ratio of Al₂O₃ and SiO₂ are about 21 and 65 per cent, there are good for fire clay in industrial minerals

3.5-O-03

SWOT Balneology in the Canary Islands

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WEAKNESSES: Very few classified Waters. No regulation. Little aids an support concesión. Little experience. Difficulties in topography.

STRENGTHS: Sea. Pickles. Climate. Unique water. Historical burden. Medical Hydrology Professorship.

THREATS: Lack of new Inversions. Competition with another countries in Wellness Area. Social Security.

OPPORTUNITIES: Alternatives to tourism. Some kind of waters which are rejected for another uses. Abundance in several kind of waters. Another quality;

Radon. Social termalism. Rural termalism. Existence of markets. Creation of employment. Apogee of thermalism is coming back.

SURVIVAL STRATEGIES: To do researchs about some kind of waters which are rejected. To centralize the location of several therapies. To involve the Government through Health.

DEFFENSIVE STRATEGY: To take advantage of the uniqueness of water to eliminate competition. To take advantage of Medical Hydrology's Professorship to modify Social Security.

REORIENTATION STRATEGY: Staff education. Therapy's centralization. To give priority to therapeutic use and reuse water.

OFFENSIVE STRATEGY: To take advantage of balneotherapy's revival to promote unicity of climate and water. To combine balneology and rural thermalism. Open air bathing resort's construction. To use pickles before pouring them

ADVICE: To bring LA FUENTE SANTA into operation . To do studies about non-used waters, which flow in tunnels, including studies about Radioactivity and Radon. To study the use of desalinator's pickles as an element of balneoterapy. To involve the Medical Hydrology's Professorship to do researches about the use of water. The unicity of waters and the Canary Island's climate gives a new tourist potential of Health and well-being, in an increasing moment of this area.

3.5-O-04

Composition of Fuente Santa's Waters and their Volcanic Origin. Possible Therapeutical Uses and Ways of Application

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Fuente Santa was a hyperthermal running water located in La Palma Island (Canarias). Since La Palma Island was incorporated to Castilla in 1493 until 1677, when St. Antonio's Volcano's eruption buried it. It was the most famous thermal resort in the whole Atlantic Sea. After trying sixteen times to look for it, finally it has been recently rediscovered. After knowing its composition, I told they were chloride carbonated-gaseous waters, the only kind that cannot be found in Spain, and they are very similar to the famous Royat's waters, in France and Nauheim, in Germany, which are nowadays used in the intermittent claudication and other afflictions thanks to their vasodilatation power. Due to this property leprous and syphilis patients were relieved in the past. Composition is about 35 grams/l of Sodium Chloride; 1,5 grams/ l of bicarbonates, 396 mg/l of CO₂. Temperature is over 42°C. Presence of CO₂ and warm temperature are caused by volcanism. We can say that the composition of waters are similar to the chlorided waters of La Toja (very suitable for Rheumatology and wound healing), but also containing bicarbonates and CO₂ that give these waters special vasodilatation properties. Nowadays it is counter indicated the use of water resorts for infectious diseases, so the therapeutical application of these waters could be the following: Every kind of rheumatism, both Arthritis and Degenerative Osteoarthritis. Healing of sores and wounds. And it must be investigated in intermittent claudication and related

diseases and in hypertension. The way of application would be in bath both in pool and in sink. It has been known that two large sinks outside were used in the past, with different temperatures. It has to be studied the possible effect of Hipotension due to the peripheral vasodilatation and check the counter indications.

3.5-O-05 - Keynote lecture

Groundwater in Volcanic Islands and Its Development

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Groundwater in volcanic islands depends entirely on precipitation infiltration. Aquifer recharge is the result of the balance in the soil, in some case in almost bare land. Groundwater flows through an often complex hydrogeological system and discharges partly through springs and partly diffuse along the coast. In small, high permeability islands most of discharge is to the sea but in complex islands with high rainfall, temporal or permanent perched springs may form, although high altitude springs from elevated water tables are common situations when there is a low permeability volcanic material core. Then, for hydrogeological purposes it is important to distinguish between intracaldera and extra-caldera volcanic formations, as well as to consider the role of volcanoclastics and associated sediments. Groundwater salinity and chemical composition is a compound of climatic effects and volcanic rock weathering near the surface, but where deep volcanic gases are present important changes may be added. Along the coast, with variable penetration into the island, the mixing zone between island water and marine water may be quite thick. Often the main groundwater use is through tapping springs and in the coastal low altitude areas by means of small penetration wells to avoid saline upconing. However in some islands, such as the Canaries, extensive water works at mid and high altitude have been developed to obtain groundwater. They consist mostly on long horizontal tunnels –water galleries– and deep, large diameter shaft wells, and more recently deep drilled boreholes. This has often resulted in a conspicuous groundwater level drawdown that oblidges to progressively extend the water works to maintain the yield, at an increasing cost and sometimes a water quality loss, increased seawater intrusion, and drainage of the upper more permeable volcanic formations. This has been a long transient evolution to new water supply systems that combine groundwater catchment with increased surface regulation, water blending, brackish water treatment through reverse osmosis, seawater desalination and water reuse.

3.5-O-06

Volcanic Hot Springs – Health Benefits and Visual Attraction

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People are often unaware of the origin of natural hot springs. While in some countries they are derived from artesian basins (e.g. Argentina, Uruguay and Australia) the majority of geothermal springs are of volcanic origin. However, it is common knowledge that natural hot springs have a curative value due to the dissolved minerals and trace elements they contain. The history of hot spring use relates many stories, commonly linked to a legend based on divine intervention related to a particular hot spring which cured either illness or injury. This well-known reputation of natural geothermal resources for healing encourages hot spring tourism worldwide, with ever growing numbers of people spending time at health and wellness spas based on volcanic hot springs. In Australia and New Zealand for example geothermal resources are being increasingly explored to determine whether they can be accessed for future development of medical or wellness facilities. Yet, the focus is not only on the integration of hot springs in health and wellness spa tourism; particular attention also needs to be given to those geothermal attractions which are a common by-product of volcanic activity with a high visual appeal, such as geysers, boiling ponds, sinter terraces or hot waterfalls. At this point risk management and visitor guidelines for such geothermal attractions should be in line with safety guidelines for volcano tourists, which so far only exist on an individual basis in some national parks. The main objective of this paper is to discuss how the management and maintenance of natural resources such as volcanic hot springs may be carried out in a responsible manner to protect them for continuous future use while broadening their appeal to tourists.

3.5-P-01

Hazard or Resource? People's Behaviour in the Face of Lahar Onslaughts and Implications for Disaster Risk Reduction

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There are two ways for looking at people's behaviour in the face volcanic threats. The first is hazard-centred and considers that people behave according to their perception of volcanic phenomena and associated risks. The second is hazard-independent and argues that people's behaviour is constrained by social, economic and political forces beyond their control. The present contribution explores both hypotheses through the particular lens of people's behaviour in facing lahar onslaughts. It is based on extensive field works conducted around Mt Pinatubo (Philippines), Mt Merapi (Indonesia) and Mt Karthala (Comoros) with additional insights from

Taal and Mayon volcanoes (Philippines), and the island of Fogo (Cape Verde). The study demonstrates that in most instances, people are fully conscious of the threat but rather consider lahars as a resource. Lahar sandy materials are indeed easily collectable and of significant economic value for people who struggle for making a living on a daily basis. Therefore, people living in the vicinity of active volcanoes consciously face the threat of lahars to be able to sustain pressing everyday needs. Ultimately, the behaviour of people confronted with volcanic threats is strongly tied to the strength, diversity and sustainability of their livelihoods. Reinforcing and protecting people's livelihoods should thus be a primary concern of disaster risk reduction policies in volcanic environment. Such policies require a strong involvement of local communities in both the evaluation of disaster risks and the planning of mitigating measures through Community-Based Disaster Risk Reduction (CBDRR).

3.5-P-02

Economic Potential of Volcanoes Activities, A Case Study: Khonj Bentonite Mine Formation (Northeast of Iran)

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Khonj Bentonite mine with area about 15 km² locate in Khorassan Razavi province in the east of Iran. Lithology exposes of the rocks is consist of Shale and Sandstones (Jurassic), Limestone and Marl (Cretaceous), Andesite and Dacite (Oligomiocene), green sandstone, Andesite, Tuff, Argillite and Conglomerate (Eocene). From geological viewpoint, a Bentonite horizon with 10 m and more thickness have been extended in mine area and have been formed more than 1800000 ton Bentonite. Forming of this Bentonite horizon is because of acidic submarine volcanism activities and part of silicate rocks, Montmorillonite, Tuff and volcanic ash with Eocene age. These complexes in diagenesis level undergo mineralogy changes and after that have been affected by surface weathering. Bentonite horizon divides to 4 classification super quality, high, normal and low quality. Mineralogy studies by XRD analysis show that main former mineral phase of Bentonite is consist of Montmorillonite, Crystobalite, and Calcite and secondary phase is consist of Quartz, Albite and Gypsum. Chemical analysis result by XRF show that Khonj Bentonite is Soda type as maximum amount of Na₂O is about 3.29% while maximum amount of K₂O is less than 1.51%. According to chemical and physical test result like acidity (Ph~9-10) and absorption index (597-705), best application for this Bentonite is using in sinker and found industrials.

3.5-P-03

Bentonite a Volcanic Rock with Wide Range of Uses and Applications from Eastern Iran

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The term Bentonite was first used for a clay found in about 1890 in upper cretaceous tuff near Fort Benton, Wyoming. Bentonite consists of montmorillonite, quartz ± feldspar ± cristobalite ± calcite ± gypsum ± halite. The presence of these minerals can impact the industrial value of a deposit, reducing or increasing its value depending on the application. Chemical composition of montmorillonite (Ca-Na-K-Fe) determine the special properties of bentonite (hydration, swelling, water absorption, viscosity, thixotropy) make it a valuable material for a wide range of uses and applications. In Eastern Iran, during tertiary time extensive explosive volcanic activity produced waste amount volcanic ashes. These ashes were deposited in saline lake and due to alteration montmorillonite and other minerals were formed. Chemical composition of montmorillonite and presence of other minerals control by magma and saline lakes. At the present time, more than 20 bentonite mines are active in Eastern Iran. Bentonite from Eastern Iran has verities of application such as: 1- Foundry: Bentonite is used as a bonding material in the preparation of molding sand for the production of iron, steel and non-ferrous casting. 2- Drilling: bentonite is as a mud constituent for oil and water well drilling. 3- Environmental Markets, Bentonite's adsorption/absorption properties are very useful for wastewater purification. 4- Pelletizing: Bentonite is used as a binding agent in the production of iron ore pellets. 5- Construction and Civil Engineering: Bentonite in civil engineering applications is used traditionally as a thixotropic, support and lubricant agent in diaphragm walls and foundations, in tunnelling, in horizontal directional drilling and pipe jacking. 6- Oils/Food Markets: Bentonite is utilized in the removal of impurities in oils where its adsorptive properties are crucial in the processing of edible oils and fats (Soya/palm/canola oil). 8- Agriculture: Bentonite is used as an animal feed supplement. 9- Pharmaceuticals, Cosmetics and Medical Markets: Bentonite is used as filler in pharmaceuticals, and due to its absorption/adsorption functions, it allows paste formation. 10- Detergents, Paints, Dyes and Polishes, Paper, Catalyst.

3.5-P-04

A Study Of The Relationship Between Natural Resource Exploitation And Societal Development In Volcanic Regions.

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Other natural resources in volcanic environments

Discussions of regions of active volcanism have often questioned the use of the term 'natural hazard'. Whilst such areas pose a threat to millions of people across the globe during periods of explosivity, in times of quiescence they can provide an endowment of economic gain to societies.

The ability to practice livelihoods profitably can greatly empower communities at risk to natural phe-

nomenon and is a leading factor in controlling decision-making and responses to volcanic hazards in particular. However, in reaping the rewards of these unique landscapes, this research asks if those communities in question generate further risk through the extraction of resources in their region and what can decision makers do to manage that risk that does not result in stalling that regions development?

Compared to other natural hazards which yield little or no resources; volcanism can work positively to drive development forward where other natural events can put it back decades. Although agricultural opportunities provided by the fertility of volcanic soils have frequently been discussed, less so has the extraction of natural resources produced by active volcanism such as sulphur, bentonite and pumice. This study will look at the significance of those volcanic resources in contrasting regions of the world and question the opportunities those industries present for people's lives and livelihoods.

To date the field of Disaster Economics remains small, often criticized for over simplifying what are usually very complex social systems and failing to build a comprehensive viewpoint on which to base decision making. This research seeks to provide a series of tools to help assess the effects of volcanism on regional economies and provide ways in which to value those resources being exploited. In doing so this project aims to look towards what social targets volcanic management programmes can work towards to protect communities and their socio-economic activities.

3.5-P-05

Geothermal Geochemistry And Potential Health Hazards Of The Sulphur Springs Geothermal Field, Saint Lucia

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Sulphur Springs Park in Saint Lucia is a site of vigorous geothermal activity associated with the potentially active Soufrière Volcanic Centre. The Park is one of Saint Lucia's most important tourist attractions, and is marketed as the 'world's only drive-in volcano'. It has an on-site staff of tour guides, and over 200,000 visitors annually. Moreover, recreational use is made of the geothermal waters for bathing, and in some cases drinking. As part of an overall volcano monitoring program for the island, its numerous volcanic emissions (hot springs, mud pools and fumaroles) have been regularly monitored since 2001. In recent years, the Park's managers have expressed concern about the health effects of exposure to volcanic emissions at the Park. In response to this, we expanded our regular geothermal monitoring program to include a preliminary evaluation of potential health hazards. Overall, the geothermal waters are acid-sulphate in character, resulting from the dissolution of acidic sulphur gases into waters of mainly meteoric origin. The gases have strong hydrothermal signatures, being dominated by carbon dioxide, with hydrogen sulphide as the main sulphurous gas. The reservoir temperature of the Sulphur Springs geothermal system derived from mineral chemistry is estimated to be ~150°C, with

deeper temperatures of 180°C – 280°C being revealed from the evaluation of molar ratios of CH₄/CO₂ and CO/CO₂. Chemical analysis of the waters being used for recreation in the Park reveal that concentrations of Pb, Cd, Fe, NO₂, and Al exceeded the USEPA's safe drinking water standards. In-situ monitoring of SO₂ concentrations indicated occasional spiking over 5 ppm, which can result in short-term health effects including irritation of the skin, and the tissues and mucous membranes of the eyes, nose, and throat. These results may be used in the development of guidelines for recreational use of the geothermal waters at Sulphur Springs.

3.5-P-06

The Potential of Tenerife's Groundwaters for Therapeutic and/or Thermal Use

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The beneficial properties of natural waters to health have been known for over 2,000 years by different civilizations around the world. In the last decades a resurgence of spas and health centers that use therapeutic mineral waters is blooming in many parts of Europe and mainland Spain. Tenerife (2,037 km²) with ~1 million inhabitants and ~ 3-4 million tourists visiting each year attracted by its unique natural and climatic conditions has a potential to diversify and enhance this tourist attraction highlighting the special characteristics of its groundwater resources with a clear volcanic "fingerprint". Due to the interaction between deep-seated CO₂ (HCl, H₂S, SO₂)-rich volcanic gases, host rocks and groundwater, they acquire a physical-chemical and radioactive characteristics that may be potentially useful from therapeutic and/or thermal point of view. Due to lack of specific studies in the Canary Islands on this issue, the Centro Canario del Agua carried out a study at Tenerife island where 10 groundwater observation sites were selected and analyzed based on their abnormally high values of electrical conductivity, temperature, bicarbonate, sulfate and/or chloride. Electrical conductivity, pH and water temperature was determined in the field and different samples were taken to laboratory for the analysis of major ion components, silica, minor and trace elements, natural radioactivity, and a complete micro-bacteriological analysis. Most waters are Na-HCO₃ type, although Na-Mg-HCO₃ and Na-Mg-SO₄ waters were observed, and even a Na-Cl-SO₄ water. Relatively high Al, Fe, Sr, Mo, B and Hg concentrations, and b-radioactivity levels between 0.1 and 3.2 Bq/L (always below maximum permitted levels), were observed in some groundwaters. Overall, 9 of 10 analyzed natural water samples can be classified as minero-medicinal waters and 6 of them are thermal waters. Such studies, although should be expanded with a higher number of natural water samples, shows that there is a potential therapeutic and/or thermal use of Tenerife's groundwaters because of its volcanic nature "fingerprint".

3.5-P-07
Physical-chemical Characterization of Las Cañadas Volcanic Aquifer Through Geochemical Models.

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At Tenerife Island (537 inhabitants/km²), ground waters represent more than 90% of water resources. These aquifers are possible because there is large porous volcanic structure that allows the infiltration processes and also a dense dyke network which acts like a wall to the ground water flow towards the sea. From the beginning of the 20th century, the main system for ground water exploitation on Tenerife island are the “galleries” or a subhorizontal drillings. Las Cañadas aquifer, which comprises a ≈150 km² collapse caldera, the Teide-Pico Viejo Volcanic Complex and the landslide-formed Icod-La Guancha Valley, probably represents the biggest groundwater reserve in the whole island and the last drilled. Due to the importance of Las Cañadas aquifer not only from a purely socio-economic view for the water supply of Tenerife Island but also from a scientific standpoint, we have carried out a hydrogeochemical model to help understand how the ground water system works. Groundwaters hosted in the Las Cañadas volcanic aquifer are dominantly sodium bicarbonate-rich and shows relatively high contents of total dissolved solids. CHILLER geochemical equilibrium’s software for fluid-rock-gas interaction was used, obtaining that the chemical composition of the groundwaters at Las Cañadas aquifer is strongly influenced by deep-seated CO₂ gas emission from the Teide-Pico Viejo volcanic-hydrothermal system, which provide aggressiveness to the groundwaters enhancing different degrees of rock dissolution and alteration products. Water-rock chemical equilibrium mainly occurs between 80 and 90 °C, after silica geothermometers. These features are typical of cold CO₂-rich peripheral groundwaters flowing along the margins of volcanic edifices. Beside, most of this deep CO₂ emitted is released to the unsaturated zone, but a significant fraction (between 33 and 50 %) remains dissolved in solution and it is transported away from the volcano by the groundwater flow. The hydrogeochemical characterization of Las Cañadas aquifer could represent an important step in the knowledge of their behaviour. References: Giggenbach (1991), Reed and Spycher (1984).

Myths are described as liminal phenomena; they are created and told at times of transformation and change. While accepting that premise, I argue that the event of volcanic eruption in archaeological conception often suffers an over-emphasis upon a before/after and change in relation to eruption that obscures the very long-term intersections that past people have with volcanic landscapes. Such a focus on a single ‘event’ also elides the very long time span over which many eruptions occur. Using fieldwork conducted in highland western Panamá, I discuss volcanic eruption as a ‘narrative block’ rather than as a discrete an event. Scientific narratives and oral traditions can intersect and overlap in the space of these narrative blocks. In particular, I examine the eruption history of the Volcán Barú in western Panamá in relation to a common Amerindian myth called The Revolt of Objects. In this myth, the sun dies, rocks bang one another, grinding stones eat men, houses and trees shake themselves free of people and caves shut their mouths. The imagery of this myth embraces a reversal of orders that can be seen as a cross-cultural component of the intersection between human life, the geophysical planet, and cultural objects. Rather than suggesting that volcanic eruption is the sole source of the Revolt of Objects myth – or even that ethnohistoric stories necessarily have direct material or phenomenal correlates - I highlight that a volcanic event could have easily have been interpreted through the pre-existing myth and/or the myth could be transformed in re-telling in response to volcanic activity. The concept of order and its reversal in the Amerindian myth invokes the revolt of objects, though I point out that a shared uneasiness between past and present contexts is derived from the revolt of Earth embodied by volcanic eruption as well as the specter of global climate change.

3.6-O-02
The Time Dependence of Vulnerability to Infrequent Hazards: Tsunamis, Volcanoes, Traditional Knowledge and Black Swans.

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The financial practitioner and essayist Nassim Taleb uses the term “Black Swans” (borrowed from John Stuart Mill via Karl Popper) for the rare unexpected events that produce most risk. Here, using examples from Papua New Guinea and elsewhere, I consider the implications of the concept for approaches to natural hazard mitigation based on the traditional knowledge of these hazards that is often found in communities with long residence times compared to the hazard recurrence intervals. Critically, traditional knowledge is inductive knowledge: it assumes that the next hazardous event will be like those in the traditions, and so the mitigation strategy that worked before will work again. The survival of indigenous communities in the 2004 Indian Ocean tsunami is one of many examples of effective protection against tsunamis through traditional knowledge, particularly from the South Pacific. Immigrant communities are more vulnerable to tsunamis, by up to two

Session 3.6
3.6-O-01
Revolting Objects, De-scribing Disasters, and Exceptional Events in Pre-Columbian Volcanic Landscapes

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orders of magnitude. Most tsunamis, however, are relatively uniform in their effects and so traditional, inductive knowledge provides protection; but giant tsunamis will cause catastrophic failure of the mitigation strategy. The inductive nature of traditional knowledge is much more problematic in the case of volcanoes, because the nature and extent of the hazards can be qualitatively different between successive eruptions. Different types of traditional knowledge (especially forms of mysticism) can cause behaviour that increases rather than decreases vulnerability to volcanoes. Volcanoes also differ from each other: communities on volcanoes next to ones with small, frequent eruptions may believe that these are manageable hazards, and expose themselves to the greater hazards of the infrequent but large eruptions of their own volcano. Whilst traditional knowledge can protect against more frequent volcanic hazards, "Black Swan" volcanic events need to be dealt with by systematic investigation of all volcanoes in a region, not just monitoring of a few.

3.6-O-03

Rationalising a Crisis through Literature: Montserratian Verse and the Reconstruction of National Identity

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The volcanic eruption on Montserrat (1995 to present) resulted in the migration of a nation, both on the island of Montserrat and far beyond it, creating a global diaspora. Montserratian cultural expression takes many forms, all of which were impacted by the disaster, and which tell the story from the perspective of individual Montserratians. This paper will examine several collections of writings produced during the eruption, which describe the emotional and practical responses of Montserratians not only to the volcanic awakening, but also to the arrival and activity of international teams of scientists on the island. Overnight, the nation became heavily dependent on the scientists for its protection. This led to the development of complex interactions between the public, the scientists, politicians and the media. Montserratian literary offerings generated during this period are a valuable source of information for scientists seeking to evaluate both public understanding of scientific concepts, and the response of the public to the crisis at a personal level. The eruption of the Soufriere Hills Volcano has overturned a small island culture, producing a deep grieving process for the Emerald Isle, and yet simultaneously precipitating the birth of new forms of national identity and cultural ownership of their volcanic experience. The poems and accounts considered here cast light on these processes, and providing insights into the impact of this eruption on the islanders. For readers who are also scientists and policymakers, these texts are useful records and sources of new perspectives on the physical events themselves, and allow for deeper analyses of the role of science and scientists in societies on active volcanoes.

3.6-O-04

The Time Depth of Oral Traditions

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The 'time depth' of oral traditions is a topic of active debate in the anthropology community. Oral traditions of volcanic eruptions provide a unique opportunity to constrain time depth, because the eruptions themselves are easily dated. Studies of volcano oral traditions are also important from a volcanological perspective, as they provide insight into the ways in which non-literate societies transmitted hazard information and developed resilience to volcanic hazards. The question then becomes, how can oral traditions be unambiguously linked to specific eruptions? Here we review oral traditions from several cultures to explore the transmission of past volcanic activity through cultural memories. We find some stories to be remarkably explicit about the various hazards posed by local volcanoes, while elsewhere only remnants of stories remain. A particularly interesting example is the 7700 ybp eruption of Mt. Mazama, where the details of eruptive activity argue strongly for oral transmission of stories over several millennia. We also examine the conditions under which oral traditions are lost, such as: changing cultural practices; overshadowing by greater events (such as major migrations, wars or cultural upheaval); long repose intervals; too little impact on the society; possibly too-frequent impact; or even the absence of an appropriate cultural context for assimilating hazard information. To summarize this information, we compare time depth of oral traditions with the inferred impact of the eruption on the society. Not surprisingly, we find the longest time depth to equate to the highest impact eruptions, that is, those eruptions that caused large-scale migrations of entire populations. Aside from this factor, cultural stability and a host of the other factors can also be important. From the perspective of hazard mitigation, a common consequence of these stories is designation of hazardous areas as sacred, which has important implications for land use planning.

3.6-O-05

Archaeological and Volcanological Evidence of a Repetitive History of Human Colonization and Abandon Due to Volcanic Activity in the Vesuvius Plain (Italy), between the Ancient Bronze Age and AD 79

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Archaeological and volcanological studies revealed that eruptions of Neapolitan volcanoes have interacted with human life since prehistoric times. The occurrence of high intensity explosive eruptions, interspersed with long periods of quiescence, has characterized the last

10 ka of activity of these volcanoes. The investigations carried out in advance of public works, provided a detailed picture of human settlements and activities between the Late Neolithic and the historical times around these volcanoes. Through this time-span the Plain was variably inhabited, crossed by long-lived roads and subject to agricultural exploitation. Volcanic eruptions caused significant breaks in the occupation of the area, but also maintained the plain's extraordinary fertility and thus favoured its development. In particular the Vesuvius volcanic activity, strongly influenced the evolution of the surrounding plains in a very interesting, though poorly known, period of activity, included between the Pomici di Avellino and Pompeii Plinian eruptions. During this period at least six eruptions occurred, two of which were sub-Plinian to phreato-Plinian events, and four were violent Strombolian to Vulcanian events. Thin paleosols or erosional unconformities separate the deposits of these eruptions. Some of these events interacted with human settlements in the Plain, and the related sequences often retain many traces of people displacement during the eruptions, and land reclamation and re-utilization soon after them. The accumulation during eruptions of large amount of loose material above the relieves surrounding Vesuvius, favoured the extensive generation of lahars, hyperconcentrated debris streams and flood flows. Despite the variable kinds of hazards posed by volcanic and related phenomena, in the Campanian Plain humans have nevertheless found good reasons for settlement and development, mostly for soil fertility and favourable climatic conditions, but also for time intervals between eruptions that usually exceed a human life-time.

3.6-O-06

When Ashes Fell: Distal and Proximal Volcanic Ash Layers Capping Cultural Horizons 4500 to 800 yBP, Ecuador

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The archaeological record of the last 5000 years for coastal and highland Ecuador displays a wealth of stratigraphy that implies infrequent but at times severe ash impacts. The well-known Valdivia culture in central (coastal) Manabi flourished upon a dark organic soil until interment by a 25 cm-thick distal rhyolitic ash from Cotopaxi volcano 4500 yBP. After this event, scarce ceramics and fewer inhabitation sites leads us to the hypothesis that the Valdivians moved elsewhere, but without taking along their cultural heritage of notable ceramic skills. Quilotoa's VEI 6 eruption 800 yBP covered most of the northern highlands of Ecuador with a 10-15 cm ash layer that often mantles abandoned agricultural furrows. A 5000 km² swath of then intensively cultivated areas of the InterAndean Valley appears to have been abandoned for a long period, as the volcanic ash infilling the furrows was not subsequently disturbed. Like the Valdivians, these people moved out of the area and didn't leave much trace as to their final destination. Since many of the major eruptions of multiple volcanoes were separated by hundreds of years, one has to ponder if there was a generational memory amongst the early cultures about volcanic phenomena, particularly

for people living in settlements located hundreds of kilometers from a volcano. Absent are depictions in artwork or ceramics of eruption scenes or impacts. People living next to volcanoes where ash falls are generally minimal undoubtedly coped with the situation, letting the rain wash off the ash from crops and living areas. But, for the rare occurrence of a thick ash fall (15-25 cm), earlier cultures might have had few coping strategies and perhaps most moved out of their domains.

3.6-P-01

Determination of Paleo Volcanoes Location According to Sedimentology Studies, a Case Study: Sina Formation (NE – Iran).

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Paleo volcanoes are important factors for basin analysis. Aq Darband erosion window is famous exposes of Touran plate and Kopet Dagh sedimentary basin basement rock in north east of Iran. Active magmatic arc in southern part of this area have been created because of paleotethys subduction in late Paleozoic and early Mesozoic. Deposits related to this arc have been deposited from late Paleozoic to late Mesozoic. In late Triassic, after short period, again because of subduction and increasing of magmatic activities, tuff deposit (Tuff Sandstones) have been deposited. Observations show that these deposits have been created in a fore arc basin on continental slope. Also these deposits have been reported in southern part of Touran plate in Afghanistan and Turkmenistan.

3.6-P-02

The Entangled Landscape: Volcanism, Archaeology, and Ecotourism

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Archaeologists working in volcanic regions can offer unique contributions to understandings of risk perception and the long-term intersection of human life and natural phenomena. While much of scientific endeavor is framed in terms of 'disentangling' data, my contention is that a high level of entanglement is inherent to the phenomena of volcanic eruption and life in both past and contemporary volcanic landscapes. Through its merging of social and earth sciences techniques and approaches, archaeology is uniquely positioned to consider and combine multiple data sources and time periods. In this paper I draw together archaeological field data, ethnohistoric stories, and tephrochronology to consider a 2,000 year span of intersections between people in western Panamá and the Volcán Barú. I discuss the role of my interpretations in the context of a growing importance of ecotourism in volcanic areas of Latin America and draw upon contrasting examples from Soufrière Hills on the island of Montserrat and Chaitén in southern Chile.

3.6-P-03

Vomiting Lobsters, Burning Fields, and a Diversity of Phenomena: Merging Our Ideas of the Past, the Volcano, and the Artistic Process

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The 20th century saw an explosion in the hyper-specialization of academic fields; the separation of social sciences from earth sciences was compounded by a general divide between the sciences and the arts or humanities. Recent calls for more cosmopolitan vantages in research – that is, for research that transcends narrow nationalistic, disciplinary, or dogmatic borders – add further impetus to the decades of earnest though often unheeded calls for truly multi-disciplinary or interdisciplinary research. Volcanic regions in particular provide fertile opportunities for exceptionally varied cross-fertilization of vantages between the arts and the sciences. I argue that a model for the overlaps between these can be provided by early volcanologists Athanasius Kircher (1602-1680), William Hamilton (1730-1803), and Alexander von Humboldt (1769-1859). I then present a discussion of contemporary artists who engage with the volcano, volcanism, or volcanic materials. These include well-known artists such as Joseph Beuys, Eleanor Antin, James Turrell, Richard Serra, Matthew Barney, Allan McCollum and Olafur Eliasson. I also discuss the ongoing collaborative process and projects in which I have combined my archaeological work in volcanic regions with the creative processes and artwork of contemporary artists Ilana Halperin (Glasgow) and Keith Edmier (New York City).

3.6-P-04

The Island on (and Now Under) the Soufrière Hills Volcano: Surveying Endangered Archaeological Resources on Montserrat, West Indies.

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On July 18, 1995 the Soufriere Hills volcano erupted in the southern half of the Caribbean island of Montserrat, destroying the capital city of Plymouth and countless archaeological sites, and also forcing two-thirds of the island's population of 11,000 to flee abroad. Currently approximately 3,000 residents live on Montserrat in the shadow of the continuously active volcano. This remaining population is undergoing a rapid transition, marked by relocation to and redevelopment in the northern portion of the island, an area outside of the exclusion zone that has been deemed safe from direct volcanic impact.

Nearly all prior archaeological work conducted on Montserrat was focused in the southern and south-eastern regions of the island, areas that are now within the exclusion zone, and, in many cases, covered by meters of pyroclastic flows and lahars. By

contrast, the north of the island is home to countless rich, largely undocumented archaeological resources. This area is quickly becoming an endangered cultural and archaeological landscape, as it is now under direct threat from rapid resettlement, development and continuing volcanic activity.

Beginning in January 2010, the Survey and Landscape Archaeology project on Montserrat, based at Brown University (Rhode Island, USA), initiated a study of the archaeological remains in the non-exclusion zone as part of a longer-term, interdisciplinary survey and resource development program. This presentation will discuss the initial results and future directions of the project, which include: documenting previously unknown, unrecorded Caribbean archaeological sites under direct threat; providing a heritage management resource to the Montserrat National Trust; assessing environmental and developmental threats to archaeological sites; and involving the results in an educational program.

3.6-P-05

The Volcanic Activity About 40000 Years Ago And Its Influence On The Prehistoric People Of Caucasus

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The investigations of Mezmay cave deposits in Caucasus region allowed us to reconstruct the Upper Pleistocene paleogeography. During Upper Pleistocene period the Mezmay cave was occupied by Neanderthal people. In the deposits formed after 40000 years ago, the first artifacts of Homo sapiens have been found.

The cave sediments were studied by the mineralogical, geochemical, radiocarbon and pollen analysis. The composition of deposit changes sharply in the layers 2B1 and 1D. It is the soil which contents the volcanic ash. The ages of layers 2B1 and 1D on the base of radiocarbon dating are about 40 000 years ago and 32 000 years ago respectively. These deposits content a high concentration of volcanic glass. The plagioclases have a high order structure, which is characteristic of low temperature formation (effusive origin). The chemical and mineral composition of volcanic products from cave deposits allows us to assume the sources could be the eruptions from Elbrus and Kazbek volcanic provinces in period between 40-30 ka.

In the history of the Earth the period between 40000-30000 years ago was the period of intense volcanic activity. The most intense volcanic explosions are fixed in this time at the America, the Europe and the Japan. These catastrophic events of volcanism concern to period, when modern humans arrived in Europe and numerous important innovations of the Upper Paleolithic occurred.

The new data about volcanic activity on the Caucasus at 40-30 ka in connection with the data about the global radioisotope fluctuations, the change in geomagnetic excursions, the active volcanism and the global cooling confirms that this period was one of most global catastrophe time on the Earth. This, probably, had in-

fluence on the disappearance of Neanderthal man and distribution of the modern humans.

3.6-P-06

Paleogeography Studies According to Paleo Volcanoes Study, A Case Study: Qare Qeitan Formation (NE-Iran).

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Paleo volcanoes are important factors for interpretation of earth evolution. Kopet Dagh sedimentary basin with carbohydrate potential located in northeast of Iran. Basement rock of this basin observed in Aq Darband erosion window. There are some theories for location of these deposits. Some bodies believe, these deposits are located on southern part of Touran plate and others believe that these deposits are located on northern part of Iran plate. For this reason Permo Triassic deposits of this window (Qare Qeitan Formation) have been studied. These deposits are sandstones and conglomerate. Most conglomerate pebbles are igneous fragments (Andesite, Rhyolite, Dacite, Granodiorite and Tonalite) that deposited in River environment. In order to determination of fragment origins, some analyses have been done. Results show that these pebbles are because of magmatic arc and basement erosion. This arc has been created because of Touran plate subduction. Its place determined by geophysics method in Turkmenistan. Therefore results show that an active arc in Permo Triassic caused to creation of these deposits in southern part of Touran plate.

3.6-P-07

The Origin of Rome Between Myth and Volcanism

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Italy is one of the countries that has conserved a remarkable amount of information about the transformations that occurred on and in its unstable geologic territory. The myths presiding the Foundation of Rome involve pre-existing divinities that operate prodigiously in the Latium territory. The existence of a Latium vetus and a Latium novum (adiectum), on which Aeneas with its companions landed after Troy was destroyed and burnt, is reminded not only from oral tradition but also from the witnesses of imperial age on the noble origin of Rome. The "sacred" seven hills and other existing morphologies of uncertain interpretation and the vicissitudes that happened during the age of the seven Kings of Rome are very interesting. In order to interpret the prodigies and their auspices, Romulus chooses the Palatine and Remus the Aventine. The latter "hill" is already the site of the fire-monster Cacus and of its furious fight with Hercules. Based on the number of divine signs flying in the sky, it would be decided who will be the founder of the sacred city. The myth of the death of Romulus

(716 B.C.), first King of Rome, rises in a mysterious way, along with events of incredible nature and prodigious alterations: he disappears in such a dense cloud that the light was obscured (Livius I, 16).

An inter-disciplinary approach, based also on historical-humanistic data, can be really instrumental for a correct analysis of the temporal history of volcanic activity.

The new techniques, based on differential interferometry on multitemporal satellite radar images, put into evidence variations in the morphology of the apparatuses, subsidence and bradyseism, before and after the activity, showing living breath of volcanoes. The underestimation of their objective hazard and their diffused presence in the populations on the territory could induce to a fatal error.

3.6-P-08

Pre-Industrial Responses to Volcanic Eruptions and Earthquakes in Western Europe and their Role in Contemporary Civil Defence Plans.

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Historical information is often considered in modern natural hazard assessment, though this normally focuses on physical rather than societal responses. Three principal types of responses are associated with natural hazards: (i) Folk or Pre-industrial; (ii) Modern technological or Industrial; and (iii) Comprehensive or Post-industrial (White 1973). Following a disaster a folk or pre-industrial society will recover by harmonising its responses with nature, rather than employing technological solutions to manage and control it. This poster shall assess pre-industrial responses to volcanic eruptions and earthquakes in Western Europe and their role in contemporary civil defence plans, through the construction of historical databases compiled from data from previous research and historical documentation from the classical period to the dawn of the industrial age. Even in an age of instrumentation and remote sensing, the observations of scientists and non-experts have become essential in reconstructing sequences of eruptive and seismic events. Research has found that many responses present in the coping strategies in the pre-industrial period have continued to influence contemporary responses, although they are hardly considered by civil defence planners. Societal adjustments could facilitate more effective hazard prevention plans, through improved interaction amongst social scientists, civil defence authorities and the local communities.

3.6-P-09

Volcanoes in the Canary Islands Prehispanic Cosmogony

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In religious magical practices, old canaries recorded messages left on the volcanic rocks, different motives

reflect beliefs and feelings of complex meaning, which interprets archaeological research for cultural parallels between the populations of North Africa. In ethnohistorical sources, some texts reflect aspects of their cosmogony and its relation to some sacred mountains and the possible design of the Axis Mundi, a belief that the sky was sustained by a pillar of the earth, the worlds top and bottom, where placed the spirits benefactors and evil beings.

In relation to the Teide volcano and the guanches say "hell have known and had to himself was at the Teide and so called Echeyde hell and the devil Guayota. A. Espinosa, [1980]: 35). (158) Idefe Roque in La Palma, was revered by the auritas "and had so much fear and not fall ... they agreed to kill all the animals they kill to eat, gave to the pluck Idefe. (A. Galindo, [1977]: 270. (177)

The bimbaches "They worshiped the natives of this island of Hierro two gods, ... and place your room pretending to do good was accomplished in two rocks by way of landmarks, it called Santillo of the Ancients". (A. Galindo, [1977]: 90) (216)

In the high Garajonay in La Gomera are culling reasons and make offerings to the canaries in the Roque Almogaren Bentaiga in Gran Canaria, poured milk, blood or butter in cups supplied by wells. In Fuerteventura archaeological research has recognized a group of mountains with engravings, highlighting the silhouettes of figures feet (podomorfos) at the summit of Mount Teide Tindaya oriented to the sunset at the winter equinox and elsewhere in Lanzarote . (A. Tejera, [2001]: 33)

3.6-P-10

Late Holocene Volcanic Ash Distribution Along the Coastal Region of Ecuador

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Ecuador has several active volcanic centers whose activity was very intense during the late Holocene – Pleistocene period and which also continues up to the present. Many volcanic ash layers are found in sedimentary sequences in two principal regions of the country-- the Sierra and Coast. This as a consequence of the preferential direction of the winds which generally carried ash towards the west. Most of these layers in the Sierra have been identified very well, but in the Coast region little is known about them. Nevertheless, in this region various archeologists found ash layers in association with pre-Incan cultural layers-- but they could not identify the source and the date of the eruption. To understand the ash characteristics and possibly their sources, we made a regional tephra stratigraphic correlation of more than 50 ash samples that were collected in 21 different sites-- mainly archaeological--between northern Esmeraldas and southern Manabi provinces. We examined under binocular microscope all of these samples in order to determine mineralogical content and physical features of the different components of them, such as: pumice grains, minerals and the varied forms of glass. This description helps us to compare these distal ashes with proximal samples of known source and dated eruptive products in the Sierra region. Through this procedure we were able to assign a par-

ent volcano for the different distal ashes. Also we analyzed geochemical data for distal and proximal samples to identify the geochemical signature of the different volcanoes. For this procedure we analyze the biggest eruptions in the last 7000 yr of six volcanoes: Cuicocha, Pululahua, Guagua Pichincha, Atacazo – Ninahuilca, Cotopaxi and Quilotoa, which are located in the Western and Eastern cordilleras.

3.6-P-11

The 1973 Heimaey Eruption, off South Iceland. The Role of Man-Made Barriers and Water Cooling in Diverting the Lava Flow

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From January 23th to June 1973 a volcanic eruption took place on the eastern edge of the small town Vestmannaeyjar (pop. 5300) on the 11 km² island of Heimaey in the Westman Islands archipelago, lying 9 km off South Iceland. Attempts were made to stop or divert the lava that eventually flowed over part of the town. The methods used were mainly construction of barriers, made of the ash and pumice formed earlier in the same eruption, and by pumping sea water on the lava front. Much has been written about the water cooling but very little attention has been paid to the effect of the barriers, which stopped the movement of the lava front long enough for the water cooling to take effect and obstruct or divert the lavaflow towards the sea. The lava would not advance over the barrier until the lava front had become about 4-5 times higher than the barrier. In hindsight it is highly likely that if the barriers and dykes had been aligned differently, or additional dykes had been constructed early enough, up to 200 houses would have been saved on Heimaey island, including costly fish factories and the power station. The situation in the Heimaey eruption was favourable for diverting the lava away from the town: A) The lava was quite viscous slow moving aa lava giving time for various kind of action, B) There was plenty of area to divert the lava into, i.e. into the sea, C) There was enough sea water for pumping, but unfortunately the most powerful pumps (with a tenfold increase) did not arrive until at the end of March, just after the lava had flowed through the town centre. D) There was plenty of good material for making earth dykes, but the alignment of the dykes could have been more favourable.

3.6-P-12

The Miracle of Chinyero Volcano, Tenerife, Canary Islands

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The Chinyero eruption, which occurred along the NW volcanic rift zone of Tenerife on November 18, 1909, is the most influential historical event happened in this part of island since the Spanish conquest. Never

before that date, the Valle de Santiago, that lacked road access and telephone, was the subject of much attention by the rest of the world. The Chinyero eruption, which caused no major damage and fortunately no human victims (except in the mythical novel *The Necklace Caracoles*), had the peculiarity of being present in the story at a particularly propitious moment for the attention of the media that on or about its activity, deployed across the technical and human capacity at that time was possible. It was the first event of this nature that could be photographed and called the attention a film crew from Paris who traveled to Tenerife. The local, national and international newspapers followed this eruption from the beginning and it was described as the eruption with a higher media impact by the time being. However, the huge flow of information left in oblivion other key documentary sources for understanding the management of this volcanic event and whose discovery by the Colectivo Arguayo substantially alter what has been published so far. We refer to the military (completely unedited) and religious intervention, known only in part. The telegrams sent to the highest civil authority were immediately released in the media, however the information sent to the military authorities have never been made public. Moreover, the memory of the population about this eruption in the affected areas focuses mainly on the maintenance of religious celebrations to commemorate the religious activities performed at the time of the eruption which were considered a key factor to stop the eruption; a miraculous event. Knowledge of this volcanic event has come down to us through the oral transmission, but now we can provide, as a novelty, handwritten documents in summary form only known in religious circles.

Session 3.7

3.7-O-01

Spectral Biosignatures in Planetary Atmospheres: Perspectives for the Search for Life in Our Galaxy in the Coming Decades.

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Since the discovery in 1992 of the first planet outside the solar system (or exoplanet), the number of planet detections is increasing steadily. Although we are not capable of detecting and exploring planets like our own yet, ambitious missions, both ground and space-based, are already being planned for the next decades, and the discovery of Earth-like planets is probably just a matter of time. Once these planets are found, the efforts will concentrate in the detection and characterization of their atmospheres, including the possibility of finding conditions suitable for life. Here, we will discuss the biosignatures that are present in the spectrum of Earth, and the prospects for finding similar biomarkers

in extrasolar Earth-like planets in the near future. Special emphasis will be put on the role of volcanoes on planetary habitability and the detection of their spectral signatures.

3.7-P-01

International Cataloging Collection of Meteorites at the Museum of Natural Sciences of Tenerife

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The Museum of Natural Sciences of Tenerife (MCNT), holds an important collection of meteorites, collected since 1985 by researchers from such Museum in various expeditions to the south of Morocco, Sahara, Mauritania and Senegal. Initially, seven specimens (mainly stones) have been selected. Their study constitutes the first phase of the catalogue that is intended to carry out, according to the structure of the international databases on meteorites (eg Natural History Museum, London). For the seven specimens, data about descriptive properties such as provisional denomination, place of origin in NW Africa, on if the encounter is a find or fall type, number of fragments, dimensions, weight, density, mineralogy, geochemistry and comprehensive information on the main mineral phases (light microscopy transmitted and reflected, XRD, ICP-MS and electron microprobe) are presented. Recently, the information obtained so far in the study of the seven copies has been sent to the Meteoritical Bulletin, in order to obtain an official numbering of the catalog and according to the rules of the Meteoritical Society. The Meteoritical Bulletin contains a listing of all recognized and classified meteorites, which are accepted by the Nomenclature Committee. By the time "the Nomenclature Committee of the Meteoritical Society," has given to each of the sample collection MCNT, an official of the group NWA, as the study of specimens from the NW of Africa. References: Grady M. M. (2000); Hernández-Fernández, S et al (2008); Martínez-Frías J et al. (1989); Muñoz-Espadas, M.J et al (2002); Muñoz Sanz, J. (1997); Rull, F et al (2004).

Session 4.1

4.1-O-01

Tephra Stratigraphy And Volume Of The May, 2008, Chaitén Eruption, Chile

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After more than 9000 years of inactivity, Mount Chaitén (southern Chile) interrupted his quiescence on May 2nd 2008, generating a sequence of explosions of VEI 2-4. The new activity was characterized by the production of several plumes that reached a maximum height of about 19 km a.s.l., and a wide dispersion of the products, mainly toward E, reaching the Atlantic coast of Argentina. The eruption has produced substantial impacts on human life, causing the spontaneous evacuation of Chaitén village located a few kilometers south of the volcano, generating damage to agriculture, killing cattle, and inflicting serious problems to aviation in Chile and Argentina. Our field observations consist of 69 stratigraphic stations located in the proximal-medial area (3-25 km from the vent). Chaitén stratigraphy indicates that the May 2008 tephra deposit consists of numerous layers, most of which can be correlated with individual small explosions and subsequent fallout events. The stratigraphy consists of two sequences of tephra layers, located SE and N of the vent, with grain size varying from fine ash to lapilli and blocks. On the basis of the stratigraphy we propose a correlation between chronology and tephra deposits of the first events, which occurred between 2nd and 8th May 2008, and a physical characterization of the eruption. The stratigraphy is associated with the three main explosive events on 2nd May, 3rd-5th May and 6th May, with an estimated total volume of $0.257 \pm 0.039 \text{ km}^3$ (integration of power-law fitting). For the 6th May event, represented by a layer composed mainly of lithic lapilli and blocks (>2 mm), an isopleth map was compiled and the associated plume height was determined, which is in good agreement with satellite observations.

4.1-O-02

The 2007-09 Eruptive Cycle of Llaima Volcano: Features and Emergency Management

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Llaima (Southern Andes; 3.169 m above sea level) is one of the most active volcanoes of the Andean Range and an eruptive cycle of basaltic composition (~51% SiO₂) started on May 2007 (Moreno et al., 2009). Within the eruptive cycle, three mayor (VEI: 3) Strombolian eruptions took place on January 1-2nd 2008, July 1-27th 2008 and April 3-6th 2009. An effusive Hawaiian eruption occurred on February 2-13th 2008. After the last ash eruptions on July 23rd 2009, Llaima volcano main crater has remained partially obstructed. Lahars toward the western and northern flanks were generated during the mayor Strombolian eruptions, mainly causing road damages. One of the main features of this eruption has been the sudden seismic activity increase recorded just before the eruptions, through Llaima seismic net. As an example, on December 31st the seismic energy released (RSAM) was 17 units and on January 1st in a few hours increased to 5000 RSAM units. Thus, there was almost no time to advertise the authorities and only during the 2008 July eruptions, the SERNAGEOMIN Observatory

could announce an eruption, few hours before. Therefore, as a result of Llaima volcano behaviour, the authorities through Chile's Emergency Office (ONEMI) and the Municipalities had to react in a very short time. Also the Police, Army, Civil defence, Fire brigades and Health Institutions had to remain for long time in the towns and villages around the volcano as the Observatory reports had the Yellow Alert. Emergency plans were actualized promptly and distributed to the community together with map evacuation roads. A complete cadastre of people and land property around the volcano, based on the Llaima Hazard Map (Naranjo and Moreno, 2003) was made since the 2008 January 1st mayor Strombolian eruption. References: Moreno et al., 2009 (XII Chilean Geologic Congress), Naranjo and Moreno, 2004 (SERNAGEOMIN).

4.1-O-03

Renewed Volcanic Activity At Soufrière Hills Volcano, Montserrat 2009-2010

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On 4 October 2009 eruptive activity at Soufriere Hills volcano restarted after a 10 month hiatus. Activity began with a series of 13 ash venting episodes over 3 days. On 9 October 2009 new lava extrusion was observed from the southern side of the pre-existing lava dome. Thousands of pyroclastic flows have been generated by small dome collapses, several vulcanian explosions (in January and February 2010) and a large dome collapse on 11 February 2010.

Since eruptive activity restarted ashfall has occurred regularly across inhabited areas of the island and a number of periods of acid rain have destroyed crops.

Volcanic hazards on Montserrat are managed using a 'Hazard Level System' that defines a single Hazard Level and seven distinct zones, which have pre-defined access restrictions for each level.

During the 10 month period of no magma extrusion in 2009 the 'hazard level' remained at '3' due largely to the presence of a > 200 M m³ lava dome and the fact that explosions and other volcanic activity had occurred without any precursory signals.

Inhabited areas around the Belham valley, which drains from the volcano to the northwest, are at threat from large pyroclastic flows. As a consequence when pyroclastic flows began moving down the upper reaches of this valley in December 2009 the hazard level was raised to '4'. Access to Zone B was allowed only during the day, with a proviso that the zone might have to be evacuated rapidly on escalation of volcanic activity. Three such evacuations occurred in January and February 2010 when pyroclastic flows associated with dome collapses or vulcanian explosions have travelled into the Belham valley.

4.1-O-04

The 2008-2009 Mt. Etna Eruption : Monitoring and Modelling through Integrated Multi-disciplinary Approach

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After a recharging phase during 2007, on 13 May 2008 a new eruption started at Mt. Etna volcano and lasted about 14 months. Dike intrusion was accompanied by a violent seismic swarm (more than 230 events were recorded in the first six hours with the largest of M_L 3.9) and marked ground deformation recorded at permanent tilt and GPS stations. Dike intrusion was detected also by sudden changes in the summit area at five continuously recording magnetic stations. Important information was provided by the Meteosat satellite, that detected the start of lava fountains from the eruptive fissure feeding a lava flow which in a few hours covered a distance of about 5 km inside the Valle del Bove depression, in the south-eastern flank of the volcano. As shown by the seismicity propagation and deformation pattern, dike intrusion attempted to propagate northwards, producing a dry fracture field that generated concern for the possibility that the eruptive fissures might propagate downslope towards populated areas. The ground deformation modelling explains both the mechanism of dike intrusion as well as its attempt to propagate in the shallower part of the northern sector of the volcano.

A prompt alert was communicated from the INGV surveillance centre to the Civil Protection Department several hours before the eruption onset. Several volcanological and geophysical reports, also with simulations of lava flows and ash dispersion, were updated in the following hours and in the next days to describe and interpret the ongoing phenomena.

Monitoring and modelling the multi-disciplinary data allowed both to infer the eruptive mechanisms and to provide a correct interpretation of the ongoing phenomena, furnishing helpful information for civil defence purposes. This approach confirmed a commendable process of feedback between monitoring and research for a modern and useful support to risk evaluation.

4.1-O-05

The 2009 Eruption of Redoubt Volcano, Alaska: Mitigation Efforts of Flow-related Hazards Through Collaboration

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In spring, 2009, Redoubt Volcano, a 3110-m glaciated, andesitic stratovolcano, erupted for the third time in 45 years. Between March 15 and April 4, 2009, more than 20 explosions produced ash plumes to 60,000 ft asl and tephra accumulation up to 1.5 mm onto surrounding communities, pyroclastic flows, and multiple

lahars. Following 3 major explosions, lahars containing glacier and river ice and mixed volcanic and alluvial debris, flooded the Drift River valley to the coast, covering a distance of ~35 km. Between April 4 and ~mid-June a lava dome grew in the summit crater, threatening dome collapse, pyroclastic flows and additional flooding. Airlines were forced to cancel or divert hundreds of international and domestic flights and Ted Stevens Anchorage International airport closed for over 12 hours. The lahars in the Drift River valley forced Drift River Marine Terminal (DRMT) to shut down, which in turn caused oil production in Cook Inlet to be halted.

Due to pre-eruption dike and levee construction by the oil pipeline company, none of the 148,000 barrels of oil stored at the facility spilled. Nonetheless, the ongoing threat of lahars to the DRMT facility required an Incident Command be established. The team included the US Coast Guard, Alaska Dept. of Environmental Conservation, and the Cook Inlet Pipeline Company. The team utilized real-time data updates and interpretations of seismic, geologic, gps, web-camera, radar and satellite data, as well as hazard analysis, by the Alaska Volcano Observatory (AVO). As a result, no personnel were injured or aircraft damaged, and the oil was safely removed from the storage facilities— in large part because of the collaborative efforts among incident command team members, between the incident command team and the AVO, and among the AVO interagency partners.

4.1-O-06

The Ongoing Summit Eruption of Kilauea Volcano, Hawai'i, USA

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In the 26th year of the ongoing east rift zone eruption of Kilauea volcano, an increase in activity was detected at the summit. By February, 2008, the south part of the summit caldera was bathed in high concentrations of SO₂ forcing Hawai'i Volcanoes National Park to close public access. A large fumarole at the base of the east wall of Halema'uma'u Crater was noted on March 12 and the first throat-clearing explosion occurred a week later. This was the first explosive eruption of Kilauea's summit since 1924 and was followed by 7 more before the first major vent collapse in early December which darkened the incandescent vent. Activity resumed before a second collapse and vent darkening at the end of June, 2009. The low intensity and location of the 2008-9 explosive activity within the heavily monitored and easily accessible summit has allowed a number of near-vent studies. Daily ashfall measurements have revealed temporal variations in tephra production and changes in the proportion of juvenile and lithics. Direct observation of the lava surface within the vent allowed cross correlation with geophysical signals to suggest new interpretations of tremor, infrasound, and tilt data. Near-source emission measurements allowed full characterization of content. Hazards posed by the summit activity were near-vent ballistic impact and wide-area low air quality due to increased SO₂ emissions. The continuing high

rate emissions of SO₂ directly impacted downwind communities resulting in exceedances of annual and 24-hr limits for both SO₂ and PM_{2.5} in monitored communities on Hawai'i Island. In retrospect, changes in 2002 suggesting an increase in magma supply to the volcano resulted in an intrusion in 2007 and the 2008 summit explosive activity. Decreasing summit CO₂ emissions suggest that the supply increase is coming to an end.

4.1-O-07

Thermal Images as a Useful Tool to Map Recently Emitted Lava Flows; Examples on Reventador Volcano

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Reventador, one of the most active volcanoes in Ecuador is located in the Eastern Subandean zone in the NE part of the country; a young and small andesitic stratocone is located inside the NW corner of an older (3 x 4 km) caldera. After 26 years of relative quiescence; Reventador erupted violently in November 2002 (VEI 4), blowing the upper part of the previous crater and producing large pyroclastic density currents which descended to the Coca River, some 7.5 km downstream. The explosive phase of the eruption finished with the emission of two lava flows. Following the 2002 eruption, three different periods of activity occurred in 2004-2005, 2007 and 2008-2009, the style of the different eruptive process include vulcanian and strombolian activity, generating ash emissions, small pyroclastic flows, debris flows and blocky lava flows. Since 2002 a total of 17 different lava flows have been recognized, 12 of them descended the southern slopes of the cone, 4 others originated in the crater descending the northern slopes of the cone and 1 lava flow originated in a lateral vent on the SE flank of the cone, all of them remained inside the caldera limits. The almost continuous volcanic activity, besides the difficult access to the volcano has prevented a detailed mapping of the different lava flows during these seven years of continuous activity. As part of the monitoring activities of the Instituto Geofísico (IG) on Reventador volcano, regular oblique and vertical aerial thermal images has been taken since 2002 to the present. The thermal contrast between recently emitted lava flows and older flows, allowed us to precisely define the extent of the new lava flows, finally using a digital elevation model (DEM) a map showing all the 17 lava flows produced during 2002 – 2009 was generated.

4.1-O-08

Lessons Learned from the May 2008 to Present Eruption of Volcan Chaitén, Chile: Emergency Management, Evacuation, Welfare and Recovery.

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Approximately 6000 people were evacuated in response to the May 2008 eruption of Volcan Chaitén in Chile's Southern Volcanic Zone, primarily from Chaitén and Futaleufú townships in response to a range of ash fall and flow hazards. Most of these people remain displaced in 2009. This paper will discuss results of interviews with emergency and welfare personnel carried out during our field visit of 23 January-12 February 2009.

In the Chaitén area, earthquakes increased in the days prior to 1 May, causing some local residents to self-evacuate. Early on 2 May as ashfall was noticed, residents of isolated rural areas evacuated to Chaitén township. After daybreak, pyroclastic flow concerns led to the evacuation of thousands from the town. With just two gravel road exits, all available ships amassed at Chaitén harbour; private companies organised boat logistics as government agencies coordinated strategically. Residents commented favourably on the calm, orderly, fast evacuation, largely completed by the morning of 3 May. Many residents were expecting to be away only a few days and left with few clothes or personal effects. No pets or possessions were evacuated due to space and time constraints. In Futaleufú, temporary evacuation occurred around 6 May, in response to ash thickness and health concerns and with uncertainty as to duration and intensity of continuing ashfall. Discussion of evacuation on health grounds also occurred in Esquel, farther downwind in Argentina.

Provision of welfare soon became critically important as evacuees needed food, accommodation, money, work, communications, and reassurance about home, with these latter two important factors in reducing traumatic impact. Residents were distressed by images of the damage to Chaitén township and pets roaming wild, and media management became important. The well-being of pets and farm livestock emerged as a major psychosocial issue.

4.1-O-09

Management of the Nevado del Huila Volcanic Crisis (Colombia): Experiences of the Scientists-Community Work

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The first historical eruptions on Nevado del Huila Volcano were recorded on 19 February 2007, 18 April 2007 and November 20, 2008. These eruptions generated mudflows that flowed through the Páez and Símbola rivers, with volumes between 75 and 350 million m³ that significantly affected the infrastructure of 7 municipalities (Cauca, Huila departments), in southwestern Colombia. Notwithstanding the difficult political, communication and topographical conditions, the timely response and

efficient organization of the involved community that was informed through bulletins issued by the Volcano Observatory of INGEOMINAS in Popayan city strongly helped to safeguard the human lives (zero victims in 2007, ten victims in November 2008), occurring much lower number of fatalities than during the seismogenic mud flow experienced in 1994 (1,100 victims). In addition to the volcano monitoring, the Volcano Observatory in Popayan has actively participated in a continuous process of support in the socialization of technical information related to the seismic and volcanic phenomena, programs that have been carried out together with local authorities and several ethnical communities located in the volcanic influence area. These educative campaigns have created a significant progress in raising the community awareness about the importance of risk management against natural phenomena and the transcendental role that they have through the appropriation of their responsibility for disaster prevention as a strategy for social and economic development. The integration with agencies of local, national and international domain, the strengthening of the institutions responsible for the management and care of the volcanic crisis, which is reflected in renewed and implemented emergency plans; disclosure of information relating to the evolution of a volcanic phenomenon through some communication strategies, such as Internet, community radio stations, community talks and related agencies as a way of clearing up doubts, to maintain confidence on the scientific work carried out by INGEOMINAS.

4.1-P-01

Aerosol Emissions from Pu'u O'o Vent and the 2008-2009 Halema'uma'u Summit Eruption at Kilauea Volcano, Hawaii.

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Aerosol was sampled in the plume of two degassing vents of Kilauea volcano: Pu'u O'o in 2007 and Halema'uma'u in 2008 and 2009. The aerosol emitted at the two vents differs significantly in spite of similar gas compositions. H₂SO₄ is the most abundant aerosol species in both plumes, but significantly coarser at Pu'u O'o (1-2 µm) than at Halema'uma'u (0.3-0.5 µm). We propose that the vent structure of Pu'u O'o is favourable for high-temperature mixing of magmatic and atmospheric gases which enhances sulphate production, nucleation and growth by self-coagulation. In addition to H₂SO₄, we find a coarse mode (1-2 µm) at Halema'uma'u composed primarily of metal sulphates. Separate formation mechanisms are proposed for the two size modes: H₂SO₄ grow hygroscopically while the metal sulphates by coagulation. The coarse size mode (1-2 µm) becomes more pronounced on days with heightened vent

explosivity, attributed to increased metal exsolution caused by higher halogen emissions on these days. The aerosol composition was found to evolve as the plume age. H₂SO₄ aerosols shrink by evaporation and the dominant size mode becomes ~0.3 µm in both Pu'u O'o and Halema'uma'u plumes. Scavenging of HCl gas increases the concentration of chloride aerosol. The plume also entrains ammonia from background sources of variable strength, which reacts with sulphate aerosol. The size and concentration of sulphate aerosol measured in close lying populated centres present a justifiable public health concern.

4.1-P-02

Description of the January 2010 Eruption of Nyamulagira (North Kivu, D.R. Congo).

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Nyamulagira is a young shield volcano located in the Virunga Volcanic Province (VVP), western branch of the East African Rift, DR Congo. Although it is the most active volcano in Africa (with one eruption every two to four years), it remains poorly studied with incomplete monitoring networks mainly because of the local insecurity and poor infrastructures. Recent international efforts have helped the Goma Volcano Observatory (GVO) to develop and improve its monitoring capacities. The recent eruption of January 2-27, 2010 is the first one ever monitored in real-time in the VVP with different techniques such as seismometers, geodetic GPS and continuous tiltmeters. Coupled to optical, thermal and (In)SAR satellite remote sensing and airborne daily field observations it provided us with the most detailed description of a Nyamulagira eruption. Comparison with previous eruptive events occurred in the recent volcano history reveals some similitude. Though interestingly, unlike the previous November 2006 eruption, virtually no precursor signs were registered before the onset of the eruption on January 2nd 2010. The multiple observations acquired in 2010 enabled us to draw first hypotheses on the eruption mechanisms and the probable link with the former 2006 eruption.

Moreover, the real-time monitoring and fast response spaceborne tools allowed for the first time the GVO to provide Goma regional authorities and humanitarian community with daily hazard assessments.

4.1-P-03

Activity of Koryaksky Volcano in 2008-2009 Based on Kvert Data

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Stratovolcano Koryaksky (3456 m) is located about 25-30 km from Petropavlovsk-Kamchatsky. Possibly the volcano became active about Upper Pleistocene. Before 2008, it was known one episode of increased activity of the volcano. Events from December 1956 to May 1957 included a form of a fissure 400-500 m long on the north-western volcanic slope (at a height of 3.0-3.1 a.s.l.), and an emission of a gas and steam with low content of ash from the fissure. Ash-gas columns rose up to 5.5 km a.s.l. According to KB GS RAS first swarm of volcanic earthquakes with a magnitude of 0.7-2.8 at a depth of 3.8-16.0 km occurred in the area of the volcano from 24 March to 6 April 2008. Fumarolic activity of the volcano began to rise rapidly from late October. The vent of the fumaroles was located on the north-western volcanic slope at a height of 3 km a.s.l. in the zone of fissure 1956-1957. The gas-steam plumes containing ash extending for 200 km to the north-east from the volcano were marked first on December 23. During the intensification of the volcano Koryaksky in 2008-2009, there were three periods when gas-steam plumes contained ash, and the volcano represented a danger to aviation: 23-28 December, 2008; 4 March - 18 April, 2009, and 13-27 August, 2009. The most activity of the volcano was in March-April, 2009: the greatest height of ash-gas-steam plumes was 5.5 km a.s.l. and length - about 680 km. Repeatedly ash falls were observed in the settlements near the volcano but a thickness of ash deposits does not exceed 0.1-0.2 cm. Ash had a resurgent composition. Juvenile magmatic material was not detected during the activity of Koryaksky volcano in December 2008 - September 2009. 2008-2009 events were quite similar to the activity of Koryaksky volcano in 1956-1957.

4.1-P-04

Shallow Conduit Dynamics during the 2008 Series of Explosions from Halema'uma'u Crater, Kilauea, Hawai'i.

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A short series of eight pyroclastic eruptions from Halema'uma'u crater in 2008 represented part of the first eruptive activity from the summit of Kilauea since 1982, and first explosive events since 1924. The Halema'uma'u explosive events occur over periods of tens of seconds and thus are strictly not discrete "Strombolian"-style events, however they are not sustained on the timescales of Hawaiian fountains. The explosive phases occurred at irregular intervals during an on-going period of continuous outgassing and ash emission.

We describe here the characteristics of the deposits erupted from each explosive event in terms of clast morphology, density, bubble size distribution and vesicle number density, tied to observations of the proportions of juvenile versus lithic ejecta during a) explosive

phases; b) persistent degassing periods.

At the March onset of explosive activity, the magma was highly heterogeneous and crystalline containing both phenocrysts and microlites and the magma column was largely outgassed. The high crystallinity and low vesicularity means this early magma had the highest viscosity. A trend towards higher vesicularity from April to September culminated in the September 3-7 period of eruption of microlite free ejecta. This suggests that the extent of contemporaneous degassing is a more powerful control on eruption intensity than magma rheology

4.1-P-05

Sequence of Vulcanian Eruptions Of Galeras Volcano, Colombia: 2004 - 2010.

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Galeras volcano is the most active volcano in Colombia. The recent volcanic activity of Galeras can be summarized in two main eruptive periods: the first re-activation period (1989-1993) and the current period (2004-2010). This second period of activity has been characterized mainly for 18 vulcanian eruptions and the emplacement of two new lava domes in the main crater. The vulcanian eruptions associated with overpressurization of the volcanic system took place on August 11- 12 and November 21, 2004; November 24, 2005; July 12, 2006; January 17, 2008; February 14 and 20, March 13, April 24 (two events) and 29, June 7 and 8, September 30 and November 20, 2009 and the last one, on January 2, 2010. These eruptions were characterized by sudden onset, small eruption columns (< 12 km. in altitude), small volumes of erupted material, and generation of shock waves that were felt in Pasto city and several villages around the volcano (some of them were felt in Popayán city, at 150 km away). The material ejected consisting mainly of juvenile blocks, bombs and ash. Ballistics reached 3 km from the vent. Erupted materials are andesite in composition and the chemical characteristics had not changed remarkably. The minimum deposited volume of pyroclastic material during 2004 - 2010 eruptions was estimated around 16'000.000 m³, in contrast with the total volume for the eruptions occurred during 1989 - 1993, estimated around 3'000.000 m³. The ash plumes were distributed predominantly towards NW of the volcanic edifice. The maximum distance verified of pyroclastic fall deposits was of 180 km for June 7, 2009 and September 30, 2009 eruptions. According with the stratigraphy of the past 5000 years, the principal volcanic hazard of Galeras volcano are pyroclastic flows. The last eruption with pyroclastic flows took place on 27 August, 1936. In contrast, the most common phenomenon during the last 21 years of instrumental monitoring

has been pyroclastic falls, provoking over confidence on people living around the volcano. This situation difficulties prevention tasks done by INGEOMINAS and other government institutions.

Session 4.2

4.2-O-01

Piton de la Fournaise, A Roped Off Volcano? Consequences of the 2007 “Eruption of the Century”.

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Piton de la Fournaise is one of the most active volcanoes in the world. It is also a major tourist destination with an average of 270 000 people who visit this iconic place on La Reunion Island every year. During the April 2007 major eruption, the main summit crater's floor collapsed and created a 350 meter deep depression. Some foot paths surrounding the crater had disappeared with the collapse, while most of the remnant paths located on the edges are now highly fractured and affected by collapse hazard. For safety reasons, authorities have banned access to the summit zone, except for authorized scientists and journalists. Geodesic studies were carried out in order to determine the safest (i.e. the most stable) areas to settle an observation platform. Two years later the platform project is not brought to completion yet. The situation is not accepted by the local population and tourists. Yet despite the interdiction, tens of hikers visit the volcano summit every day. Combination of GPS measurements (to evaluate the ground deformation at the periphery of the crater) and social surveys through interviews of hikers, clearly shows that visitors predominantly walk along the most unstable crater rims. The access to the volcano thus became a main topic within the volcanic risk management at La Reunion Island. The aim of our study is to propose a detailed analysis of the relationship between dangerous sites and the motivations of hikers braving interdictions to visit this, after all, exceptional place.

4.2-O-02 - Keynote lecture

Crisis Management of the 2000 Miyakejima Volcanic Eruption

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On the evening of Monday, June 26, 2000, I was dining with acquaintances from abroad at a restaurant in central Tokyo. My cell phone rang. The call was from the staff of the TMG (Tokyo Metropolitan Government). “Emergency volcano information on Miyakejima island was issued” They said. I was a Vice governor of TMG. I decided to

excuse myself from the dinner. (Lesson1: If there is no communication, nothing will get going.) I headed to Tokyo Heliport and went to Miyakejima. I set up the on-site disaster management headquarters. (Lesson2: Remarks are frequently made as to the importance of the initial response.) More and more people were coming together from various relevant organs. (Lesson3: All the required persons concerned had better be put into on-site headquarters.) From July 8 eruptions began on a full scale. Eruptions bring on large amounts of ash fall. If it reaches the foot, the flow will have become fiercely destructive. Not only will it destroy houses; they can carry away whole roads —shoulder, sub grade, and all. As the roads are severed, so are the parallel facilities, such as power, telephone, and water lines. September 1, we decided to evacuate all residents to Tokyo. (Lesson4:It is important to determine the timing of evacuation.) It was decided that the evacuees would move by household into public housing that would be provided rent free. (Lesson5: Evacuees should not sleep on the floor of gymnasiums.) People took care of internally displaced people in public housing communities. (Lesson6:It is important to prevent the death of solitude.) Evacuation directive lifted after building 51 sediment control dams in 4.5 years. (Lesson7: The villagers were able to return because construction works were conducted.) Crisis is still going on. (Lesson8:The real crisis management is to ensure that they return to their original life.)

4.2-O-03

The Role of Scientists, Journalists and Authorities during the 2004 Tenerife Volcanic Unrest: The Biggest Problem

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In spite of the existence of a Spanish Directive of Civil Protection Planning for the Volcanic Risk since 1996 many requested actions by this directive to the authorities, mainly National and Regional Government of the Canary Islands, were not accomplished at the time of the arrival of the 2004 Tenerife volcanic unrest; therefore, becoming one of the biggest problem to start with. Nevertheless the three mayor administrations in-charge of civil protection did elaborate a plan to overcome the difficulties derived from a previous poor action of the planning. The professional conduct of scientists was also a big problem for the 2004 Tenerife volcanic crisis management in spite of the existence of an IAVCEI document related to guidelines for professional interaction during volcanic crisis available since 1999. Many of the highlighted problems from the past on this IAVCEI document did occur during the recent 2004 Tenerife volcanic crisis such as (i) failure to value diverse scientific expertise, approach, and experience, (ii) failure to honour prior work on a volcano, and, in the reverse direction, failure to share study opportunities, (iii) failure to work as a single scientific team, and thus loss of potential synergism, i.e., loss of a cooperative result that is greater than the sum of individual results, (iv) failure of scientists to use a single voice for public statements, (v) failure of scientific leaders to recognize the limits of their own technical expertise, (vi) failure to encourage those who can and wish to help, (vii) failure to develop

respect for scientific differences, (viii) Inadequate interaction with the news media, (ix) premature or excessive interaction with the news media etc. being the worst the attitude of some scientists to discredit publicly to others scientists damaging their image and their professionalism. Professional conducts from journalists were also an additional problem which might be derived from all the previous highlighted facts.

4.2-O-04

The Lessons of the 2004 Seismic-Volcanic Crisis in Tenerife, Canary Islands, Spain

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Year 2004 showed that the Canary Islands society was not prepared to confront a seismic-volcanic crisis. The public administrations did not have among their priorities to prevent the risk that involves living in an active volcanic archipelago. Scientific and technical equipments were insufficient, and there were not established any plans nor protocols in case of a crisis. Lack of coordination between the scientific institutions related to volcanism was in evidence in May of the 2004 when the mass media, after public declarations of the Director of the Volcanological Station of the Canary Islands, announced the possibility of a “quiet” eruption in Tenerife in a short period of time. The consequences were the expected ones: public confrontations more emotional than rational between the experts. Public institutions gave contradictory messages that seriously dulled the functions of the scientific-technical organism created to advise to the authorities in case a volcanic eruption would occur. Even, people in charge of some of these institutions, case of the IGN, seriously doubted about the necessity of creation of an organism that agglutinates and coordinates the different scientific and technical institutions related to the volcanic risk assessments. One of the main consequences of the 2004 volcanic-seismic crisis was the initiative of the Spanish Senate and the Parliament of Canary Islands Government to urge Spanish Government the creation of the Canary Islands Volcano Observatory (IVC). However, public responsible of Institutions like CSIC and IGN in Canary Islands pronounced publicly against this initiative alleging different reasons, regardless of the evident contradiction with the scientific and technical reality, nor with the support to the IVC by the public institutions of citizen representation. This situation had its reflection in the behaviour of the society and mass media. Disparity of opinions, differences among members of the Scientific Committee affecting even to the communication protocol to the population as it happened in the city of Icod de los Vinos that used a different Traffic Light Hazard Alarm System to the population than the official one. For these reasons, news were replaced by scientific rumour, debate by personal disqualifications and arguments by the “authority principle” that publicly deny the scientific capacity of those who maintain, based on the scientific data, the occurrence of the 2004 volcanic-seismic crisis. The final result is that the volcanic hazard in the Canary Islands is being confronted by denying its existence. This “argument” has been sufficient to those

ones that are against of any decision that implies to face up a incontestable scientific evidence: “The Canary Islands will experience more eruptions, and even we do not know at present when, where and how they will be, society must be prepared to diminish its effects and to palliate its consequences.

4.2-O-05

Countermeasure against Volcanic Hazards on Volcanic Islands in Tokyo Metropolitan City, Japan

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Tokyo Metropolitan City has 23 active volcanoes along the volcanic chain of Izu-Bonin Arc, to the south from the metropolitan Tokyo. In particular, on nine islands at the northernmost part of the volcanic chain, there are a number of inhabitants from a few hundreds to several thousands with many tourists dependent on seasons. We had experienced the total evacuation twice in the past century, i.e. the 1986 eruption of Izu-Oshima and the 2000 one of Miyake-jima volcano. Volcanic alert system was recently introduced by JMA, which may ask people to totally evacuate from the island in an emergency. However, large passenger ships are not available enough to conduct such total evacuation within a day. Based on reliable volcanic hazard information, we will be obliged to stay at some safety places for a while and then to leave the island. Refuge trainings are planned at every two years in turn with a few thousand of participants on these island. Tokyo MG had provided and maintained the volcano monitoring system with seismometers, tilt meters and thermometers on these volcanic islands, of which data are telemetered to JMA and ERI (Univ. Tokyo).

4.2-P-02

Elevated Seismic Activity beneath The Slumbering Morne Aux Diables Volcano, Northern Dominica

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Since May 2009, periods of elevated seismic activity have been experienced around the flanks of Morne Aux Diables Volcano in northern Dominica on the Lesser Antilles arc. This long-dormant volcano is a complex of 5 intact andesitic lava domes with a central depression (or pseudocrater) within which a cold soufrière is evident (Lindsay et al., 2005). Prior to this activity, seismicity was very quiet except for a short period in 2000 and an intense short-lived swarm in April 2003. The most recent earthquake activity has been regularly felt by residents in villages on all flanks. In Dec 09/Jan10, scientists from

the Seismic Research Centre (SRC), based in Trinidad & Tobago, in collaboration with staff of the Office of Disaster Management (ODM) and Public Seismic Network in Dominica improved the monitoring capacity around this volcano from 1 to 7 seismic stations. Earthquakes have since been determined to be volcano-tectonic in nature and more accurately located at shallow depths (<4 km) beneath the central depression. Additionally, in Jan/Feb 10 geothermal sampling was undertaken and 2 permanent GPS sites were deployed, one on the eastern flanks of the volcano and the other just off the south-western flanks. Public information leaflets were prepared by SRC scientists using a "Question & Answer" format that have been distributed to concerned citizens whilst many public meetings/debates were carried out by ODM staff. Preliminary field investigations indicate that the previous Late Pleistocene activity of Morne Aux Diables was predominantly of Peléan dome growth and collapse style forming extensive pyroclastic fans around the central complex. The town of Portsmouth is located on one of these fans ~5 km southwest of the central depression. Sporadic, short bursts of seismic activity continue at the time of writing (February 2010). References: Lindsay et al., 2005, Volcanic Hazard Atlas of the Lesser Antilles.

4.2-P-03

Auditing the 2004/5 Volcanic Crisis on Tenerife: Preliminary Results on Issues of Risk Perception, Trust and Governance

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As a result of both climate and ecological change at local and global levels, professionals from academia and government are warning of increased occurrences of extreme environmental events. By consequence there is an increased need for policy communities to appreciate how their warnings are perceived by local populations, and to understand how to engage with local community representatives. The issue of trust heavily influences the communication about a potential threat from a natural hazard to local communities as well as to the wider audience via the media. For scientists to successfully act as communicators during an ensuing natural crisis, political, cultural and institutional barriers to early warning should be analysed, with regard to how these impact upon threat and risk communication. Here we present preliminary results from our audit of the 2004/5 reactivation of the central volcanic complex on Tenerife to address these issues. This audit utilises archival work, interviews, observations and quantitative research to highlight in particular: i) volcanic risk perception on Tenerife, ii) how expert knowledge is perceived locally, and iii) governance procedures during the crises.

Session 4.3

4.3-O-01

The Role Of Disaster Exercises In Volcanic Crisis Management In Major Cities: Lessons Learned From Exercise Ruauumoko in Auckland, New Zealand

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The potentially active Auckland Volcanic Field (AVF) comprises ca. 50 basaltic 'monogenetic' volcanic centres and is coincident with New Zealand's largest city, Auckland. The most recent eruption occurred ca. 550 years ago and was witnessed by early indigenous Maori. Although the volcanoes in Auckland are small and their eruptions have been infrequent, the risk associated with future activity is very high given the high physical and economic vulnerability of Auckland (population 1.3 million; 2006 census). In recognition of this, in 2008 the New Zealand government ran Exercise Ruauumoko, a test of New Zealand's nationwide arrangements for responding to a major disaster resulting from a volcanic eruption in Auckland. The exercise took approximately 18 months to plan, and included the participation of over 120 organisations at local, regional and national levels. The exercise scenario was developed in secret and covered the two week period of precursory activity up until the eruption. Distributed volcanic fields such as the AVF pose unique problems for hazard mitigation as the next vent location is not known. Moreover, in these systems magma rises from mantle depths relatively quickly, giving only limited warning (days – weeks). Exercise Ruauumoko provided an excellent and rare opportunity to test a large number of mitigation, scientific and technical procedures in this uncertain geological environment. In this presentation we will summarise the main lessons learned during Exercise Ruauumoko from the point of view of a variety of participating groups, including local and national civil defense authorities, monitoring scientists, and a Science Advisory Group. We will also highlight some of the developments in volcanic hazard and risk research and volcanic crisis management in New Zealand that evolved out of Exercise Ruauumoko.

4.3-O-02

Geological Assistance During the Crisis Management of the 2008-2010 Eruption of the Chaitén Volcano, Southern Andes, Chile

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Chaitén volcano in southern Andes started a plinian to

subplinian rhyolitic eruption on 19.58 GMT during May 01, 2008 following a long period of quiescence (Naranjo and Stern, 2004). A new dome complex has been growing at high rates after the initial major explosions inside a 2 kilometers caldera like structure. A number of hazardous volcanic processes and products (pyroclastic, laharcic, block and ash flows and ash falls) have been affecting the surrounding populations, ground, vegetation, ocean and rivers, such as the laharcic flows burying the currently evacuated Chaiten city. Immediately once the eruption started also began the volcanological and seismological investigations and assessments, the geological assistance to authorities in charge of the emergency and the setting of seismic monitoring instruments (Muñoz et al., 2009), up to day conformed by 11 broad band seismic stations. The geological, volcanological and seismic knowledge produced during the eruption and the determination of evolutionary sceneries were properly transferred and consequently taken in account during complex decisions of authorities in charge of the emergency, including recommendation on evacuation, volcanic alerts and selection of sites for relocation of the Chaitén city. As a result, no fatalities or major injuries were produced during this major rhyolitic eruption. Collaboration between volcanologist and government agencies in charge of the crisis management and land use planning was clearly improved. However, it is still pending the development of a formal education programmer directed to the affected local people who are mainly due to the prolonged lapsing and evolution of the eruption, the restricted conditions of the area around the volcano, and the complex status of the social affairs. We thank SERNAGEOMIN and many colleagues and authorities that work on this crisis. This summary is dedicated to the Chaitén's people. References: Naranjo and Stern, *Rev. Geol. de Chile*, 31(2); Muñoz et al. 2009, Chilean Geological Congress.

4.3-O-03

Experience on Risk Management of Popocatepetl Volcano

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Mexico is located in a region of high volcanic activity. Popocatepetl volcano, after being dormant for almost 75 years, initiated at the end of 1994 a period of high seismic and fumarolic activity with abundant ash and gas emissions, including lava extrusion, dome formation, and moderate explosivity. Its location between the cities of Mexico and Puebla, imposes a potential threat to a population of several million people living in its vicinity.

As a joint effort of CENAPRED, and other institutions (USGS, UNAM), a real time remote observation system was established in 1994 when this volcano became active. The objective of this system is to monitor and timely detect and evaluate the state of activity and thus the associated risk during episodes of unrest. An automatic warning system and a dissemination strategy have been implemented to notify staff in charge

and responsible government authorities whenever the activity levels reach critical pre-established thresholds. This allows an effective response and represents an essential tool for decision making, crisis management and communication of risk levels to the public. In December 2000 the system and the adopted procedures proofed its effectiveness with the preventive evacuation of 40,000 people hours before a major eruption.

4.3-O-04

Risk Associated to Pre-eruption Earthquakes: A Relevant Problem in Vesuvius Emergency Planning

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The scenario of the Vesuvius emergency plan is based on a Sub-Plinian eruption and includes the following main phenomena: roof collapses and lifelines/communications breakdown by pyroclastic ash fallout, emplacement of pyroclastic flows (PF), lahars by rain mobilization of loose ash on steep slopes. Nearly 600,000 people live in the zone exposed to PF (Red Zone) and they should be evacuated before the eruption onset. The plan foresees that this evacuation will require 3 days and includes a detailed description of the escape routes to be utilized. As shallow earthquakes ($h=3.5$ Km) with magnitude of 5-5.5 will likely occur in the crater area during the volcano unrest phase preceding the evacuation order for the Red Zone, we thought that it was of crucial importance to investigate the potential impact of these earthquakes (expected seismic intensity VII or VIII in the inhabited area to be evacuated) on the practicability of the escape routes. To this aim the probability of having road links interrupted by partial or total building collapses has been evaluated by assessing the seismic vulnerability of the buildings located on both sides of all the roads to be used for the evacuation. Results are impressive, as in each of the 18 Red Zone Municipalities there is a high probability that eruption forerunner earthquakes will cause from tens to hundreds of road link interruptions. Consequently: i) many destructions and casualties might occur in the Red Zone shortly before the eruption onset and ii) Red Zone quick pre-eruption evacuation might become impossible because of building collapses obstructing the escape routes. These results indicate that it is urgent to promote interventions for seismic risk reduction aimed also to ensure the practicability of Vesuvius escape routes.

4.3-P-01

Analysis of the influence of Popocatepetl volcano in the SO₂ levels in Mexico City

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Because of its location and intensity of emission, Popocatepetl volcano can impact the SO₂ levels in the Mexico City and can also contribute significantly to the regional SO₂ levels of aerosol formation. The magnitude of the impact depends largely on the rate of emission of gases from the volcano but also the presence of vertical mixing regional conditions vigorous enough to promote the fall of the volcanic cloud. Both features (emission rate and the need for meteorological and transport conditions favorable to the impact) are essentially unpredictable and random in nature. Finding long-term correlation between the estimated volcanic SO₂ emissions and SO₂ levels in Mexico City is a major challenge. Even in the case of a direct source-receptor, it is necessary to consider the time it takes for the volcanic SO₂ emission to be recorded at any of the downwind air quality monitoring stations in the city. The time required for transport of the volcanic cloud to the receptor sites is variable and is influenced by the meteorological conditions along with a significant component of vertical mixing. In order to determine the influence of the volcanic SO₂ emissions on the SO₂ levels in Mexico City, we correlated time series of long-term volcanic SO₂ emissions and the corresponding values recorded by the ambient air-monitoring network of the city. The correlations show a large variability for all analyzed stations. Back trajectories and air quality model results are used to determine impact area and influence from volcano emissions and other sources. Our analysis indicates that although emissions of SO₂ from the volcano are very important (>20 kg/s on the average), it has relatively small effect on the air quality in Mexico City; however, regional impact could be much higher.

4.3-P-02

The LUSI Mud Volcano in the Suburb of Surabaya Megacity. Environmental Impacts and Crisis Management

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The LUSI mud volcano is born in May 2006 in Sidoarjo, an industrial suburb of Surabaya megacity, Indonesia. For 4 years, different craters expelled millions of cubic meters of mud that flow in the Porong River. The mudflows have already buried 4 villages, and more than 30,000 people have left their house. In order to protect the external zone that has not yet been filled by the mud, a ring dyke has been built. However, secondary hazards have occurred off the dyke, with a geographic distribution: westward, flammable gases, hot water and mud are expelled, sometimes inside the houses. In addition, cracks appear in houses due to subsidence, forcing the local people to move. Northward, the salt water within

the mud pond is dumped in small rivers traditionally used for irrigation. Salinization problems therefore appear in the surrounding rice fields. Southward, the mud is discharged into the Porong River. The analysis of 11 transverse profiles across the river in 2008 showed that thick mud deposits may block the channel during the dry season (May to October), increasing the flood hazard at the beginning of the rainy season. However, floods are usually sufficient to evacuate the muddy sediments after the first floods. In this paper, a synthetic scheme presents the main issues of this unusual disaster, based on a geographical analysis.

4.3-P-03

Volcanic Hazard Preparedness in Ecuador

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In a mega-vulnerable country towards natural disasters like Ecuador with its density of around 250 continental volcanoes of which some 18 are potentially active, it is highly indispensable during and prior a volcanic crisis for decision makers to know the level of knowledge and degree of preparation of a public exposed to volcanoes and their hazards. Therefore, some recent annual (2007-2010) nationwide survey have been undertaken with a twenty-two questions catalogue about natural disasters, including volcanic hazards, in the Ecuadorian academic environment in order to analyze and evaluate Ecuador's knowledge and perception related to natural hazardous events along its territory. A second issue was related to the public preparedness towards these various natural disasters and its potential ability to respond. The obtained results indicate a huge lack in memory of historic occurred events as a majority (constantly around 82-84%) of the interviewed persons (total N = 3000-4000 persons per year) had a low knowledge about past major catastrophic events and therefore as a consequence it can be considered and interpreted that the Ecuadorian public is still unprepared for future potential catastrophic events to come. Volcanism is considered as the deadliest of all natural hazards in Ecuador (around 33%), although in the scale of mortality between the year 1900 and today 2010 the amount of lethal victims is far behind landslides, earthquakes and flooding. Although a high percentage (33.7%) answered to have been personally affected by volcanism during their life, only some 30.8% at the highlands and as low as only 3.5% at the coast have ever participated in preventive workshops about volcanic risk reduction. The preparedness for disaster emergency response is even worse. Even if a given time (like 24 hours to react) would theoretically exist, the preparedness of the public for any natural disasters is of about only 12.3%.

Lately submitted Abstracts

The Eyjafjallajökull Volcano, Iceland: Tectonic Setting, Structure, and Magma Plumbing During the Current Activity

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The Eyjafjallajökull volcano is located in the volcanic flank zone of South Iceland, a few tens of kilometers off the nearest branch of the mid-Atlantic plate boundary. It is an elongated, flat cone of about 1650 m height. A 100-200 m thick glacier covers the upper part of the volcano and its elliptical 2.5-km-wide summit caldera. Eyjafjallajökull products have an alkalic composition, similar to other off-rift volcanoes in Iceland. An E-W trending rift zone transects the volcano. Eruptive fissures on the west flank are curved and tend to follow the topographic gradient. The E-W orientation of the rift zone suggests a tectonic control of a regional stress field with the least compressive stress oriented N-S. This change may be related to a southward propagation of the Eastern Rift Zone of Iceland and the transfer of spreading from the Western Rift Zone. Eyjafjallajökull is a moderately active volcano, with eruptions in ~920 AD, 1612, and 1821-23. Intrusion episodes in 1994 and 1999 marked the reawakening of the volcano. The pathway of magma was traced by earthquakes and surface deformation measurements from the deep crust to the emplacement of sills at 5-6 km depth. Similar events were detected in the spring of 2009 and towards the end of the year. A small lava eruption of olivine basalt broke out on the eastern flank on March 20 and lasted about 3 weeks. A second eruption began from the summit caldera on April 14. The eruptive products are trachyandesite and the eruption is characterized by high explosivity, amplified by magma-ice interaction in the glacier-filled caldera. The ongoing activity is monitored by GPS geodetic measurements, interferometric analysis of satellite radar images, and seismic measurements, revealing a temporally and spatially complex plumbing system of the volcano.

Session 1.3

Airborne in-situ measurements of the volcanic ash dust plume over a part of Germany caused by the volcano eruption of the Eyjafjallajökull (Iceland) by means of an optical particle counter and a light sport aircraft

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The eruption of the volcano Eyjafjallajökull (Iceland) in 2010 has caused a transportation of an ash dust plume over large areas of Europe. In April 2010 many airports of cities in Europe were closed for several days because of the volcano ash plume and even in May 2010 several German and European city airports were closed for shorter periods because of the danger caused by the volcanic ash dust. The VAAC (Volcanic Ash Advisory Center), London, has continuously published graphics of the predicted spread and dispersion of the volcanic ash plume, which were partly basis for the air traffic restrictions in Germany.

In this situation the Laboratory for Environmental Measurement Techniques of the University of Applied Sciences in Duesseldorf has performed several measurement flights starting from April 23 2010 to get real airborne in-situ dust measurement data over a part of Germany (western part of the state North-Rhine-Westphalia) and for comparison with the predicted ash dispersion model data of the VAAC.

For these measurements a laser based optical particle counter (OPC, Model Grimm 1.107) has been used, which was mounted in a light sport aircraft (Model CT Shortwing). With this OPC in-situ and on-line measurements of particles in a range of sizes between 250 nm and 32 µm were possible. The OPC was combined with an isokinetic sampling device suitable to a travelling velocity of the aircraft of 90 km/h to 120 km/h. Airborne dust measurements were performed during flights up to a maximum altitude of nearly 4000 m. The results of the airborne optical dust measurements were compared with the model dispersion predictions for the ash plume by the VAAC and with European limit concentrations.

Session 3.4

The Volcanic Sand and Flower Carpets of La Orotava, Tenerife, Canary Islands, Spain

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Every year and coinciding with the festival of Corpus Christi (this year on June 10th), the quaint streets of La Orotava's old quarter in north Tenerife are transformed into a colourful display of carpets made with flowers and volcanic sand from the island

The whole town gets up very early that day when the locals, armed with petals, heather branches and different coloured sand, start creating wonderful, fanciful works of art which look like they have been painted by an artist on the cobbles. The colours and the natural fragrances fill the air in a ritual that ends well into the night, when the ephemeral art of the carpets honours its name and the faithful who follow the Corpus procession along the decorated streets.

The maximum expression of this tradition, which dates back to the XIX century, is the striking tapestry of colours which covers the Town Hall square with a splendid carpet dedicated to the Priestly Year, inspired in the Last Dinner and based on an original spanish genial artist Salvador Dalí, with an astonishing display of 1400kg of 23 different sand colours, 41,5 meters long, 21 meters wide.

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