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ABSTRACT BOOKLET
(in alphabetic order)

Solubility of sulfur in basaltic melts

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Sulfur is the third most abundant volatile element in magmatic melts, after H_2O and CO_2. Involved as a chief actor in many igneous processes, from the volcanic degassing to the formation of ore deposits, and due to the strong dependence between speciation and oxygen fugacity, sulfur always attracted the geochemical community in the effort to understand and model its behavior in magmatic systems. In the framework of Vuelco, we are interested to the volcanic degassing aspect, with an affect on volcanic hazard, not forgetting the impact on global climate change. We want to produce solubility data for sulfur under well controlled conditions to calibrate an accurate fluid-melt sulfur saturation model. We will perform experiments using a sample of basaltic pumice from Stromboli Island, PST9. To rigorously attain to this aim, we plan three series of experiments: 1) Fe pre-saturation of Pt capsules using a 1-atm furnace withCO-CO_2 gas mixture; 2) calibration of f_{S2} using a 1 atm-furnace with CO-CO_2-SO_2 gas mixture; and finally 3) sulfur solubility experiments, doping the PST9 sample with about 1 wt% pyrrhotite (FeS), slightly under-saturated in H_2O, at T = 1200 °C, $\log f_{O2} \sim$ NNO and in a range of pressure between 200 and 20 MPa.
Series 1 allows us to minimize iron loss from the silicate melt during the high P experiments (series 3), and series 2 to calculate the fugacities of S-bearing species in the fluid in the high P experiments.
At present the first series of experiments is complete. We checked the efficiency of the method comparing the simple PST9 with the PST9 pre-loaded with Fe, either 5 % or 13 %. The addition of 5% Fe accelerates the kinetics of Fe transport without dramatically changing the original melt composition, encouraging us to test a direct enrichment of the sample at high pressure, shortening the whole process.

MAGMA DEGASSING AT CAMPI FLEGREI CALDERA OVER THE LAST 5 ka

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Volcanic products extruded from the Campi Flegrei caldera (Southern Italy) during the last 5 ka have been studied in order to investigate the role of crystal fractionation, magma mingling/mixing and degassing in triggering these volcanic eruptions. Due to persistent unrest, the explosive character of its volcanism and the large population living within the caldera and its surroundings, the volcanic risk in this nested, resurgent caldera is among the highest on Earth and demands an accurate reconstruction of processes driving recent volcanism, in order to help forecasting its future behavior. We present isotope data on bulk rock, ground mass and separated phenocrysts, along with major and volatile elements contents determined on clinopyroxene-hosted melt inclusions from Nisida, Capo Miseno and Astroni 6 erupted products. The new isotope data suggest that crystal fractionation may account for the chemical variability of the extruded melt, although additional processes, such as magma mingling/mixing and/or entrapment of antecrysts into the magma prior to eruption are required to explain the large isotopic variation displayed by the analyzed products. Furthermore, the new volatile elements data, together with those from literature, allow us to put forward hypothesis on the nature of the volatile rich-magma component feeding the Campi Flegrei volcanic activity in the investigated time interval. New data show that among the investigated eruptions, Nisida eruption was triggered by the arrival of a poor differentiated (latite), volatile-rich magma (H2O up to 4 wt.%; CO2 up to 600 ppm), poorly enriched in radiogenic Sr and unradiogenic Nd (87Sr/86Sr ~ 0.7073; 143Nd/144Nd ~ 0.5125). This is in line with what already proposed for the Agnano-Monte Spina (~ 4.1 ka) and Minopoli 2 eruptions (~ 9.7 ka), both occurred in the eastern sector of the Campi Flegrei caldera. In particular, at Campi Flegrei caldera, poorly differentiated magmas, rose from large depth, along portions of faults of the NE-SW and SE-NW systems, in the eastern sector of the caldera affected by extensional processes, determining geochemical features that are not observed in the western sector, subject to compression.

A PROBABILISTIC METHOD TO CALCULATE VOLCANIC SUSCEPTIBILITY

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In modern volcanology one of the most important aim is to perform hazard maps simulating different eruptive scenarios. The first step is to evaluate the spatial distribution of future vents, based on the past behavior of the studied area. Previous work were done using the kernel density estimation, a probabilistic method to evaluate the susceptibility, based on the priori assumption that new vents will not form far from the existing ones. This method allows to estimate how the density of the opening of new vents varies across a study area, based on a past eruption points pattern. Hence, the importance in choosing an optimal smoothing parameter, well-known bandwidth. The choice of bandwidth depends on the field size and degree of clustering, and it determines the probability distribution far from the structure or vents. Once the bandwidth parameter is obtained, the next step is evaluate the Gaussian kernel to describe the spatial density.

Volcanic hazard assessment is an important step for risk-based decision-making in land use planning and emergency management. The main steps in this work to calculate volcanic susceptibility are the following: (1) Identifing different methods to evaluate the smoothing parameter (bandwidth); (2) Comparing results using differents input parameters and different values of bandwidth in a Gaussian kernel.

Further step consists in building a new plugin in a qGis to create a user friendly evaluation, in a free, multi-platform, and user friendly applicability. It permits to choose the appropriate methods to evaluate bandwidth, depending on the input parameters, depending on the shapefile geometry, and evaluate Gaussian kernel density to obtain susceptibility maps.

STRUCTURAL CONTROLS ON MONOGENETIC VOLCANISM: THE GARROTXA VOLCANIC FIELD CASE STUDY

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The factors controlling the precursory activity in monogenetic volcanic fields are still poorly understood, which makes that eruption forecasts in these systems is not very accurate. The fact that in monogenetic volcanism each eruption has a different vent suggests that volcanic susceptibility has a high degree of randomness, so that accurate forecasting is subjected to a very high uncertainty. This has been illustrated in the case of the recent El Hierro eruption, in which the exact determination of the vent was not possible before the onset of the eruption. Recent studies on monogenetic volcanism reveal how sensitive magma migration may be to the existence of changes in the regional and/or local stress field produced by tectonics or lithological contrasts (i.e., intrusion of magma bodies), which may induce variations in the pattern of further movements of magma, thus changing the location of future eruptions. This implies that a precise knowledge of the stress configuration and distribution of rheological and structural discontinuities in such regions is crucial to forecast monogenetic volcanism.

We use the Garrotxa Volcanic Field as a case study to improve our understanding of the local 3D geology of monogenetic volcanic fields. We have used a combination of high precision geophysical techniques, including gravimetry, self-potential and electrical resistivity tomography, in order to investigate the relationship between local tectonics and the spatial distribution of monogenetic volcanoes in the Garrotxa. Our results show that this volcanic field is underlain by low-density material, which partly can be interpreted as the roots of surface manifestations of volcanic activity. They also show that most of the eruptive fissures which have controlled the volcanic activity in this area for more than 300 ka correspond to NE-SW and NW-SE oriented tectonic structures. This suggest that ascent and eruption of magmas in this volcanic field has been controlled by the same regional normal faults bounding the horsts and grabens of the area and which seems to be related to the origin of magmas at the base of the lithosphere. This explains the high magma ascent velocities (0.2- 2m/s) found in these volcanoes, which together with the presence of mantle xenoliths and lower crust cumulates suggest that some of the eruptive fissures and faults reached quite deep in the lithosphere. The occasional diversification of magma at the upper part of the crust towards secondary fractures of the same structural system seems due to stress barriers caused by the presence of intrusive bodies from previous eruptions and stratigraphic discontinuities in the substrate

Lessons from the VUELCO-Colima 2012 Simulation Exercise - Hazard Assessment Reports must be in writing but what should they contain and why?

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Immediately after the VUELCO-Colima 2012 volcanic unrest simulation exercise, feedback was obtained from the two Civil Protection authorities that took part – the authorities for the States of Colima and Jalisco respectively. The feedback was mixed and yet very informative. It covered the content and format of the scientific output from the expert elicitations and the perceived strengths and weakness of the exercise.

We will present not only a detailed written analysis of the feedback but also a draft pro-forma "boilerplate" hazard assessment report for discussion.

This exercise (the first of four VUELCO unrest simulations) raises a surprising variety of challenging issues, which need to be considered before the next simulation later this year. They include:

- the representative status of individual committee members;
- the allocation of roles for communication with stakeholders and the media (the "L'Aquila issue");
- the clear, accurate and full presentation of hazard scenarios, probabilities and trends;
- advice regarding:
    - alert levels; and
    - future monitoring activities and related safety issues; and
- the careful explanation of terms, assumptions and limitations.

A further interesting dilemma arose during the exercise. What should scientists (hazard assessors) do when the Civil Protection authorities, to whom they are reporting, have very different expectations in relation to the role of scientists and the content and purpose of their contribution?

"Reflections on the L'Aquila verdict - A candid risk assessment of the role of the earth scientist and some suggestions for risk management"

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The scientific community's public reaction to the conviction and sentencing of seven Italian scientists was immediate, passionate and, too large extent, ill-informed. The after-shock waves were predictable; the Twitter feeds, blogs and press releases vitriolic. There was unanimity that we were witnessing a "modern world of litigation" and a "blame game" with vulnerable "scapegoats". It was noted that the case showed "very vividly how the media, and thus certain fractions of society, can misinterpret… scientific statements…and misuse them for their own purposes". It was predicted that subjecting scientists to criminal charges may:

- have very adverse effects on academic research:
- prevent the free exchange of ideas that is essential for progress in science; and
- discourage scientists from participating in matters of great public importance.

The real issues raised by L'Aquila must be identified, assessed and confronted without delay and we are responding to the following statement from the IAVCEI.

> "Scientists involved in natural hazard assessment must clarify with their employer or the organization they are accountable or report to, just exactly what is expected of them, what their level of responsibility is, and what the chain of command and reporting protocols are between them as scientists and the civil and government authorities they work with. Without establishing such an agreed…understanding, such scientists are vulnerable and quite frankly, in the modern world of litigation, they would be foolish."

We suggest that there is no need for scientists to withdraw their irreplaceable services provided they adopt self-protection strategies that have been used and perfected by other at-risk professionals over many years.

When condemning the prosecuting authorities, the scientific community showed impressive solidarity. Only time will tell whether it can also craft a protocol, which will protect vulnerable scientists in an increasingly open and litigious society – one frequented by blame-shifting officials and watched by a voracious media.

FEARING THE KNOCK ON THE DOOR: CRITICAL SECURITY STUDIES INSIGHTS INTO LIMITED COOPERATION WITH DISASTER MANAGEMENT REGIMES

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In seeking to provide for the safety and resilience of local communities in the global south, there has been an apparent policy focus on making early warning systems more robust, and improving the operation of disaster management programmes. However, the critical security studies literature has highlighted the ways in which security practices, including those nominally implemented on behalf of local communities can have negative impacts on peoples. Human security literature, in particular, highlights the ways in which the state security apparatus, which is often relied upon to notify and enforce evacuations, may often be perceived as a serious risk to communities.

At the same time individuals live within complex security situations where daily threats to peoples' lives may outweigh geological hazards. Grounded within critical literature on the social construction of risk (Lupton; Beck, Douglas), the ways in which volcanic risk is calculated, communicated, and enacted upon, will be assessed in relation to the local communities' security dilemmas.

This paper explores the ways in which competing claims of what constitutes security challenge the operating assumptions in emergency preparedness. Drawing on initial field work in communities at risk from lahars generated from Cotopaxi in Sangolqui, Ecuador, this paper challenges the operating assumptions in emergency preparedness. In June 2012, over 150 primary interviews were undertaken as a part of the EU funded VUELCO project in Ecuador. The findings were analyzed using quantitative and qualitative methodologies, drawing most heavily on interpretive methodologies to argue that the scientific representation of Volcanic hazards, and the resultant disaster management strategies, do not account for local context. Indeed, the majority of interviewees indicated a lack of trust in either scientific expertise or government representatives, on questions of security. By incorporating a broader narrative of security, disaster preparedness and communication plans can be more effective.

COLIMA VOLCANO EXERCISE: PLANNING, DEVELOPMENT AND LESSONS LEARNED

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In the context of Work Package n. 9 *"Decision making and unrest management"*, Task n. 9.6 *"Simulation of unrest and decision-making"* is aimed at the organization of four simulation exercises at different target volcanoes, through the four years of project duration.

According to the decision of the *Steering Committee*, the first exercise was held at *Volcan de Fuego de Colima* (Mexico) on November 2012, in coincidence with the 7th edition of the international congress *"Cities on Volcanoes"*.

The main purpose of these exercises is to explore the applicability of models, methods, protocols and procedures, developed within the other work packages of the project, to unrest crises.

Products to be tested in an evaluation-decisional-operational chain, are mainly the probabilistic models for eruption prevision and the communication protocols for the interaction between scientists and decision-makers, and for the information to the exposed population.

With this presentation we describe how the exercise was planned, including the definition of goals and different phases, elaborated in strict conjunction with the UNAM, the CENAPRED, the Colima University and the Civil Protection of the States of Colima and Jalisco.

We also illustrate the development of the simulation exercise through the scientific meetings, the information assemblies with local people, the decision making process and the final evacuation drill.

Finally we try to retrieve useful indications in order to capitalize the experience for the next exercises.

Through the development of simulations on different volcanoes, in dissimilar social, cultural and economic contexts, we aim at the improvement of the products, in order to get - at the end of VUELCO project - to the definition of best practices for the management of real unrest crises worldwide.

Hazard Communication and Local Perception of Lahar Risk at Cotopaxi Volcano, Ecuador

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This research examines risk perception and hazard communication for Cotopaxi Volcano, Ecuador, which has shown increased unrest in recent decades, since the last eruption in 1940, which may be suggestive of a future phase of eruptive activity. One of the main eruptive and non-eruptive volcanic risks on glacier-clad Cotopaxi are lahars. This study focuses on the Valle de los Chillos, one of three drainage systems down which lahars are channelled.

Risk perception at it's simplest can be seen as how risk is understood or interpreted by a person(s). The perception a population has of a volcanic hazard influences their reaction to disasters, as well as influencing mitigation procedures. Allied to risk perception is hazard communication, which seeks to educate people about risks and mitigation.

Individuals and communities face multiple sources of risk, and their perception of volcanic risk can potentially increase or decrease vulnerability. Therefore, risk perception and hazard communication need to be studied in relation to volcanic risk, and in relation to the Northern Valley of Cotopaxi, lahar risk.

This study focussed on the towns of San Rafael and Sangolquí, and comprises of 158 interviewees. The focus was on individuals' perceptions of lahar risk, broader perceptions of insecurity, and hazard communication and education, applying qualitative and quantitative methods. Statistical evaluation of the interviews, aimed to determine a view of the overall risk perception and communication in the towns.

Output from this research aims to improve the understanding of risk perception and hazard communication around Cotopaxi and other densely populated areas along lahar drainage systems. Research has generated a number of results including that perception of volcanic risk is low, as well as there being a lack of trust in officials. Ultimately, research into this important topic should provide long-term solutions to improve the protection of at-risk populations.

COMUNICATION PROTOCOLS QUESTIONNAIRE

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Within WP8 activities, a questionnaire has been designed to collect information of the way the scientists and decision-makers transmit the information between them and to the population and to the media. We hope it will help us to identify different communication structures and strategies on different countries / volcanoes.

The questionnaire has been designed for both scientists and decision-makers, and therefore is divided into two main sections. The first (and longest) section is specific to scientists and tries to decipher the structure and organisation of the Scientific Committee(s). It is followed by a block about how scientists communicate both to the decision makers and (if it is the case) to the media and population. The second section is specific to decision-makers and tries to identify how they want to receive the scientific information (language, qualitative/quantitative information, probabilities… etc) and how they communicate with both the media and the population. After each section, an open question asks the respondent about his opinion on the suitability of the present structure/rules/praxis and (if there is any) aspects that he/she would modify.

ADVANCES IN INTEGRATED VOLCANIC GEODETIC MODELLING AND APPLICATION TO DEEP-SEATED UNREST AT UTURUNCU VOLCANO, BOLIVIA

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Moving on from simple, analytical deformation models, we have developed a suite of numerical models that can account for a range of realistic crustal complexities and are thus more consistent with multi-disciplinary constraints. Using Finite Element techniques through commercial code COMSOL Multiphysics we can incorporate the following additional intricacies over the homogeneous, isotropic, elastic half-space's usually employed: viscoelasticity, elasto-plasticity, crustal heterogeneity, lateral discontinuities, topography, gravity-loading, multiple or irregular shaped sources and temperature-dependent rheology. These developments allow for more advanced and integrated models of deforming volcanoes that better constrain causative sources of unrest. Successful benchmarking against analytical equivalents has been carried out where possible to validate model results.

We apply the models to an on-going period of unrest at Uturuncu volcano in southern Bolivia, focusing on the driving mechanism behind a 70 km wide region of ground uplift. To constrain a viable model we test for first-order parameters that reproduce the observed maximum uplift rate of 1 – 2 cm/yr between 1992 and 2006. We account for heterogeneous and homogeneous subsurface structure in elastic and viscoelastic rheologies. Contrasting crustal heterogeneity and homogeneity highlights the significant effect of a mechanically weak source-depth layer. This alters surface deformation patterns by absorbing more of the subsurface strain than its surroundings, thereby acting as a mechanical buffer. As elastic models can only account for the spatial component of deformation, their results are used solely to guide the parameters tested in the viscoelastic models. We explore a range of possible source geometries but reject spherical and oblate shapes on the grounds of their depth and likely unsustainable pressurisation given the expected crustal mechanics. Our preferred model suggests that pressurisation of a magma source extending upward is causing the observed uplift and requires a continued increase in this pressure to explain both the spatial and temporal displacement patterns.

THE SOURCE MECHANISMS OF LOW FREQUENCY EVENTS AT VOLCANOES

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Low frequency (LF) events have been observed in many volcanic settings worldwide. LF seismicity in volcanoes is associated with a stable, non-destructive and repeatable process such as fluid movement in, or resonance of a fluid-filled conduit. In-depth investigation of the trigger of LF events, as well as their spatial and temporal extent, is crucial to gain a better understanding of the sub-surface dynamics leading to, or preventing, volcanic eruptions. Neuberg et al. (2006) proposed a conceptual model for the trigger of LF events at Montserrat involving the brittle failure of magma in the glass transition in response to high shear stresses during the upwards movement of magma in the volcanic edifice.

For this study, synthetic seismograms were generated following the proposed concept by using an extended source modelled as an octagonal arrangement of double couple sources approximating a ring fault. The model adopts the seismic station distribution and velocity structure as encountered on Soufrière Hills Volcano, Montserrat.

In an attempt to gain a better quantitative understanding of the driving forces of LFs, inversions for the physical source mechanisms have become increasingly common. Therefore, we performed moment tensor inversions carried out under the common (but wrong) assumption of a point source rather than an extended source triggering the LF events. For comparison we interpreted the same data in terms of a ring fault structure.

We discuss these inversion results, and how to interpret the moment tensor components (double couple, isotropic, or CLVD), which were based on a point source in comparison to an extended source. Due to interference, the amplitude of the seismic signals of a ring fault is greatly reduced when compared to a single double couple source. Furthermore, best (but misleading) inversion results yield a solution comprised of positive isotropic and compensated linear vector dipole components. Thus, the physical source mechanisms of volcano seismic signals may be misinterpreted as opening shear or tensile cracks when wrongly assuming a point source. If interpreted as magma movement the reduced amplitudes will lead to an underestimation of magma ascent rate by an order of magnitude, and finally the time history of the magma motion will be distorted as well.

BUBBLE NUCLEATION IN H2O-CO2 BEARING BASALTIC MELTS: RESULTS OF HIGH TEMPERATURE DECOMPRESSION EXPERIMENTS

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Previous experiments have demonstrated that mechanisms of basalt degassing are strongly contrasted when gas bubbles are present or when they are absent. Consequently, experimental information on the kinetics of bubble nucleation in basaltic melts is needed, and high temperature decompression experiments have been investigated.

All experiments used basaltic pumice from Stromboli as starting material. The sample was fused in air at 1400°C for 3h and then cylinders were cored. Synthesis experiments were performed to produce the volatile-bearing melts to be used in the decompression experiments. Glass cores, distilled H_2O and $Ag_2C_2O_4$ were loaded in AuPd capsules (3 different dissolved H_2O/CO_2 were introduced). The synthesis experiments were ran at 1200°C during about 40h in an internally heated pressure vessel. At the end, glasses were cut in 2 parts: one for the decompression experiments and the other for the analysis. Decompression experiments were conducted at a fast rate of 39kPa/s and 1200°C, from an initial pressure (P_{in}) of 200 MPa and to final pressures (P_f) of 200, 150, 100, 50 and 25 MPa. Charges were rapid-quenched immediately after attainment of P_f. Textures were analyzed by X-ray microtomography, and volatile concentrations and spatial distributions in pre- and post-decompression glasses were determined by FTIR.

Pre-decompression glasses have homogeneous volatile contents and distributions: group #1 (average H_2O content = 4.82 wt.%, average CO_2 content = 0 ppm), group #2 (2.15 wt.%, 883 ppm), group #3 (0.82 wt.%, 849 ppm).
Textural characteristics (vesicularities, bubble numbers, densities and sizes) suggest that homogeneous bubble nucleation occurs between 50 and 25 MPa.
Decompression experiments show that equilibrium (groups #1 and 3) and disequilibrium degassing paths (group #2) can be obtained and that final glass compositions can be CO_2 supersaturated.

BEST PRACTICE AND COMMUNICATION PROTOCOLS OF THE SPANISH VOLCANO MONITORING AND ALERT SYSTEM

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Penultimate eruption in Spain took place in 1971 (Teneguía volcano, La Palma Island), when no volcano monitoring network and no legal framework for volcano emergencies management existed in Spain. In 1996 a National Basic Directive for Volcanic Risk Management was published, followed in 2010 by the Canarian Plan for Volcanic Emergencies and Risk (PEVOLCA) and, more recently (February 2013) by the National Civil Defence Plan for Volcanic Risk. Meanwhile, in 2004, the National Geographic Institute (IGN), already in charge of National Seismic Network, was designated as the institution in charge of volcano monitoring and the declaration of volcanic alerts.

The unrest, eruption and post-eruption activity on El Hierro Island during 2011-2012 has been the first opportunity to test the effectiveness of the volcano monitoring system and the Regional Plan (PEVOLCA). This test has shown that while volcano monitoring has been conducted satisfactorily, obtaining a real time full record of geophysical and geochemical signals during the whole process, improvement is needed in the communication between the different institutions involved, and from these to the media and population. It has also evidenced the need of a detailed protocol of good communication practices between all partners at every level, and, specifically for the diffusion of the information to the media and population.

This presentation will show the experience of El Hierro eruption, pointing out different aspects of communication that should be improved.

Geodynamic constraints of Canarian volcanism

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The intimate relationship between tectonism and magmatism is evident in all volcanic environments, where magma production, magma ascent rate, loci of volcanic activity, and the style of volcanic activity, are directly dependent on the regional/local tectonic characteristics of the area. A good understanding of the geodynamic controls of volcanism is crucial to characterise its associated hazards and to forecast future volcanic eruptions. Unfortunately, very few active volcanic areas are well constrained in terms of their geodynamics, which are basically investigated at a regional scale in order to understand the origin of the related magmatism, but not at a more local scale trying to characterise the structural controls on magma evolution and eruption. In this contribution we investigate the geodynamic framework of Canarian volcanism, applying numerical modelling to determine the current distribution of regional and local stresses. On the light of the results obtained we discuss the structural controls of the Canarian volcanism, and propose a conceptual model that explains the interplay between volcanism and geodynamics as an effective way to forecast future volcanic activity in this area.

UNDERSTANDING VOLCANIC UNREST: LESSONS LEARNED FROM THE 2011-2012 EL HIERRO ERUPTION

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Forecasting volcanic eruptions based on the analysis of precursory activity recorded by monitoring systems is possible, as it has been demonstrated in a number of recent eruptions which have been successfully anticipated . Also, there exist older cases that illustrate how the knowledge of local people on volcanic activity and its effects, even much earlier than having monitoring systems, permitted them to anticipate to volcanic eruptions and to scape to their effects. However, the history of predicting volcanic eruptions also includes an important number of failed forecasts with a number of false alarms and wrong interpretations of what had to happen.

The recent eruption at El Hierro has demonstrated that magma migration in monogenetic volcanism is strongly dependent on stress barriers defined by structural and rheological discontinuities. In El Hierro eruption, the location of initial seismicity (i.e., magma accumulation) in the northern side of the island and the presence of recent volcanism (Tanganasoga) in the same area and on the neighbouring western rift zone, led us to think that the eruption could occur there. However, the final outcome showed how far off our assumed scenario was from the actual eruption location, thus demonstrating once again that forecasting volcanic eruptions must rely on a good understanding of the monitoring signals but also on a good knowledge of the local 3D geology and geophysics.

CONSTRAINING CONDITIONS FOR PHREATIC ERUPTIONS AND EVALUATING THE INFLUENCE OF HYDROTHERMAL ALTERATION ON THE PROCESS: AN EXPERIMENTAL APPROACH

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Phreatic eruptions are caused by rapid evaporation of hydrothermal fluids to steam with the resulting pore overpressure leading to fragmentation of overlying rocks.
We investigate White Island (New Zealand) and the active volcanic sites Solfatara and Monte Nuovo in Campi Flegrei (Italy); further our study will involve Valley of Desolation and Wotten Waven (Dominica). All of these sites are characterised by intense hydrothermal alteration and have high potential of future phreatic, phreatomagmatic and magmatic eruptions. Here, we constrain the influence of alteration on phreatic eruption conditions and on the stability of an edifice subjected to an active hydrothermal system. White Island was chosen as a first case study, where we worked on hydrothermally altered lavas, four lithified pyroclastic deposits with different grades of alteration, unconsolidated material and sulfur- and iron-rich crusts from the crater-fill.
The low porosity (6.6-8%) altered lava was found to be moderately strong (110-140 MPa) when deformed in uniaxial compression tests. The altered pyroclastic rocks are more heterogeneous, porous (32-48%) and weaker (3-20 MPa). Conditions for phreatic eruptions were constrained by fragmentation experiments due to rapid decompression (from 9 MPa to atmospheric pressure) at temperatures ≤ 300°C. This provided information about the energy threshold, fragmentation efficiency, the maximum speed and evolution of particle ejection velocities. The fragmentation threshold increases with decreasing porosity. Higher applied energy and water saturation of the sample improves the fragmentation efficiency. The particle ejection velocity after fragmentation rises with the applied pressure and porosity. For fragmentation experiments at 6.5 MPa and 300°C on dry consolidated samples, the ejection speed (45 m/s) is significantly lower than for fully water-saturated samples (145 m/s). Our study suggests that hydrothermal alteration and fluid-saturation associated with the presence of a hydrothermal system weakens the rocks, which may result in slope destabilisation, lateral/sector collapse and further phreatic eruptions.

COMPLEX MAGMATIC SYSTEMS AND GEOPHYSICAL SIGNAL ANALYSIS: WHAT CAN WE REALLY UNDERSTAND FROM INVERSIONS?

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Many volcanic eruptions are shortly preceded by new magma injection into a pre-existing, shallow (< 10 km) magma chamber, causing convection and mixing between the incoming and resident magmas. These processes may trigger dyke propagation and further magma rise, inducing long-term (days to months) volcano deformation, seismic swarms, gravity anomalies, and changes in the composition of volcanic plumes and fumaroles, eventually culminating in an eruption. Although new magma injection in shallow magma chambers is a potentially hazardous event, its occurrence is still not systematically detected and recognized. Here we present the results of numerical simulations of magma chamber replenishment by buoyant magma of deeper origin, and the associated gravity changes, seismicity, and ground deformation. Synthetic gravity changes and ground deformation patterns are then inverted with classical methods, to check their capability to detect the source of signals. The results show that the invaded shallow chamber may be not revealed by inversion of ground deformation, as a consequence of non-homogeneous pressure changes resulting into substantial deviations from usual simplifying assumptions when inverting the data. While ground deformation patterns and volcanic seismicity tend to illuminate the deeper regions of the magmatic system, gravity changes are controlled by the shallow system where gas expansion dominates. These results suggest that i) classic simplifications in data inversion techniques may be largely inadequate for magmatic systems, and ii) more robust inversions require joint use of a variety of data including gravity changes.

Experimental constraints on magma mixing: case studies from Phlegrean Fields and Montserrat

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The mixing process in nature is observed at different scales in the rock record, evident through variable structural and textural patterns and morphologies such as filament-like structures, enclaves, and mineral phases showing physico-chemical disequilibrium. The type and geometry of these structures strongly depends on the mixing dynamics (e.g. Perugini et al., 2012; Morgavi et al., 2013). The quantification of the morphology and the compositional variability of these structures are essential to understand this fundamental igneous process and require detailed analytical and experimental studies. Although mixing between mafic and felsic magmas is regarded as a major process affecting compositional variability of igneous rocks in the Earth system and eruption trigger, the mechanisms acting to promote melt interaction, both from the physical and chemical point of view, are still poorly understood.

We will perform the first set of chaotic mixing experiments using trachytic and phonolitic magma from the Phlegraean Fields volcanic area and andesitic and basaltic magmas from the Soufriere Hills Volcano, Montserrat.The mixing process will be trigged by a recently developed apparatus that generates chaotic streamlines in the melts, mimicking the development of magma mixing in nature. The study of the interplay of physical dynamics and chemical exchanges between melts it will be carried out by time series mixing experiments under controlled chaotic dynamic conditions. The variation of major and trace elements it will be studied in detail by electron microprobe (EMPA) and Laser Ablation ICP-MS (LA-ICP-MS).

The aim of our work is to quantify how different chemical elements homogenize in the magmas at differing rates. The mobility of each element during mixing it will be estimated by calculating the decrease of concentration variance in time. These results will constitute a robust basis for determining the timescale of the mixing process at Phlegrean Fields and Soufriere volcano using the differential mobility of chemical elements.

MULTIPLE MAGMA DEGASSING SOURCES AT AN EXPLOSIVE VOLCANO

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Persistent degassing of closed-conduit explosive volcanoes may be used to inspect and monitor magmatic processes. After interaction with shallow hydrothermal fluids, volcanic gases collected at surface can differ substantially from those exsolved from magma. We report here on an innovative approach to identify and separate the contribution of variable magmatic components from fumarolic gases, by processing the 30-year-long geochemical dataset from the Campi Flegrei caldera, Southern Italy. The geochemical record shows periodic variations, which are well correlated with geophysical signals. Such variations are interpreted as due to the time-varying interplay of two magma degassing sources, each differing in size, depth, composition, and cooling/crystallization histories. Similar multiple degassing sources are common at explosive volcanoes, with frequent ascent and intrusion of small magma batches. Our innovative method permits the identification of those magma batches, which contributes to the interpretation of unrest signals, forecasting and assessment of volcanic hazards.

MAGMA CHAMBER PARADOX: DECOMPRESSION UPON REPLENISHMENT

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The invasion of active magma chambers by fresh magma of deeper provenance is invariably assumed to cause chamber pressurization. Pressure increase thus stands as an intuitive consequence of magma chamber replenishment. However, new numerical simulations demonstrate that pressure evolution is highly non-linear, and that decompression dominates when large density contrasts exist between injected and resident magmas. This apparent paradox originates from the compressible nature of volatile-rich magma and the dynamics of convection associated with injections of buoyant magma. While decompression can dominate in a shallow chamber, pressure increase develops in the connected deep regions of magma provenance. These results contradict classical views adopted to interpret observations at active as well as fossil magma chambers, and demonstrate that a simple reliance on intuition is insufficient: what may be perceived as a paradox – magma chamber decompression upon replenishment – is instead likely, and rooted in the complex physics that governs the multiphase, multi-component dynamics of magma transport in geometrically composite, spatially extended magmatic systems.

VOLCANIC UNREST IN THE 21ST CENTURY

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One of the most pertinent issues in volcanic risk management is the question whether volcanic unrest will culminate in an eruption in the short-term or not. This question is particularly difficult to answer at volcanoes where unrest is preceded by lengthy periods of quiescence and where hard data on pre-eruptive processes before previous eruptions is absent.
Here, we review and evaluate global unrest reports between January 2000 and June 2011, which draw largely from information presented by the Global Volcanism Program but also from the scientific literature. We aim to evaluate the nature and length of unrest activity in a view to help better assess future unrest episodes. The available information on 229 volcanoes is categorised into eruptive and non-eruptive unrest to evaluate the temporal distribution of unrest activity and to test the significance of observed unrest patterns at different volcano types. Timelines for different volcanoes were created to demonstrate how unrest develops over time and to highlight different modes of unrest including reawakening, pulsatory, prolonged, and sporadic unrest. Through combination of time series and statistical analyses we find that 2 out of 3 volcanoes with reported unrest erupt in the short-term. Although this ratio varies when considering different volcano types, the median average unrest duration is about one month before eruption, regardless of the length of the inter-eruptive period. Assuming that the investigation period is representative for any given observation period then there is an almost 50\% chance of an eruption within about 20 days of the beginning of unrest. By contrast, if unrest outlasts a period of about 11 weeks, the chance of an immediate eruption decreases significantly to about one in five. We find that there are very poor correlations between the length of the inter-eruptive periods and unrest durations across all investigated volcano types. This suggests that the hypothesis that volcanoes with long periods of quiescence between eruptions will undergo prolonged periods of unrest before eruption is not supported by our analysis. Our findings may have implications for hazard assessment, risk mitigation and scenario planning during future unrest crises.

WORK-IN-PROGRESS: NON-MAGMATIC BRANCHES IN THE BAYESIAN EVENT TREE FOR ERUPTION FORECASTING (BET_EF), AND THEIR IMPLICATIONS FOR UNREST TRACKING

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In the previous set up of the Bayesian Event Tree for eruption forecasting (BET_EF), only magmatic eruptions are considered. However, non–magmatic events, such as increased hydrothermal, seismic or phreatic activity, are often obvious signals of volcanic unrest that may cause damages. Here we propose an implementation of the BET_EF that considers these kind of non–magmatic risks related to volcanic areas. This implementation requires a modification at Node 2 of the Event Tree where the nature of the unrest is introduced. In order to assign the probability to the new branches of Node 2, suitable monitoring parameters, and thresholds should be established; ultimately, this requires a more profound understanding of the delicate transition from volcanic quiescence to unrest, and of the differences in the processes generating different kinds of volcanic unrest (e.g., what could be a precursor for a phreatic eruption?). We think that this further ramification of the BET_EF code will bring several advantages: it permits to (1) better describe the cause of unrest of any volcano, also including the numerous volcanoes in a state of non–magmatic unrest, not considered earlier, (2) forecast the evolution of non–magmatic unrest into non–magmatic eruptions (Node 3) that pose direct volcanic hazard without magma involvement (e.g., phreatic eruptions, mechanic failure of volcanic edifices, gas hazard), and (3) quantify the probability of non–magmatic unrest being precursory signals themselves when building up towards magmatic unrest or magmatic eruptions (e.g., tectonic earthquakes triggering an eruption, transition from phreatic to phreatomagmatic eruptions). The latter point implies strong modifications in the numerical calculations of the BET_EF probabilities. The proposed modifications are useful to better describe volcanic unrest, especially for the closed–conduit VUELCO target volcanic systems of Campi Flegrei (Italy), Morne Aux Diables (Dominica), Teide (Tenerife, Spain), Cotopaxi (Ecuador) and Soufrière Hills (Montserrat).

FORECASTING VOLCANIC UNREST USING SEISMICITY: THE GOOD, THE BAD AND THE TIME CONSUMING

R. Salvage[1] **and J. W. Neuberg**[1]
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Volcanic eruptions are inherently unpredictable in nature, with scientists still struggling to forecast the type and timing of events. Current understanding suggests that the use of statistical patterns within precursory datasets of seismicity prior to eruptive events could hold the potential to be used as real time forecasting tools since they allow us to determine times of clear deviation in data, which might be indicative of volcanic unrest.

The identification of low frequency seismic swarms and its acceleration prior to observed volcanic unrest may be key in developing forecasting tools. We concentrate on understanding the significance and development of these seismic swarms as unrest develops at Soufriere Hills Volcano, Montserrat, with application of the Material Failure Law as a forecasting technique for the timing of eruption. In particular, analysis of accelerations in event rate, amplitude and energy rates released by seismicity prior to eruption suggests that these are important indicators of developing unrest which could be used in real time forecasting systems.

Although more time and computationally intense, cross correlation techniques applied to continuous seismicity prior to volcanic unrest scenarios allows all significant seismic events to be analysed, rather than only those which can be detected by an automated identification system. This may allow a more accurate forecast since all precursory seismicity can be taken into account. In addition, the classification of seismic events based on similarities in waveforms seems to herald a more accurate forecast of the timing of volcanic unrest using the Material Failure Law if only one "family" (events with similar waveforms) is considered. Therefore, the pre-processing of seismicity prior to using it as a forecasting aid of volcanic unrest may be extremely important, but whether this can successfully be applied in real-time forecasting scenarios is yet to be fully explored.

BLIND RETROSPECTIVE APPLICATION OF BET_EF DURING COLIMA EXERCISE: SETUP AND RESULTS

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Bayesian Event Tree for Eruption Forecasting (BET_EF) is a tool to assess the probability of different outcomes linked to magmatic unrest. It is based on Bayesian inference, allowing the merging of heterogeneous sources of two broad classes fo information: non-monitoring (models, past data, expert judgement, mostly used when monitoring data do not reveal unrest), and monitoring data (mostly important during an unrest phase). BET_EF provides a quantification of two distinct uncertainties: aleatory, quantified by the "best guess" and due to the intrinsic stochasticity of volcanic unrest, and epistemic, quantified by a dispersion around the best guess and due to our limited knowledge.

In setting up BET_EF for Colima volcano *prior* to the beginning of the drill, we mostly relied on literature in the Colima dossier, and on two reports received from R.Arambula and G.Reyes from UNAM, referring to the period 1998-2011 (except for size forecasting, based on Mendoza-Rosas & DeLaCruz-Reyna, 2008). The forecasting time window was of 1 month. For the monitoring information, we only included systematically measured parameters, with a reasonable consensus on the meaning of their potential anomalies. The anomaly thresholds were selected by inspecting published time series of these parameters.

On the drill's first day, Colima volcano was already in magmatic eruption (dome was already extruding). This precluded any further use of BET_EF, and the VUELCO group continued with a basic expert elicitation. Thus, we decided to re-analyze the monitoring information provided about the few months before the drill's beginning, and retrospectively apply BET_EF to blindly check its performance. The most relevant result is that unrest (revealed by increased VTs) was clear by the end of October 2011, and its magmatic nature (revealed by numerous LPs) after the 1st week of November approximately.
Results of the VUELCO experts' elicitation will also be provided in this talk.

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HASSET: A PROBABILITY EVENT TREE TOOL TO EVALUATE FUTURE ERUPTIVE SCENARIOS BASED ON BAYESIAN INFERENCE. PRESENTED AS A PLUGIN FOR QGIS

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Event tree structures constitute one of the most useful and necessary tools of modern volcanology to assess the volcanic hazard of future eruptive scenarios. They are particularly relevant to evaluate long- and short-term probabilities of occurrence of possible volcanic scenarios and their potential impacts on urbanized areas. In this contribution we present HASSET, a Hazard Assessment Event Tree probability tool, built on an extended version of the Bayesian event tree structure previously published for Teide-Pico Viejo stratovolcanoes, Tenerife, Canary Islands. This extended version of the event tree includes two additional nodes to account for the type and extension of the hazard phenomena. Also, the new version introduces the Delta method to approximate the accuracy in the probability estimates, by constructing a one standard deviation variability interval around the expected value for each scenario. The method uses Bayesian Inference to assess volcanic hazard of future eruptive scenarios, by evaluating the most relevant sources of uncertainty when estimating the future probability of a specific volcanic event. HASSET is presented as a free software package in the form of a plugin for the open source geographic information system Quantum Gis (QGIS), providing a graphically supported computation of the event tree structure in an interactive and user-friendly way.

INTERPRETING TREMOR CHANGES DURING 2011-2012 EL HIERRO ERUPTION (CANARY ISLANDS)

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One of the most informative geophysical signals that can be recorded on a volcano is the tremor, which has been used as a precursor of eruptive activity as well as a marker of changes of the eruption dynamics. In this contribution we analyse the strong tremor signal that was observed during the 2011-2012 El Hierro eruption and use it to correlate with variations in the eruption dynamics caused by stress and petrological changes of the plumbing system. This continuos seismic signal appeared at the onset of the eruption and finished at the end of it, showing significant variations in intensity, frequency and dynamical parameters during the whole episode. There was no tremor signal during the unrest episode that preceded the eruption, so in this case it was not possible to use this seismic signal as an eruption precursor. However, the comparison of its analysis with other geophysical data recorded during the eruption and the petrological and geochemical composition of the erupted products reveals that there is a strong coincidence between time variations observed in the tremor signal and those observed in tectonic seismicity and magma composition during the eruptions. This suggests that the tremor signal was highly sensitive to changes in the stress conditions of the plumbing system, dimensions of the conduit and vent, intensity of the explosive episodes, and rheological changes of the erupting magma. The results obtained show how the tremor signal was strongly influenced by stress changes in the host rock and rheological variations of the erupting magma, so we conclude that tracking real-time syn-eruptive tremor signals may provide an effective tool to interpret (and forecast ?) eruption dynamics in terms of plumbing system and magma physics variations.

PREDICTING CHANGES IN VOLCANIC ACTIVITY THROUGH MODELLING MAGMA ASCENT RATE

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It is a simple fact that changes in volcanic activity happen and in retrospect they are easy to spot, the dissimilar eruption dynamics between an effusive and explosive event, or simply the appearance of magma at the surface where it was not previously are signs hard not to miss. However to be able to predict such changes is a much more complicated process.

To cause altering styles of activity we know that some part or combination of parts within the volcanic system must vary with time, as if there is no physical change within the system, why would the change in eruptive activity occur? What is unknown is which parts or how big a change is needed. We present the results of a suite of conduit flow models that aim to answer these questions by assessing the influence of individual model parameters such as the dissolved water content or magma temperature. By altering these variables in a systematic manner we measure the affect of the changes by observing the modelled ascent rate. We use the ascent rate as we believe it is a very important indicator that can control the style of eruptive activity.

Linking these changes to observable monitoring data in a way that these data could be used as a predictive tool is the ultimate goal of this work. We will show that changes in ascent rate can be estimated by a particular type of seismicity. Low frequency seismicity, thought to be caused by the brittle failure of melt is often linked with the movement of magma within a conduit. We show that acceleration in the rate of low frequency seismicity can correspond to an increase in the rate of magma movement and be used as an indicator for potential changes in eruptive activity.

DETERMINING THE RELEVANCE OF PRECURSORS. A DYNAMIC INDEXING METHOD FOR ANALYSIS: A POTENTIAL DECISION-MAKING TOOL

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Among the objectives of the VUELCO project is the identification of signals precursory to the eruptive activity, and developing an improved understanding of the links between such precursory signals and the outcome of volcanic unrest. These objectives are aimed to improve decision-making. The WP5 group has addressed this task through a method of precursor indexing aimed to build a database of precursors that may be readily consulted. The method to search for precursors is based on the postulate that a volcano that has shown a long-term period of unrest, signals relevant enough to be used as decision-making factors should appear within a time range of one to three months prior to a significant eruptive event. Precursory signals after a decades-long repose interval may appear and become recognizable over a much longer period. The first stage of the project involves the construction of an indexed database of precursors for Popocatépetl volcano. This task, aimed to rank the precursory signals relevance for further decision-making processes, requires approaches that allows handling large databases and efficiently retrieve and analyze the precursory signals. The main problem, the large size of the monitoring database to be analyzed, has been addressed considering as “Significant Events” only eruptions that have produced columns exceeding 4 km above the crater level. The relevant monitoring data have been compiled for the month (and in some cases two or three months) preceding a SE. The currently uploaded seismic database comprises 172420 files (i.e. nearly 246 Gb of information, as for February 2013). Precursors in this large database have been indexed in a dynamic spreadsheet (Dynamic Data Base), and links to the corresponding data may be visualized, analyzed and processed in a simple and straightforward way.

BETWEEN CYCLIC ERUPTIONS: DENSIFICATION OF SHALLOW BUBBLE-BEARING MAGMA

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Volcanic unrest begins with precursory signals which are the detectable manifestation of dynamic subsurface changes. In 1997, Vulcanian eruptions from Soufrière Hills volcano (SHV), Montserrat, had a mean repose time of 9.5 hours and produced remarkably regular precursory signals. Cyclic Vulcanian eruptions are associated with inflation and deflation and commonly interpreted as periods of gas pressurisation and depressurisation in partially degassed plugs. Inflation and deflation could be explained by changes in pore-volume in cracks or bubbles in or beneath this plug. However, the specific mechanism by which this occurs and the timescales over which pore-networks can collapse remain poorly constrained. To investigate a densification scenario we present results from experiments using pumice from the February 2010 partial collapse of Soufrière Hills volcano (SHV). We measured the change in volume and the pore network by helium pycnometry, P and S wave velocities and permeability. We used X-ray computed tomography and optical microscopy to compare the 3D and 2D textural evolution of experimentally deformed samples with naturally dense samples from the same eruption. Sample core volume, porosity and texture were measured and assessed before and after experiments. We heated samples under atmospheric pressure conditions at 2 ˚C.min^{-1} and 20 ˚C.min^{-1} to isotherms of 860 ˚C, 900 ˚C and 940 ˚C for intervals up to 8 hours before cooling. Over an 8 hour timescale relevant to SHV cyclicity, samples show a ≤ 54% volume loss. For a given peak temperature, samples with initial total porosities of 80-84% reduce in volume an order of magnitude more quickly than samples with an initial total porosity 70-74%. Using thermo-gravimetric analysis (TGA) we confirm that the peak volatile loss at these heating rates occurs below the glass transition interval and thus the de-volatilisation effect on melt viscosity does not contribute significantly to the collapse rate. Samples of similar porosity but different aspect ratios collapse proportionally, leading to the exclusion of gravity as the significant mechanism driving densification in our experiments. Consequently, we propose that surface tension acts to increase pore connectivity and reduce internal surface area. We show that the initial rate of volume loss can be correlated with the initial pore volume and the temperature. Therefore we propose that for a given melt composition the collapse under static atmospheric conditions can be estimated from the initial porosity. In a volcanic context, the pore and confining pressures modify the effective pressure, thus the dynamics. Our experiments provide a constraint of the timescale and resultant textures during the collapse of bubble-bearing magma at temperature conditions relevant to SHV following explosive eruptions. Densification by rapid porosity reduction could contribute to the precursory signals, such as flank tilt, of volcanic unrest observed between the 1997 cyclic Vulcanian explosions.