Working Group of the European Seismological Commission
SEISMIC PHENOMENA ASSOCIATED WITH VOLCANIC ACTIVITY

Annual Workshop

"Seismicity related to the reactivation of dormant volcanoes"

Olot, Catalunya, Spain – 18-24 September 2006

Conveners

Jurgen Neuberg, University of Leeds, UK (WG chairman)
Roberto Carniel, University of Udine, Italy (WG secretary)
Alicia Garcia, CSIC, Madrid, Spain
Ramon Ortiz, CSIC, Madrid, Spain
Joan Marti, CSIC, Barcelona, Spain
Ton Correig, University of Barcelona, Spain

Local organising committee

Xevi Puig, Director of the Natural Parc of the La Garrotxa Volcanic Zone
Emili Bassols, Coordinator of the Natural Heritage of the PNZVG
Llorenç Planagumà, Geologist of the PNZVG

Monday, 18 September

18:00 Recepción offered by the Ayuntamiento de Olot

Tuesday, 19 September

09:00 Workshop opening

09:45 – 18:00 Olot Volcanic complex.
Field trip: Natural Park "La Garrotxa":Volcanic field and phreatomagmatic activity.
Joan Martí: Leader

22:30 White Wine tasting session

Wednesday, 20 September

09:00-12:00 Scientific Session: Seismo-volcanic crisis in Tenerife (2004)

SEISMO-VOLCANIC CRISIS IN TENERIFE (2004): A MULTIDISCIPLINARY PROJECT TO STUDY ITS ORIGIN AND TEMPORAL EVOLUTION.

Alicia Garcia[1] and TEGETEIDE Team

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The Canary Islands, with more than two million inhabitants, constitute an area of high volcanic risk. Several eruptions have taken place in the Canary I. in recent times with an estimated recurrence period of about 25 years. Although recent eruptions were of effusive type, the Teide is a stratovolcano with permanent fumarolic activity and the possibility of explosive eruptions should not be ignored. The last explosive episode has been dated 2000 years ago. It is also known that the explosive eruptions of the Teide volcano are due to processes of magma mixing in which basaltic eruptions acted as a triggering mechanism. Although the time between the basaltic injection and the explosive episodes may be of hundreds of years, cases with a gap of few centuries are known.

At the end of 2001 the Canary Islands region started to show signs of seismic activity with a significant increase in 2003. In spring 2004, the number of seismic events located inland Tenerife increased significantly. After several seismic events felt by the population, a first alert level was declared by the civil defence division of the local government. The seismic activity increased further during 2004 together with an increase of fumarolic activity at the Teide crater, besides that new fumaroles appeared far away from the crater in one of the most populated valleys of the island of Tenerife (Benijo, La Orotava Valley). Due to this situation, the Spanish Ministry of Education and Science recommends and supports the development of a multidisciplinary research project.

TEGETEIDE Project, coordinated by A. Garcia (CSIC) involves to more than 100 researches from different institutions and countries. In this session, the methodologies, new techniques and main results are presented.

The Tenerife Information Seismic Server (TISS): fundamentals, structure and evaluation after two years of operation

Josep Vila (1,2)

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One of the most important developments carried out in the of the seismic actuation on the TEGETEIDE project (CGL2003-21643-E), supported by the Spanish Ministry of Education and Science and directed to study the Teide-Pico Viejo volcanic complex, has been the set up of a system able to interpret time sequence data. The system, named Teide Information Seismic Server (TISS), has been designed to provide tasks of datafarm, server, quality-control of incoming data and to provide a fast and easy to interpret output related to the activity of the studied area. Nowadays the TISS is in normal operation and it consists on two independent hardware systems working in parallel running under linux and using only GNU and/or free distribution software. The TISS receives seismic data in near-real time and it creates a datafarm that unifies all received information using a standard format in time series data storage in Earth Sciences. Using the linux cron facilities and remote synchronization packages, the system applies in real-time a set of programs that perform an automatic analysis to recover the most significant information contained in the waveforms. The TISS provides second level time series directly comparable to SOH and weather/environmental information that can be used to get new insights on the status of a dynamical system (the area under study) and generates graphs of time evolution of all variables considered to provide information on the variation of the status of all stations. Because of the nature of the TEGETEIDE Project, the TISS operates all data analysis procedures automatically and with no delay after the arrival of new data. This includes the generation of a plots of the variation of the selected parameters and the dissemination of results using diverse communication protocols as well as direct access to data in standard formats. After two years of operation, the TISS has revealed as an excellent tool to monitor the internal status of a volcano. The system has been able to identify changes in advance to any external manifestation recorded or felt using classical seismological methods. Several examples on its success will be presented. All of these encourage to keep on continuing analysing data in real time to be prepared to provide fast and coherent responses to any symptom of activity of a volcanic area.

THE MEMORY OF THE SEISMIC NOISE IN THE UNREST OF LAS CAÑADAS CALDERA, TENERIFE, SPAIN.

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The origin of the continuous seismic noise recorded during the last few years in the volcanic island of Tenerife (Canary Islands, Spain) is under debate, due to the important implications in terms of hazard. The seismic noise is strongly affected by anthropogenic contamination, but previous work has recognized the existence of a bidirectional relationship between this noise and the occurrence of local tectonic events. This suggests that the seismic noise is highly informative and could be the source of potential precursors highlighting variations in the volcanic activity. The search for such precursors however needs the presence of persistence in the time series, which reflects a memory of the underlying dynamical system. In this paper, the variogram tool is used to characterize and quantify this persistence.

SEISMICITY OF TENERIFE I.: SPATIAL AND TEMPORAL RELATIONS

Ortiz, R(1); De la Cruz-Reyna, S(2); Marrero, J.M(1),; Tarraga, M. (1); Garcia. A.(1)

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2. Instituto de Geofisica de la UNAM, México

The preliminary analysis of the spatial and temporal distribution of seismic activity in Tenerife I. shows specific behaviour patterns. The analysis of the events shows a different statistical behaviour between the events occurred inside and outside the island. A Markov model has been applied, showing a great stability in the matrix coefficients corresponding to the months with the highest level of activity.

MAGNETIC STUDIES IN TENERIFE

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3. Istituto de Geofisica e Vulcanología, Roma, Italy

The preliminary results of marine and aeromagnetic surveys carried out in Tenerife with the aim of obtaining a better definition of cortical structure, are shown. Besides this, a volcanomagnetic network has been designed as a new forecast indicator of the Teide volcanic activity.

TIME-LAPSE GRAVITY DATA REVEALS MASS MIGRATION DURING THE REACTIVATION OF THE CENTRAL VOLCANIC COMPLEX ON TENERIFE

Gottsmann, J.(1,2), Wooler, L. (3). Martí, J. (1), Fernandez, J.(4), Camacho, A.G. (4), Gonzalez, P.J. (4,5), Garcia, A., (6), Rymer, H. (3)

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5. ITER, Tenerife, Spain
6. Dep. de Volcanologia, MNCN-CSIC, Madrid, Spain

Geophysical signals accompanying the reactivation of a volcano after a period of quiescence must be evaluated as potential precursors to impending eruption. Here we report on the reactivation of the central volcanic complex of Tenerife, Spain, in spring 2004 and present gravity change maps constructed by time-lapse microgravity measurements taken between May 2004 and July 2005. The gravity changes indicate that the recent reactivation after almost a century of inactivity was accompanied by a sub-surface mass addition, yet we did not detect widespread surface deformation. We find that the causative source was evolving in space and time and infer fluid migration at depth as the most likely cause for mass increase. Our results demonstrate that, even in the absence of previous baseline data and ground deformation, microgravity measurements early in developing crises provide crucial insight into the dynamic changes beneath a volcano.

GEODETIC RESEARCH IN TENERIFE I.

Berrocoso, M.[1]; Garcia, A.[2] & UCA Team

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With the aim of distinguishing volcanic and tectonic activity, a key point in the deformation monitoring of an active area, a geodynamical network has been designed. The network is composed by seven GPS stations, two of them in continuous recording at 1 Hz. A high precision line of levelling at 1600 m with radial lines down to 1200 m has been observed for controlling the possibility of occurrence of landsliding in the northern part of Teide edifice, where the present seismic activity is concentrated. A spatial inclinometer has been specifically designed to control the Teide edifice deformation and several radial lines at Las Cañadas caldera for monitoring deformations of Teide-Pico Viejo active complex.

PRELIMINARY RESULTS OF SEISMIC ARRAYS DEPLOYED IN LAS CAÑADAS CALDERA (TENERIFE I.)

Carmona, E. [1]; Garcia, A.[2] and IAG-UGR Team

1. Instituto Andaluz de Geofisica, Univ. de Granada. Granada, Spain
2. Dep. de Volcanología. Museo Nacional de Ciencias Naturales, CSIC, Madrid, Spain.

With the aim of analyzing the seismic activity of Teide volcano, two seismic arrays have been deployed since June to October, 2005 in Las Cañadas caldera, close to Teide-Pico Viejo volcanic complex. The seismic arrays are composed by 9 seismic stations, only one of them of 3-components, with opening of 400 m. The analysis shows volcano-tectonic events, regional earthquakes and other signals of natural origin but unidentified relation to volcano.

ON OSCILLATIONS AND OSCILLATORS. NEW INSIGHTS FOR OLD PROBLEMS: APPLICATION TO THE ANALYSIS OF VOLCANIC TREMORS.

Antoni M. Correig, University of Barcelona

It is a common practice to analyze seismic records at distinct observation points and to connect them via wave propagation. Information is then (very often) recovered through spectral analysis, and interpreted in terms of the resonances predicted by linear models. In the present study we follow a different approach, that of the observation point and directly look at the seismogram as the record of the oscillations an observer will feel when located at a fixed point. The recorded oscillations may be very complicated and our aim is to model them in terms of coupled oscillators. To do so we consider a system composed of three oscillators: an external time dependent force (corresponding to the magma motion), the system response (the medium response) and time dependent noise (the microseism activity). As predictions of the model, the power spectrum and the evolution in phase space are compared with observations with a good qualitative agreement, and confirm previous results about the stochasticity, non-stationarity and non-linearity of the analyzed volcanic tremor time series. We discuss the difficulties of separating the contributions of the three oscillators and emphasize that no reliable information can be retrieved without taking into account the constrains displayed by the system in phase space.

Real-Time monitor of time sequence data: software and applications.

Josep Vila (1,2), Ramon Macià (3,1) & Reinoud Sleeman (4)

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Based on the analysis of the continuous incoming data, a real-time quality-control monitor has been designed for the detection of anomalies on any type of incoming raw seismic data. It is a powerful, simple and easy to implement procedure that can be customized according to the needs of any network or station operations. By means of spectral based subroutines, anomalies related both to instrumental malfunctioning or site modifications are identified. The system has demonstrated to be very powerful in its operation both in large, medium and local scale networks. The system we present outputs instantaneously time domain series being the only delay due to the length of the time segments analyzed and any anomaly is quickly detected. The procedure also allow to extract significant information from the time series very suitable for research purposes, thus being comparable to other methodologies such as RSAM (Endo and

Murray, 1991) or SSAM (Rogers and Stephens, 1995) in the sense of lower sampling rate output time series directly comparable with other state-of-health or control parameters. Under the assumption that technically the system works properly, the system also can be used as a real-time monitor of volcanic active areas where variations of the background seismic noise may reflect variations of the internal status of a volcano, considered this as a dynamical system. The application of this method to wide (Virtual European Broadband Seismograph Network), local (Hellenic Network) and very local (Teide volcano) network areas has proved to be an interesting tool both for research, controlling systems and also as a surveillance methodology. Several examples leads us to consider that the system and other parameters based on the spectral analysis such as the integrated square amplitude are a good tool for improving knowledge of the status of a given site. This includes both instrumentation and site response. The very low requirements in terms of the instruments to be used and logistical maintenance as well as its effortless implementation, make this method also very appropriate for any routine of analysis or control. The low computational requirements make this method also suitable to be implemented in a real-time monitoring system.

16:00-19:30 Scientific session

Volcano seismology in a wider volcanological context

Jurgen Neuberg [1,2]

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Volcano seismology has been for many years the major monitoring tool on active and dormant volcanoes alike. The ultimate aim is to detect changes in volcanic activity by identifying changes in the seismic behaviour in order to forecast an eruption, or in case of an ongoing eruption, forecast the short and longterm behaviour of the volcanic system. A major boost in recent years arose through several attempts of multi-parameter volcanic monitoring and modelling programs, which allowed multi-disciplinary groups of volcanologists to interpret seismic signals together with, e.g. ground deformation, stress field analysis and petrological information.
This talk will give several examples of such multi-disciplinary projects, from first attempts to state-of-the-art. Examples will include the joint modelling of seismic source processes for tremor and low-frequency events together with advanced magma flow models, and the manifestation of magma movement at depth in the corresponding

deformation and stress field at the surface. The volcanic settings comprise Soufriere Hills volcano, Montserrat, and Piton de la Fournaise, La Reunion, for an andesitic and basaltic volcanic end-member, respectively.

First attempt to consider 2D gass loss into numerical magma flow modeling

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Previous 2D fluid flow modeling showed that a possible trigger mechanism for low frequency events could be the brittle failure of the melt near the conduit walls. This brittle failure mechanism requires both high strain rates and viscosity due to cooling at the conduit walls. Since the amount of gas inside the volcanic conduit influences several fundamental parameters of the magma flow such as viscosity and velocity, it has therefore a direct impact on physical processes occurring in the conduit, and especially on the depth of the brittle failure. Introduction of 2D gas loss inside flow modeling thus requires special consideration. Taking into account the bubble shape, it is possible to link the gas volume fraction for a given depth, with the magma permeability. First attempts have then been made in order to map the potential gas loss linked with anisotropic magma permeability. First results of these models will be presented.

Multivariate geostatistical model for the long term estimation of volcanic hazards

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Due to the difficulty of describing the complex spatial and temporal patterns inherent to volcanism, the use of solely deterministic models is not sufficient for long term estimation of volcanic hazards. In order to account of the intrinsic uncertainty of volcanism that occurs in the space-time domain, the use of probabilistic models becomes quite natural for long term hazard assessment. The motivation of this on-going work is driven by the necessity of developing a multivariate geostatistical approach for the estimation of volcanic hazards in relation to high-level radioactive waste repository siting. In particular, the integration of additional sources of data linked to the distribution of volcanic events in space as well as to their occurrence need to be accounted for by the modelling. The concepts and the multivariate geostatistical models of the proposed approach will be presented and illustrated by a case study.

The methodology of quantification of volcanic explosions from broadband seismic signals and its application to the 2004-2005 explosions at Volcán de Colima, México

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A methodology is proposed for the quantification of volcanic explosions based on three parameters derived from broadband seismic signals: the counter force of the eruption *F*, the power of the explosion *P,* and the duration of the upward movement of the gas slug in the conduit to the magma free surface *D*. This methodology was applied to the 2004-2005 sequence of explosions at Volcán de Colima, México. The broadband records of more than 100 explosive events were obtained at a distance of 4 km from the crater. We determined the counter force of the eruption by modeling the low-frequency impulse of the seismic records of 66 volcanic explosions and estimated the power of 116 explosions from the spectra of the high-frequency impulse. The power of Colima explosions spans 5 orders of magnitude; the counter force spans 4 orders of magnitude. We show that the power of a volcanic explosion is proportional to the counter force of the eruption. These parameters may be used for the elaboration of a scale of volcanic explosions.

Characterization of seismic swarms happened on April and May 2005 in the Western region of El Salvador.

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This research shows the results of the characterization of two seismic swarms happened in the Western region of El Salvador, on the volcanic complex of Santa Ana-Izalco-Coatepeque. This characterization involves: the localization with three algorithms, composed focal mechanism, 'a' and 'b' values, relationship of the P and S velocities and quality factor Q, of 354 seismic events registered by the Servicio Nacional de Estudios Territoriales (SNET) of El Salvador, over the period of April and May of 2005. The seismic parameters, 'a' y 'b' and the Vp/Vs relationship of each swarm do not show significant differences. These results point that the geological conditions in both places are similar, expecting a maximum coda magnitude around five. The solution for the focal mechanism projects strike-slip faults. On April, two different generating sources were found, the first has north-northwest orientation; the other

one, has north-northeast orientation. For May swarm, the generating source was found it has north-northeast orientation. The quality factor Q was determined in function of frequency, in the range of 2-16 hertz, using 323 microearthquakes, with focal depth between 0-25 km. The Aki and Chouet model of propagation and generation of coda waves was used. The analysis was made for April and May seismicity separated, finding that Q coda has dependence on frequency and on window length. The 1/q factor reports a small but significant increase from April to May; and a much larger increase with respect to the only one precedent research on Q in El Salvador. This phenomenon has happened in other places before the occurrence of a volcanic eruption. However, although in this case an eruptive event occurred on October of the same year in the Santa Ana volcano, which is part of the volcanic complex referred before, having only one case it can not be made the statement that in all cases an increment of the quality factor Q will always go before an eruptive episode.

22:30 Red Wine tasting session

Thursday, 21 September

09:00-18:00 The 1427 earthquakes in Catalonia.

Field trip: Amer-Brugent fault system. Epicentral area of the 1427, May 15th, earthquake.

19:30 Popular session: El vulcanisme Africà – First Day

Friday, 22 September

09:00-13:30 Scientific session

Combining magma flow models with seismic signals

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Low frequency seismic events have been observed on many volcanoes worldwide and are considered key tools in volcanic monitoring and eruption forecasting. The seismic parameters in a volcanic environment are strongly dependent on the properties of the magma, which control the character of the low frequency seismicity.

Spatial distributions of magma properties within a volcanic conduit were taken from Finite Element Method (FEM) models of magma flow. From these data the variation of seismic velocity and density within the volcanic conduit were calculated and these datasets were then incorporated into finite difference models of the seismic wavefield.

Incorporating the flow model parameter distributions was found to produce more complex seismograms containing more noise and high frequency content. Large vertical gradients in the impedance contrast were found to exist within the conduit. This allowed more energy to be transmitted from the lower end of the conduit, reflected in the large amplitude of corresponding sub-events within the synthetic signals. The arrival times of the sub-events and hence also the spacing of the spectral peaks in frequency were found to be less regular.

The resonance characteristics of a fluid filled body depend on both the geometry and the parameter contrast between the solid and the fluid. The role of the so-called 'crack stiffness factor' in controlling these characteristics was also examined for a range of narrower more dyke-like conduits. It was shown that the stiffness factor does not completely define the resonant frequencies, as increasing the stiffness factor by adjusting either the acoustic velocity or density displayed opposite effects. Therefore, a better approach is to consider the effect of its three component ratios (of velocity, density and aspect ratio) individually.

Recent evidence has suggested a widening of the volcanic conduit of the Soufrière Hills volcano on Montserrat from 30m to 50m. The effects of this widening on the low-frequency signals were tested using a finite difference model and the numerical results displayed the expected shift towards higher resonant frequencies. This result provides further evidence and validation for the increase in the width of the conduit, which may mark a significant change in the volcano's behaviour.

TIME VARIATION OF SPECTRAL AND WAVEFIELD FEATURES OF VOLCANIC TREMOR AT MT. ETNA DURING 1999

S. Alparone

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Abstract

We have studied the volcanic tremor recorded at Mt. Etna during 1999, by using three-component seismic stations. This time period was characterised by both explosive and effusive eruptions occurred at the summit craters. During the first half of the year volcanic activity consisted in a quiet lava effusion from a fissure at the base of the SE Crater. We found significant time variations in the trend of the overall spectral amplitude of tremor, as well as in the dominant spectral peaks. Moreover, the tremor wavefield features (polarization, particle motion and ratios between the amplitude of the three components of the ground displacement) have been studied too, confirming significant time variations. This lead us to suggest the existence of at least two tremor sources: a shallow one, mainly characterised by relatively high frequencies (3.5-7 Hz), is linked to the upper portions of the active conduits, and directly related to the observed eruptive activity. The latter deeper source was active only few weeks, and characterised by frequencies lower than about 2.5 Hz. It has been roughly located south-west of summit area, 3 km b.s.l.

The second half of the year has been mainly characterized by short lived lava fountains at three of the four summit craters: Voragine, Bocca Nuova and SE Crater. The analysis of volcanic tremor was mainly devoted to six lava fountain episodes. A general behaviour at the different craters was observed: i) a gentle increase of the tremor amplitude during the strombolian activity preceding the lava fountain; ii) the highest values during the paroxysmal (lava fountain) phase; iii) a sharp decrease following the end of the fountains. In spite of this common behaviour, some differences were evidenced in the energy content at different frequency bands, and in the spectral ratios by considering the lava fountains at the different craters.

Curious seismicity in the Herdubreid area at the divergent plate boundary in north Iceland

Heidi Soosalu[1], Robert S. White[1], Páll Einarsson[2], Ásta Rut Hjartardóttir[2], Steinunn S. Jakobsdóttir[3], Rikke Pedersen[2] and Erik Sturkell[2]

[1]Bullard Laboratories, University of Cambridge, [2]Institute of Earth Sciences, University of Iceland, [3]Icelandic Meteorological Office

Herdubreid area is located within the northern segment of the Icelandic spreading plate boundary adjacent to the Askja volcano. Askja is a nested caldera volcano, which last erupted in 1961. Geodetic measurements indicate that it has been continuously deflating for the latest three decades. Askja is characterised by persistent minor seismicity, principally related to geothermal activity in the eastern part of its caldera system. The main seismic activity in the region, however, is now concentrated in an area extending

away from the volcano towards the north-east, across the hyaloclastite mountains of Herdubreidartögl and Herdubreid. These mountains were formed in subglacial eruptions during the last Ice Age (> 9000 yrs BP) and their location above the current seismicity is probably coincidental.

The seismicity in the Herdubreid area appears to be increasing and also spreading further to the north-east. The earthquakes typically occur in bursts of tens of events below magnitude 3 lasting from a few hours to a few days. The locations of epicentral clusters shift within a few kilometre wide belt of activity with a north-eastern strike, probably forming an en-echelon system of left-lateral strike-slip faults. Detailed mapping of fissures and faults in the Askja region reveals a multitude of surface structures with a north-north-east trend. Interestingly, the currently seismically active area lacks such features: only a few fissures occur across the Herdubreidartögl mountain and they cannot be directly linked to the ongoing seismicity.

In August 2005, we operated a pilot network of five Güralp 6TD seismometers in the area for three weeks, and its data were combined with the observations of more distant stations of the permanent network run by the Icelandic Meteorological Office. A promising dataset was gathered, consisting of some 200 locatable earthquakes, mainly at depths of 2-8 km. For a detailed study on the Herdubreid seismicity, a tight network of 20 Güralp 6TDs was deployed in the area in the summer 2006. Preliminary results from the new deployment are presented here.

Possible candidates for causes of the seismicity in the Herdubreid area are: 1) intrusive igneous activity fed from the magma chamber system of Askja; 2) regional stress field due to movements across the plate boundary; or 3) adjustments due to deflation of Askja. Geodetic measurements are not consistent with the accumulation of magma under the seismically active area. Thus stress field changes related to spreading of the plate boundary, possibly combined with the local sinking of Askja and regional uplift of central Iceland provide a more plausible explanation for this seismicity.

Local earthquake tomography and seismicity study of the Katla volcano, Iceland

Kristín Jónsdóttir 1 , Ari Tryggvason 1 , Roland Roberts 1 , Björn Lund 1 , Heidi Soosalu 2 , Reynir Böðvarsson 1

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Abstract: The Katla volcano, overlain by the glacier Mýrdalsjökull, is one of the most active and hazardous volcanoes in Iceland. In 1991 the South Iceland Lowland (SIL) network started recording the earthquakes in Katla. The earthquakes are mainly seen to occur in two distinct areas, within the oval caldera (9x14 km) and at Goðabunga, a nunatak on its western rim. The seismicity shows seasonal behaviour, i.e. the number of events increases towards the fall, usually with October being the most active month, and decreases during December. We calculate a snow budget index which gives an estimate of the glacial loading, using precipitation and temperature data from a nearby weather station. When these results are compared to the seismic activity a good correlation is seen both on an annual scale as well for longer term variations. Apart from the seasonal behaviour another unusual pattern in the seismicity has been observed. A preliminary study of the interevent time distribution, i.e. distribution of the times between successive events, suggests that the seismicity does not generally constitute of aftershock sequences (being well separated in time or not). Instead, the data is reminiscent of that expected for a purely random (Poisson) process, but there are significant deviations from this pattern suggesting a definite and so far unanalysed pattern of time-behaviour. In addition to the temporal pattern, seismic data from this area can be significantly anomalous in frequency content, amplitude and length of coda. Since 1999, the seismicity has increased dramatically, particularly in Goðabunga. There, an intense earthquake swarm has been observed by the SIL network, as well as by a temporary network which operated in the spring of 2003 with four broadband stations. Data from these networks is used to invert for a seismic velocity model in a profile across Eyjafjallajökull, Godabunga and the Katla caldera. The tomography presented here reveals the major structures down to 10 km depth. It resolves a 15 km wide, aseismic, high velocity structure, at a depth of more than 4 km between the volcano Eyjafjallajökull in the west and the Katla volcanic system in the east. Anomalously low velocities are seen beneath the Katla caldera with a sharp vertical velocity boundary to the west. The broad low velocity zone is interpreted as a temperature anomaly in a higly fractured media. The observed nearly constant Vp/Vs ratio suggests that no larger volumes of magma exist in the study area.

Earthquakes in volcanic systems in Iceland during the last 15 years, an overview

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The seismic activity in icelandic volcanic systems varies conciderably from one volcano to another. Some show daily activity while others are very quiet between eruptions. During the last 15 years, while the SIL seismic system has been active, 5 visible eruptions and 3 or more volcanic episodes have taken place in

Iceland. Only one of them was preceded by a M5 earthquake, the others had precursory activity of earthquakes of magnitudes in the range M0-M3.
In Iceland so called tremor plots have shown to be a very effective way to monitor the onset and the intensity of a volcanic eruptions. Tremor plots show 1 minute average of data in the frequency bands 0.5-1.0 Hz, 1-2 Hz and 2-4 Hz. Some examples and comparison will be given of the precursors to and the monitoring of these 5 eruption during the last 15 years.

Regularities in seismic activity associated with the awakening process at dormant andesitic and dacitic volcanoes

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The presentation is based on the seismic history of five eruptions at andesitic and dacitic volcanoes: Bezymianny (Kamchatka, 1955-1956), Mount St. Helens (Cascades, 1980), El Chichon (México, 1982), Unzen (Kyushu, 1990-1991) and Soufriere Hills (Montserrat, 1995). These volcanoes were re-awakening after more than 100 years of patience. Three stages in the seismo-eruptive process during the awakening process at dormant andesitic and dacitic volcanoes are discriminated: preliminary stage, stage between the first small explosion and large or great explosion, and the stage of new dome building. I discuss the volcanological significance of each of three stages in the seismo-eruptive process.

15:30-17:00 Scientific session

The relationship between tremor and outgassing dynamics at Villarrica volcano

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Villarrica is an open-vent stratovolcano characteristically basaltic to basaltic-andesite in composition. Since at least 1984, it has shown persistent gas plume emission and activity that ranges from gentle lava overturn to discrete moderate strombolian explosions. A spatter roof, located only a few meters above the lava pond, partially conceals the bubble-burst activity within the magma free surface.

In order to study the relation between tremor and volcanic activity, we have combined seismic data, collected with short-period seismic station located 3.7 km NW to the volcano, visual observations from the crater rim, and SO_2 flux measurements. Our analysis has focused on the period November 2004 - April 2005, when the volcano showed an increase in activity reflected in the magnitude and frequency of explosions as well as in the morphology of the vent (crater interior).

During the period of study, the seismicity shows changes in amplitude and frequency content; agreement with the evolution of the activity; long-period, hybrid, and volcano-tectonic events; and a fairly good correlation with the amount of degassing. We identified four different styles of bubble bursting that take place at the top of the magmatic column: seething magma, strombolian explosions, gas jetting, and small lava fountains. The former is continuous in time, while the last three are discrete events that correlate with higher amplitude tremor bursts.

In view of this integrated analysis, we interpret a strong link between tremor and the outgassing activity taking place in the shallowest part of the open plumbing system. Therefore, variations in volcanic tremor can reflect the dynamics of a two-phase flow within the conduit. This hypothesis is now under study.

Fracturing Regimes Controlling the Creation of New Magmatic Pathways

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If a volcano is to erupt after hundreds of years of repose, the country rock must fracture in order to create a new pathway for the magma to reach the surface. This fracturing is recorded as Volcano-Tectonic (VT) seismic events. There were hyperbolic accelerations in fracturing rates in the final 5 to 10 days before eruptions at Mount Pinatubo, Philippines in June 1991 and at Soufriere Hills, Montserrat in November 1995, which both erupted after ~500 years of repose. This pattern of fracturing can be used to forecast eruptions, and indicates that the final approach to an eruption may be controlled by the creation of a new magmatic pathway through the growth and coalescence of fractures. However, at other volcanoes erupting after more than 100 years of repose the precursory VT seismicity did not accelerate in this manner. In the final weeks before the 18th May 1980 eruption of Mount St Helens, the VT seismicity was already at high level, but did not accelerate. The recent discovery that there was juvenile magma in the eruptions previously defined as phreatic that began on 27th March indicates that the magmatic pathway was in fact formed at this earlier date. VT seismicity accelerated before these eruptions began, but the form of this acceleration differed from that observed at Mount Pinatubo and Soufriere Hills. A new model is proposed to explain fracturing rates expected before phreatomagmatic eruptions from a shallow magma body.

Short-Term Dynamic Processes at a Restless Caldera: Insights from Joint and Simultaneous Potential Field, Geodetic and Seismic Records from Nisyros, Greece

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Gravity and deformation time series data are employed both to quantify the long-term subsurface dynamics at restless calderas and for forecasting volcanic activity. Critical to the interpretation of residual gravity data in terms of magma dynamics is the assessment of signals stemming from phenomena such as, for instance, secular variations in the level of the ground water table and the mass/density changes in active hydrothermal systems. An earlier study at the restless Nisyros caldera in Greece revealed short-term (40-60 min) gravity variations with amplitudes similar to those observed during annual microgravimetric surveys. It was inferred that these short-term variations might be caused by the hydrothermal/magmatic degassing process itself (for instance, the generation, ascent and dissipation of steam pockets from the boiling hydrothermal reservoir along fracture zones or faults as well as transient pressure variations during steam/liquid interface propagation). To investigate the short-term dynamics in more detail, we ran a two-week field experiment in May 2006 in the hydrothermal areas of the collapse caldera, using one continuously recording gravimeter, two field gravimeters, three GPS receivers, one seismometer, one very-low-frequency (VLF) receiver and one audiomagnetotelluric (AMT) receiver. In addition, an AMT survey was conducted within the caldera in order to map the electrical structure of the caldera. Gravimetric and geodetic data were recorded at a frequency of 1 Hz (with the exception of the field gravimeters, operated at 0.0033 Hz), the 5 s period seismometer recorded at 125Hz and the electromagnetic data were collected at a frequency of 21.75 kHz. Preliminary results reveal residual gravity changes of up to 40 microGal (peak-to-peak amplitudes) which are not attributable to deformation effects. The power spectrum of the entire continuous gravity record reveals marked periods between 45 and 50 min consistent with earlier observations performed during discrete gravimetric readings. The same periodic signal was also recorded in VLF-EM inphase values. The correlation between the seismic and gravimetric record indicates coupling effects of seismogenic events with sub-surface mass migration. The preliminary evaluation of the continuous gravimetric and continuous VLF-EM outphase records indicates a negative correlation, whereby gravity decreases with increasing outphase values. The joint record lead us to the preliminary conclusion that the major part of the short-term geophysical signals at the caldera is related to dynamic processes in a shallow hydrothermal system at a depth of less than 500 m. Magmatic signals would need to exceed this hydrothermal signal in order to be seen.

19:30 Popular session: El vulcanisme Africà – First Day

Closure of the Workshop