source differences in the genesis of TMVB lava types. Samples analyzed thus far include relatively primitive and evolved alkaline lavas from the Colima graben (minettes and lamprophyres); calc-alkaline andesites from Volcan de Colima; gabbroic xenoliths entrained in Colima lamprophyres; and alkaline and calc-alkaline lavas from small centers in the Michoacan-Guanojuato volcanic field (MGV), including suites (and associated crustal xenoliths) from Jorullo and Paricutin. TMVB alkaline lavas vary from 3-13 ppm Li, 1-5 ppm Be, and 1-12 ppm B. Calc-alkaline Colima andesites range from 5-18 ppm Li, 0.2-1 ppm Be, and 2-8 ppm B. B/Be ratios of Colima alkaline rocks are <5 and distinct from calc-alkaline lavas (7-12), due primarily to lower Be. Li/Yb ratios are high and similar in both lava types (4-16). Lavas from Jorullo widely in Li and B (8-20 ppm Li and 1-47 ppm B) suggesting incorporation of Li and B-enriched crustal materials (Jorullo xenolith: 25 ppm Li, 95 ppm B). Gabbroic xenoliths from the Colima graben are much lower in Li and Be (<3 ppm and 0.01 ppm). B systematics in TMVB monogenetic centers suggest limited H_2O-rich inputs from the slab, and point to a significant role for crustal assimilation during magma evolution. Li systematics record the anomalous crystallizing assemblages of TMVB alkaline lavas, and may, along with elevated Ba and Be contents, indicate mantle sources modified by a higher temperature slab component.

V52A-0421 1330h POSTER

The Role of Shock in the Redistribution of Volatile Elements in Basalts. Implications for the Interpretation of Martian Magmatism.

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The mineralogy and geochemistry of martian basalts have been used to estimate the amount of water in martian magmas and to model the martian hydrologic cycle. The mineralogy of martian basalts and the composition of associated melt inclusions have been interpreted as indicating that martian basaltic magmas had very little water (less than 0.1% H2O). On the other hand, the behavior of geochemical tracers (Li and B) has been interpreted as indicating that this low water content was the product of extensive magmatic outgassing and that martian basalts initially contained significant water. This interpretation is based on the observation that Li and B decrease in the rims of pyroxenes in basaltic shergottites resulting from the partitioning of these incompatible elements into a fluid phase during degassing. In that many martian basalts experienced substantial shock (20-40 GPa), it is possible that the magmatic volatile record preserved in martian basalts has been disturbed. To better understand the possible effects of shock on this volatile record, we are studying the redistribution of volatile elements in naturally and experimentally shocked basalts. The initial study of tholeiitic basalts associated with the Lonar impact structure in India illustrates one of the possible effects of shock on the redistribution of volatile elements such as Li and B. High-Ca pyroxene in the unshocked Lonar basalt ranges in composition from approximately Fs23 in the core to Fs41 at the rim. As expected in a basaltic system, incompatible trace elements Ce, Be, Li and B increase from pyroxene core to rim. Relationships among incompatible elements are characteristic of basaltic systems (i.e. Li/Be decreases with increasing Li). The shocked basalt examined in this study is characterized by the conversion of plagioclase laths to maskelynite. This corresponds to shock pressures between 20-40 GPa. The high-Ca pyroxene in this basalt has similar major element characteristics as the unshocked basalt and both Ce and Be increase from core to rim. In contrast to the unshocked basalt, the pyroxene exhibits a decrease in Li, Li/Be and Li/Ce in the high-Fe rim. These initial observations suggest that shock may produce the decrease of volatile trace elements in pyroxenes that had been attributed to degassing.

V52A-0422 1330h POSTER

Large Iron Isotope Variations in Mantle Minerals: The Influence of Oxidation State and the Implications for the Iron Isotope Heterogeneity of the Upper Mantle

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Controversy exists over whether or not there are significant variations in the iron isotope compositions of terrestrial mantle rocks, and whether stable isotopic fractionation can take place at high temperatures. Recent studies imply that significant iron isotopic fractionations exist between high temperature mantle minerals (Zhu et al., 2002, EPSL 200, 1-2). This suggests that isotope fractionation at the mineral scale has the potential to influence the terrestrial mass balance for iron isotopes. We present MC-ICP-MS iron isotope data for minerals from mantle peridotite to determine if there is isotopic fractionation between minerals, and what the physical and chemical parameters that could cause fractionation are. In order to evaluate the level of mantle iron isotope heterogeneity at the mineral scale, spinel and spinel-garnet facies peridotites, representative of sub-arc mantle, sub-continental cratonic lithospheric mantle and MORB-source mantle, were selected. Systematic isotopic fractionations exist between silicate minerals. The $\delta\ ^{57}Fe/^{54}Fe$ compositions of the olivines are $\sim 0.20\ ^o/_{oo}$ lighter than those of clinopyroxene and orthopyroxene, consistent with the results of Zhu et al. Although the differences are small, they are greater than our long-term reproducibility ($0.13\ ^o/_{oo}$ 2 S.D.). The ranges in the $\delta\ ^{57}Fe/^{54}Fe$ compositions of olivine, clinopyroxene and orthopyroxene are 0.6, 0.7 and 0.9 $^o/_{oo}$, respectively. Spinels show a range of over 1.70 $^o/_{oo}$. The lightest isotopic compositions are for minerals from island-arc peridotites, the heaviest are for minerals from xenoliths that sample sub-continental cratonic mantle. The spinel $\delta\ ^{57}Fe/^{54}Fe$ compositions correlate negatively with spinel ferric/total iron contents, determined by Mössbauer spectroscopy, suggesting that this parameter has a strong influence on isotope fractionation. The $\delta\ ^{57}Fe/^{54}Fe$ compositions of the silicate minerals show some correlation with those of co-existing spinels. One explanation for the variations is that significant differences exist between the iron isotope compositions of sub-arc and sub-continental cratonic lithospheric mantles. These differences could arise as a consequence of melt extraction or melt-rock interaction processes as ferric iron partitions preferentially to ferrous iron into silicate melts. The iron isotope compositions of spinels may be especially sensitive to such processes because spinels are the main carriers of oxidized Fe in the shallow mantle (Wood and Virgo, 1989, GCA, 50, 6).

V52A-0423 1330h POSTER

Iron Isotope Fractionation in Metamorphic Rocks

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Polyakov and Mineev [1] predict high-T equilibrium fractionation favouring incorporation of heavy Fe isotopes into Fe(III)-containing minerals. We have confirmed this prediction for metamorphic rocks. A prerequisite was the development of highly accurate and precise protocols for Fe isotope analysis (Delta 56Fe/54Fe to 50ppm at 2 sigma of repeatedly separated natural samples; Delta 57Fe/54Fe to 70ppm; and Delta 58Fe/54Fe to 280ppm, n=40) using a Finnigan Neptune MC-ICP-MS at the University of Hannover. In greenschist facies rocks, Delta 56Fe of magnetite and pyrite is 0.3 to 0.6permil heavier than Fe in Fe(II) silicate minerals. In migmatites formed at 800C Delta 56Fe of magnetite is 0.1 to 0.3 permil above Fe(II) silicate minerals (Chlorite, Biotite). These observations confirm that (a) high-T equilibrium fractionations of Fe do indeed exist; (b) strongly-bound Fe(III) oxides and sulfides do indeed favour heavier isotopes; and that (c) a temperature-dependency exists, favouring higher fractionation at lower temperature as predicted [1]. It will now be important to explore the potential of this new isotope system for of high-T thermometry and in terms of redox conditions in metamorphic rocks and melts. 1 V.B. Polyakov and S.D. Mineev, The use of Mössbauer spectroscopy in stable isotope geochemistry, Geochimica Cosmochimica Acta 64, 849-865, 2000.

V52B MCC: Level 1 Friday 1330h

Messages from the Underworld: Linking Geophysical Signals to Eruptive and Hydrothermal Processes II Posters *(joint with S)*

Presiding: **T L Wright,** U.S. Geological Survey

V52B-0424 1330h POSTER

A statistical model for the timing of earthquakes and volcanic eruptions influenced by periodic processes

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Evidence of non-uniformity in the rate of seismicity and volcanicity has been sought on a variety of timescales ranging from 12 hours (tidal) to $10^3 - 10^4$ years (climatic), but the results are mixed. Here, we propose a simple conceptual model for the influence of periodic processes on the frequency of geophysical 'failure events' such as earthquakes and volcanic eruptions. In our model a failure event occurs at a 'failure time' $t_F = t_I + t_R$ which is controlled by an 'initiation event' at the 'initiation time' t_I and by the 'response time' of the system t_R. We treat each of the initiation time, the response time and the failure time as random variables. In physical terms, we define the initiation time to be the time at which a 'load function' exceeds a 'strength function' and we imagine that the 'response time' t_R corresponds to a physical process such as crack propagation or the movement of magma. Assuming that the magnitude and frequency of the periodic process are known, we calculate the statistical distribution of the initiation times on the assumption that the load and strength functions are otherwise linear in time. This allows the distribution of the failure times to be calculated, if the distribution of the response times is known also. The predictions of this simple theory are compared with some examples of observed periodicity in seismic and volcanic activity at tidal and annual timescales.

V52B-0425 1330h POSTER

3-d Visualization of Earthquakes and Erupting Vents in Time-series Animations: Application to Kilauea and Miyakejima volcanoes

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Computer programs have been developed to view erupting vents and earthquake sequences on and beneath transparent topography shown by a DEM, vertical image, or map. In a single frame an earthquake dataset can be rotated with the mouse to create perspective views. Multiple-frame time animations are created in which the perspective (e.g., map, cross-section) and time increments (e.g., hour, day, month) are chosen by the user. Viewed as movies, the animations allow recognition of seismicity patterns occurring over large areas and long time periods. Departures from characteristic activity are easily spotted and can be further investigated in a single frame or in animation with shorter time increments. Time animations have been made of earthquake sequences accompanying several eruptions of Kilauea volcano and the Miyakejima eruption and associated dike emplacement in 2000. An earthquake swarm shallower than 6 km beneath Miyakejima island began on the evening of 6/26/2000. The seismicity moved to the southwest, then to the north and offshore, and a submarine eruption occurred on the morning of 6/27. Shortly thereafter, earthquakes of M 4 and above migrated westward, also becoming deeper (to 20 km), marking the emplacement of a large dike northwest of Miyakejima island. Eruptions at Miyakejima from 7/8 to 9/1 were associated with formation of a new caldera. The timing and location of the submarine eruption can be seen in the seismicity, consistent with later visual observation of discolored seawater and photographs obtained of the seafloor vents. Seismicity associated with the submarine eruption plunges eastward. Seismic sequences preceding explosive eruptions at Miyakejima summit in August plunge southwest. Intersection of the opposed dips occurs near 10 km depth, consistent with existence of a deeper basaltic reservoir feeding the explosive eruptions. Sequences of vertical, pipe-like seismicity extending to very shallow depths over the propagating dike and occurring over times of 4-6 hours suggest additional episodes of undersea eruption near the islands of Kozushima and Toushima. At Kilauea the focus has been on two long eruptions, Mauna Ulu (1969-1974) and Pu'u 'O'o (1983-ongoing). In the latter a maturing magma transport system is shown by (1) diminishing shallow rift seismicity and south flank response, and (2) increasing frequency and depth of long-period seismicity beneath Kilauea's summit. An event seen in the animations and not previously noticed was a seismic sequence beneath Kilauea triggered by the M6.6 Mauna Loa earthquake of 11/16/1983. Beginning 4 hours after the mainshock, seismicity occurred on a Kaoiki fault trace buried beneath Kilauea lava and also on Kilauea's southwest flank, a zone usually active only during intrusions on Kilauea's southwest rift zone. In the former the animations vividly depict the changing seismicity beneath the growing Mauna Ulu shield and the eruptions and intrusions elsewhere on the volcano that occurred during pauses in the Mauna Ulu activity. Following the end of Mauna Ulu activity in 7/1974, the animations show the sequence of eruptions and intrusions leading up to the M7.2 Kilauea south flank earthquake of 11/29/1975. The presence of greatly elevated levels of seismicity at 30 km beneath Kilauea and at 0-15 km beneath Kilauea's southwestern flank compared to earlier times may be useful in forecasting future large south flank earthquakes. The same computer programs used for the volcano animations can be applied to mainshock aftershock sequences associated with large earthquakes, and to tectonic earthquake sequences associated with subducting or obducting plates.

V52B-0426 1330h POSTER

Source model of volcanic tremor: two-phase flow instability in a pipe-valve system

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Volcanic tremor at a shallow depth beneath the volcano is inferred to link to hydrothermal activities powered by heat supply from magma. In this study, we developed numerical simulations of the instabilities of the water-steam two-phase flow in a pipe-valve system and considered the source mechanism of volcanic tremor. The experiments of two-phase flow by Veziroglu and Lee [1968] revealed the two kinds of oscillating modes, density wave oscillation with the period of a few seconds and pressure drop oscillation with the period of dozens of seconds. These modes were mainly controlled by the pressure difference between inlet and outlet, flux rate of fluid and heat supply rate. Especially, the former mode appears when the flux rate is small and the latter does when the pressure difference and heat supply rate are larger. We performed some preliminary numerical simulation of these oscillations in water-steam flow in a cylindrical conduit. As an example, we assume the flow in conduit of 4 m length with the valves at inlet and outlet with the conditions of non-slip at the wall. As initial conditions, the inlet and outlet pressures are fixed to be 1.2E5 Pa and 1.0E5 Pa, respectively, water temperature of 370 K, heat supply of 1.0E6 - 2.0E7W/m3. The friction except the valve area is assumed to be 1000kg/m3. After the heating condition becomes stable, we shut the valve at the outlet and detect the significant oscillation. In case of the heat supply of 1.1E7W/m3, density drop oscillation with the period of 0.16s has appeared. In this model, the oscillation originates from the density change due to vaporization, and its information arrives at the outlet with the velocity of two-phase flow. The cycle of heating and boiling controls the interval of the tremor occurrence and the period is determined by the length of the pipe and the flow velocity. The shut of valve physically corresponds to geometrical narrowing, choking, and non-linear effect of flow and/or surrounding medium.

V52B-0427 1330h POSTER

Resonances of a Volcanic Conduit Triggered by Repetitive Injections of an Ash-laden gas

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Tungurahua Volcano, located at the center of the Ecuadorian Andes, entered in eruption characterized by ash emissions, vulcanian and strombolian activities in October 1999. There have been 7 to 10 short-period seismic stations and 1 broadband station to monitor the Tungurahua volcanic activity. Between December 5 and 11, 2001, a swarm of long-period (LP) events occurred. The LP waveform is characterized by screw-shaped harmonic oscillations. In this study, we used the LP waveforms to calculate temporal variations in their complex frequencies (frequency, f and quality factor, Q) to understand the source process associated with this activity. We applied the Sompi spectral method to 57 LP waveforms from the station RETU, which provided the best continuous data in the Tungurahua seismic network. We determined the temporal variations in the complex frequencies of the LP events, which indicated that the frequency gradually decreased from 3.5 to 2 Hz, whereas Q gradually increased from 100 to 400 with wide scatter along this trend. Based on the acoustic properties of a crack containing various types of magmatic and hydrothermal fluids, the observed high Q values can only be explained by a large velocity contrast between the surrounding rock and fluid. Such a high velocity contrast suggests ash-gas or water droplet-gas mixtures in a crack developed in the solid rock. Since the LP events are most probably located around 2 km below the summit, a water droplet (liquid water) may not exist at this source depth. We may therefore reasonably assume that the fluid at the source of the LP events is an ash-gas mixture. We propose that an ash-laden gas was injected into a closed conduit (pre-existing crack) just above the magmatic system, causing the resonance of the conduit or an LP event. This process repeatedly occurred and accumulated ash particles in the conduit, generating the temporal variations in the frequency and Q of the LP events. Finally, the conduit was almost filled with ash particles, and as a consequence the resonance of the conduit was no longer excited. The first explosion after this swarm occurred on December 30, and ash emissions from the summit began on January 2, 2002. Our results emphasize the link between LP seismicity and preparatory process for eruptions.

V52B-0428 1330h POSTER

Precise Hypocenter Location of Low- and High-Frequency Earthquakes Beneath Mt. Fuji, Japan

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Low- and high-frequency earthquakes (LFs and HFs) have been observed at the seismic networks of ERI, NIED and JMA around Mt. Fuji. Many LFs occurred in two periods September-November 2000 and April-May 2001. In this period, the LF occurred at a rate of 20 - 70 per month, which is about ten times higher than those of background level. Generally, the LFs have little energy above 5 Hz, emergent P arrivals and strong S arrivals unlike those of shallow LFs. P and S waves of the LFs are often contaminated by high-frequency (>5 Hz) waves at close stations. They frequently occur as bursts of overlapping events. The duration of LF bursts is usually few minutes but occasionally 20-30 minutes. HFs intensively occurred in the period form January to April 2001. We combined data of the three organizations, picked up arrival times of LFs and HFs with careful identification of phases and determined their hypocenter precisely. We located hypocenters for the 75 LFs and 58 HFs with good S/N during 1998-2002 by using the DD method. The magnitudes of the located LFs and HFs were up to 2.2 and 2.7, respectively. The LF hypocenters define an ellipsoidal volume some 5 km in diameter ranging from 11 to 16 km in focal depth beneath the northeast flank. Consulting the location errors, the extent of the volume is significant. This volume is centered at 3 km northeast of the summit and its long axis directs SE-NW. The HF hypocenters distribute between 6 and 12 km in depth along a sub-vertical plane beneath the south flank, which also directs SE-NW. The SE-NW direction coincides with the major axis direction of tectonic compression around Mt. Fuji. The locations of LFs in 2000-2001 shift 1 km northwest from those in 1998-1999 and 2002. While the focal depths of the LFs in 1998-1999 are at depths of 13-16 km, the LFs located apparently shallow with time at depths of 11-16 km in September 2000 - December 2001. Although no definite source mechanism of the LFs have been revealed, the spatial extent and migration of the LF and HF hypocenters give a key to understanding the relation between the generation of LFs and magmatic fluid.

V52B-0429 1330h POSTER

Long-Period and Very-Long-Period Seismicity Associated with Lava Extrusions and Volcanic Degassing at Popocatepetl Volcano, Mexico

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From November 1999 through July 2000 a broadband seismic experiment was carried out at Popocatepetl Volcano as part of an international cooperative program between the GeoForschungsZentrum in Potsdam, Germany, the U.S. Geological Survey, and the Institute of Geophysics at UNAM, Mexico. The goal of this experiment was to record seismic activity at Popocatepetl over a wide period range (0.04 to 100 s). The network deployed included 15 stations distributed along radial profiles on the upper flanks of Popocatepetl, and 7 stations at lower elevations on the volcano's western flank. All significant vulcanian events were well recorded by our network. Volcanic activity during the experiment was characterized by emissions of gas and ash, and by the formation of a lava dome within the summit crater. Ash emissions ranged from small short-lived plumes rising a few hundred meters above the crater rim, to larger plumes reaching up to 5 km above the crater. Resulting tephra falls dusted the entire summit area. Bursts of volcanic degassing were accompanied by long-period (LP) seismic signals observed as isolated events, or as sequences of discrete events with overall durations comparable to those of visible activity documented by video. Some gas emissions were accompanied by persistent or spasmodic tremor. LP events and tremor episodes increased in frequency and intensity in early February 2000. Individual LP signals, tremor, and swarms of hybrid events were frequently observed during intervals of active dome growth. Very-long-period (VLP) signals accompanying degassing activity were also clearly recorded at stations closest to the crater. The VLP signals exhibit quasi-identical pulse shapes with periods near 25 s from event to event. VLP signals with periods near 30 s and VLP tremor with periods in the range 15-22 s, lasting 20 min or more, clearly correlated with vulcanian processes. Preliminary locations of LP events based on phase picks, and particle-motion analyses of VLP pulses, consistently constrain shallow seismic sources within the uppermost 1000 m below the crater floor.

V52B-0430 1330h POSTER

Description and Location of Tremor at Mt. Erebus Volcano, Antarctica

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From June 2000 till July 2003, 322 distinct episodes of tremor activity have occurred at Mt. Erebus volcano, Antarctica in three extended periods (A. June 2000-October 2001; B. January-December 2002; C. January-July 2003). Period A was characterized by episodes with short duration and small amplitudes (except for a peak in February, 2001). Period B contains the largest amplitudes, reaching a maximum ground velocity of 97.8 microns/s at 0.7 km from the crater on May 21, 2002 (with a reduced displacement of 92.6 cm^2, assuming a source at sea level (3.7 km below the summit), and purely body waves). The May, 2002 activity climax was followed by long-lasting and smaller-amplitude tremor episodes lasting until December 2002, and followed later by period C. Erebus tremor exhibits

a large variation in duration, amplitude, and frequency content. Three general categories of tremor have been recognized based on predominant characteristics: harmonic (91%), chaotic (6%) and rapid-fire (3%). Within single episodes, events frequently show transitions between these types. The tremor shows no clear association with activity observed in the persistent convecting phonolite lave lake or adjacent vents. Since tremor commenced strombolian eruption frequency has declined, although the cause of this is unknown and is probably related to changes in upper-conduit geometry and not to the tremor. The precise location of these non-transient signals is difficult, and source locations were estimated using several different methods. A first-order approximation was carried out by contouring isoseismal curves and fitting real and theoretical attenuation curves. We also applied envelope cross-correlation, semblance, and spectrogram cross-correlation techniques. Results from the best harmonic and rapid-fire tremor source solutions suggest the presence of at least two distinct deep tremor sources located between 3 to 9 km beneath the summit plateau. We will discuss assumptions, methodology, and implications of the activity and source locations for the evolving dynamics of Erebus.

V52B-0431 1330h POSTER

Integration of Seismic and Video Records of Eruptive Activity on Santiaguito Volcano, Guatemala

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Santiaguito is a long-lived, dacitic volcanic dome complex, which has now been continuously active since 1922. The volcano's longevity is thought to be related to a large magma body and the pattern of extrusion is notably unsteady. Direct observations of activity are inhibited by logistics, such as cloudy weather at proximal vantage points after mid morning. Activity observable at Santiaguito each morning includes multiple vertical explosions, dome and flow collapses leading to block and ash flows or rock avalanches, steam exhalations and fumarolic discharges. These phenomena were recorded on digital video from an excellent vantage point (the summit of Santa Maria) located 1200 m above and 2.5 km NE of the active Caliente Vent of Santiaguito for about three hours on the morning of January 11, 2003, and from El Brujo Vent, located ∼200 m below and 1.2 km W for about four hours on the morning of January 9, 2003. The volcano is also ismically monitored, and we have synchronized the video with digital seismic data processed through the Seisan computer program. Our expected result is a correlated record of seismic data and visually-identified eruptive activity, allowing us to evaluate eruption characteristics. This will be in the form of a digital video of surface activity on Santiaguito with corresponding seismic signals, which will be applicable for education and scientific analysis. By correlating seismic signals to eruptive activity, monitoring agencies that are distant from the volcano can better interpret the incoming seismic data, and communicate a more complete picture of volcanic activity to the surrounding communities. It also allows us to go back through the seismic record from Santiaguito and catalog past eruptive activity. A synchronized seismic and eruptive activity video is also a valuable educational/ outreach tool. With the technique for correlating video and seismic records established, additional types of data (such as temperature and gas readings) can be compared as well.

V52B-0432 1330h POSTER

Resistivity Tomographic Imaging of the Qualibu Caldera, Soufriere, St. Lucia

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The Qualibu Caldera, Soufriere, St. Lucia is a large topographic depression formed by downfaulting. The Caldera structure has been long investigated for geothermal power generation. It houses the Sulphur springs geothermal system as evidenced by natural manifestations of hot springs and micro-seismic activity. In 1974 several lines of dipole-dipole resistivity data were collected in the area. One of the lines running through sulphur springs was interpreted by using forward models to generate a best-fit model. Using modern 2D resistivity inversion algorithms, the resistivity data collected in 1974 have been re-analyzed and interpolated into a 3D image system. The results have agreed very closely with geologic and borehole data in the area and reveals conductive features reminiscent of a convecting geothermal system.

V52B-0433 1330h POSTER

Self Potential Investigation of the Qualibu Caldera , Soufriere, St. Lucia

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The Qualibu Caldera, Soufriere, St. Lucia is a large topographic depression formed by downfaulting. The Caldera structure houses the Sulphur springs geothermal system as evidenced by natural manifestations of hot springs and micro-seismic activity. It has been long investigated for geothermal power generation using resisistivity, audiomagnetotellurics, gravity, microseismics, geochemical methods. Nine boreholes have also been drilled and tested. To add to the available dataset, 27 kilometers of SP data was collected in the Qualibou Caldera including a line adjacent to the emanations at Sulphur Springs. The area has dramatic elevation changes, thus a number of methodologies have been developed for topographic correction. Additionally the effects of tellurics, electrode polarization and noise were considered. The results show that SP is effective in locating faults and fractures. The negative SP regions are interpreted as upflows of hot fluids, typified by the known fumarole activity at the Sulphur Springs. The positive SP regions are areas of downflow or recharge. A newly identified negative SP anomaly might be a good geothermal prospect as it indicates upwardly migrating fluids.

V52B-0434 1330h POSTER

Unzen Scientific Drilling Project, Japan: Studies of Stress, Fractures and Physical Properties in Flank Wells

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We have been conducting an integrated studies of in-situ stresses, fracture geometry and permeability, and rock physical properties in the flank drilling of Unzen volcano. These measurements are indispensable for the next phase of the drilling project into the magma conduit to better understanding the dynamics of magma emplacement and degassing, the physics of volcanic seismicity, and mechanical controls on the orientation and magnitude of fracture permeability. Two boreholes were drilled in the flank of the volcano: one at Minami-Senbongi (USDP-1, 752 m deep) and the other at Ohnokoba (USDP-2, 1,462 m deep). We conducted well logging, in-situ stress measurements and an injection test in these boreholes. Similar variations in physical properties were observed in each well: electrical resistivity, 10 - 1000 Ohm-m, P-wave velocity, 2.5 - 4.0 km/sec; density, 2.2 - 2.3 g/cm3; gamma-ray intensity, 70 - 100 API; and bottom-hole temperature, 47©C (in USDP-1) and 33©C (in USDP-2). These variations correlate with small-scale changes in lithology (alternating between mud flows, lava blocks, and pumice flows) over depth intervals ranging from 1 - 20 m. In the USDP-1 well, a fluid injection and temperature recovery test was conducted to constrain the thermal and permeability structure of the volcanic flank. It was revealed that three layers exist: a relatively impermeable mud flow layer, an unconfined and highly permeable block-and-ash flow aquifer, and a thick and relatively impermeable sedimentary layer. In the USDP-1 well, the magnitudes of the maximum and minimum horizontal compressive stresses, SHmax and Shmin, were determined using the hydraulic fracturing method. The magnitude of SHmax is close to the vertical stress, indicating a transitional normal to strike-slip faulting regime. In addition, borehole televiewer logs of the hydraulic fracture indicate an SHmax azimuth azimuth determined in USDP-1 is almost parallel to the Beppu-Shimabara graben, in which the Unzen volcano resides, and coincides with the SHmax azimuth estimated from focal mechanisms of shallow earthquakes. Thus, the current orientation of Shmin is nearly optimal for driving north-south extension across the Beppu-Shimabara graben. In addition, since this Shmin direction is nearly perpendicular to the inferred orientation of the feeder dike for 1990-95 Unzen eruption, it appears that the current in-situ stress field plays an important role in controlling the dynamics of magma ascent beneath Unzen.

V52B-0435 1330h POSTER

Volcanic SO2 Emissions vs. Seismicity - July 2002 LP Swarm, Soufriere Hills Volcano, Montserrat

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Volcanic sulfur dioxide (SO2) measurements of passive plumes have recently improved with the application of Differential Optical Absorption Spectroscopy (DOAS). In January 2002, the Montserrat Volcano Observatory installed two fixed DOAS instruments which collect rapid, continuous measurements of SO2 emissions. For the first time, SO2 fluxes are being collected on a time scale of minutes, allowing short-term changes to be evaluated with respect to atmospheric transport, surface activity, and magmatic source mechanisms. In this study, we investigate relationships between SO2 emissions and seismicity for July 2002 at Montserrat. The seismic data consist of rockfall, long-period rockfall, hybrid, and long-period (LP) waveforms. Seismic energy increased slowly throughout July, culminating in a swarm of long-period earthquakes. The SO2 data used for this study consist of measurements collected every 4-5 minutes from approximately 8 a.m. to 5 p.m. daily by a DOAS instrument positioned at Lovers Lane (4.5 km west of vent). From July 1-18, seismicity is dominated by rockfalls with intermittent hybrids and LPs. During this time, SO2 fluxes generally increase and coincide with an increasing trend in the number of rockfalls per day. Average daily SO2 fluxes range from 140 to 1256 tonnes/day with an average of 616 tonnes/day. On July 19, however, the average daily SO2 flux decreases from a monthly maximum of 1256 tonnes/day to 227 tonnes/day and continues to average only 326 tonnes/day from July 20-30. July 19 marks a seismic transition into a LP earthquake swarm that continues into August. After the LP swarm begins and SO2 fluxes decrease, however, the number of daily rockfalls remains relatively high. Therefore, it appears that LPs are more strongly linked to SO2 emissions than rockfall activity. Future work will involve investigating short-term (minutes/hours) relationships between seismicity and SO2 emissions.

V52B-0436 1330h POSTER

A warning bell? Tornillo events at Galeras Volcano, Colombia

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In 1993, five of the six ash eruptions at Galeras Volcano, Colombia were preceded by distinctive seismic

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events, called tornillos. These unusual tremor wavelets have quasi-sinusoidal waveforms with screw-like envelope profiles and can last up to several minutes. Since December 1990, more than 60 of these events have been recorded at Galeras Volcano. As a class, they appear to be more complex than those previously recorded with the broadband instruments or with the shortperiod network of the Observatorio Vulcanológico y Sismológico in Pasto. They are multichromatic with a varying number of spectral peaks between 1 and up to 50 Hz. The peaks for frequencies which extend into the coda are extremely narrow, while those present only during the initial excitation are relatively broad. We parameterize the tornillo signals in the time and frequency domains, examining differences in the two classes of spectral peaks, and derive distribution and correlation functions for signal parameters such as frequency, Q, energy, and polarization. We investigate variations in these parameters with regard to ash eruptions during the past 3 years. In addition, we use the parameters along with the signal signature to derive qualitative conclusions about possible underlying processes and excitation mechanisms and to provide constraints for modelling variations of the source process, as, for example, a cavity resonator. For example, the distribution of frequencies for the suite of tornillos appears to be discrete below 6 Hz and a continuum above, as would be expected for a cavity.

V52B-0437 1330h POSTER

Andesitic Magmatic Water Which Generated Matsushiro Earthquake Swarm And S Wave Reflector

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When the Matsushiro earthquake swarm occurred between August 1965 and October 1967, large amounts of ground water were released. Even at present, ground water being released in this area, accompanied by the free gases. We measured the oxygen/hydrogen isotope ratio in ground water, the CO2/CH4 carbon isotope ratio contained in free gases, and the CH4/C2H6 ratio. The results of these measurements indicate that CO2, which was the major component of the gas, originated from the mantle, and that CH4, another major component, originated from thermal decomposition of organic materials contained in sedimentary rocks. We plotted our ground water data on the Giggebach d18O vs. dD diagram (The composition of the isotopes in the water, released when the magma below the island arc cooled and hardened, was estimated empirically on the basis of the data collected from many samples of volcanic gas and terrestrial heat water. He named this ground water "andesitic magmatic water", with d18O ranging between +5 and +10 permil and dD between -30 and -10 permil.). The linear regression line passes through the range for andesitic magmatic water. This means that this andesitic magmatic water was probably responsible for the earthquake swarm. It is known that there is a seismic wave reflective layer 15 km beneath the Matsushiro earthquake swarm area. It seems highly likely that this layer is made of aquifer. When the impermeable sheet broke and high-pressure water with CO2 rose into the upper crust, the crust was weakened, causing the Matsushiro earthquake. Hot spring waters from the Arima spa (Rokko Mountains) and Kashio spa (on the Median Tectonic Line, Nagano) have a similar characteristic to the Matsushiro ground water in chemical composition of concentration of Cl- and Na+ ion, and isotope ratio of heavy d18O and dD. The S wave reflector has been observed under the Arima spa but not under the Kashio spa. Earthquake swarm has been observed under the Arima spa but not under the Kashio spa. These mean that the S wave reflector is closely related to earthquake swarm.

V52B-0438 1330h POSTER

Interaction Between Hydrothermal and Magmatic Systems Inferred From Temporal Variations in the Complex Frequencies of Long-period Events at Kusatsu-Shirane Volcano, Japan

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The waveform of a volcanic long-period (LP) event is characterized by a superposition of decaying sinusoids. It has been recognized that the complex frequencies (frequency, f and the quality factor, Q) of the decaying sinusoids show significant temporal variations. In this paper, we present a detailed description of temporal variations in f and Q of LP events at Kusatsu-Shirane Volcano to investigate the relation between LP events and magmatic activity. Extensive LP seismicity and systematic temporal variations in the complex frequencies of LP events are identified in 1989, 1991, 1992, and 1993. The complex frequencies of the LP events occurred between 1992 and 1993 were investigated by Kumagai et al. [2002, JGR, 10.129/2001JB000653]. In this paper, we determine f and Q of LP events occurred in 1989, when the renewed eruption activity started in Kusatsu-Shirane Volcano and a swarm of 40 LP events within 25 days occured. Our Sompi spectral analysis of the LP events shows that the frequency decreases from about 3.2 Hz to 1.7 Hz at the middle of the period, and then increases up to about 4 Hz. The Q factor increases from about 30 to 100, and then decreases down to about 20 at the middle of the period. After that, the Q factor again increases up to about 100 and then decreases down to about 30 at the end of the period. We find that the observed temporal variations in 1989 can be reasonably interpreted by oscillations of a crack filled with a water-gas mixture. The frequency of the oscillations of such a crack increases with increasing gas-volume fraction (GVF). On the other hand, the Q factor is around few tens at GVF of 0 and 1, and reaches a maximum value of about 100 in the vicinity of GVF of 0.5. Therefore, the temporal variations in f and Q can be explained by a change of GVF in a water-gas mixture: In the first half of this period, GVF changes from 1 to 0, and then changes from 0 to 1 in the second half of this period. This change may be interpreted as a dry crack gets wet by a seepage of hydrothermal water into the crack in the first half of the period. As heat supply from deeper magma become higher or water supply decreases in the hydrothermal system, the crack again gets dry in the second half of the period. We suggest that the LP activity in Kusatsu-Shirane Volcano may be basically controlled by an interaction between magmatic heat and water supply with possible seasonal variations in the hydrothermal system.

V52B-0439 1330h POSTER

Fluid Influenced Faulting in the Long Valley Volcanic Region

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To better understand how hydrothermal and magmatic systems directly influence local earthquake production, we determined the extent of fluid influenced faulting in the Long Valley volcanic region. We focused on a 100 km wide circular area centered at Long Valley caldera which also encompassed the Mono-Inyo Craters to the north and the seismically active Sierra Nevada mountain block to the south. We comprehensively searched for events since 1993 with coseismic volume changes in their source regions by solving for the full moment tensor solution which includes an isotropic (volumetric) component. We use a nested F test statistic to compare this solution with the deviatoric solution, which assumes no volume change, to determine the probability that the additional volumetric component represents a true aspect of the source mechanism rather than being simply an added non-physical parameter in the inversion. Moment tensor solutions were computed from regional broadband Berkeley Digital Seismic Network data for events greater than M3.5. This investigation showed that fluid influenced earthquakes are fairly unique in this region. They occur only in the south moat of the caldera, where there has been extensive independent evidence of magma movement, and in the Sierra Nevada block, where there has been equivocal evidence of magma existence (Hough et al., 2000; Peppin et al., 1989).

URL: http://www.seismo.berkeley.edu/∼dennise/fdes.html

V52B-0440 1330h POSTER

Long Valley Deep Hole Geophysical Observatory — Strain Instrumentation and Installation.

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The Long Valley Exploratory Well, drilled in the middle of the resurgent dome in the Long Valley caldera, was started in 1989 and after rather checkered progress eventually reached a depth of about 9,831 feet. The hole is cased to a depth of 7178 feet with bare rock below that. At 8,500 feet there is an open fracture system with substantial permeability. One of the goals of the instrument installation is to enable monitoring of this deep aquifer. The most satisfactory rock away from obvious large fractures was at about 7,400 feet, and this was the installation depth. The instrumentation package consisted of a bottom hole seismometer at a depth of about 8500 feet, and a coupled instrument string that was cemented to the rock at a depth of 7400 feet. The instrument string, 73 feet long, had an inflatable packer with an extension at the bottom, coupled to a seismometer with a cement exit port above it, a 22 foot long spacing tube connected to a 20 foot long sensing volume strainmeter assembly. The strainmeter unit is essentially an annulus with the cementing pipe passing through it. In addition, two seismometer cables, two water bypass tubes and a packer inflation tube, pass through the strainmeter, which is actually two concentric strainmeters. The outer unit is a dilatometer and the inner unit is a vertical component strainmeter. Before installation, the strainmeters and the 8000 foot long stainless steel coupling tubes were filled with filtered and degassed water. The instrument string and attached bottom hole seismometer were then lowered down the hole attached to drill pipe. Two optical fiber vertical strainmeters (one interferometer and one time-of-flight loop) consisting of three fibers were attached to the drill pipe as it was installed. After the drill pipe reached target depth, it was secured to the well head. The packer, at the bottom of the instrument package, was inflated, thus providing a sealed bottom for the cement. Cement was then pumped down the drill pipe, through the strainmeter assembly and out the tube about 25 feet below the bottom of the strain sensing assembly. About 450 feet of the hole was cemented, the cement going into the casing. The coupling tubes from the strainmeters were connected to a surface mounted sensing head that had hydraulic amplification and electronic transducers. Pressure changes in the lower aquifer cause flow through two 1/4 inch diameter tubes into the annulus outside the mounting and cementing pipe. An opening sleeve in the installed pipe will allow the resulting water level changes to be monitored in a protected environment. All installed instrumentation seems to be functioning satisfactorily.

V52B-0441 1330h POSTER

Seismic Character of an Active Silicic Volcanic System: Long Valley Caldera, California

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Knowledge of crustal structure in the Long Valley Caldera region is key for interpretation of active tectonic and magmatic processes, and for volcano hazard prediction. Measured Vp and Vs from large diameter core collected in drill holes within the caldera to 1.2 km depth provide a reference section through intra-caldera units; core collected from basement sampled in LVEWIII provides data beneath the resurgent dome. Together these samples provide insight into the physical properties of an active, silicic volcanic system. Seven samples of basement (banded, meta-pelite) from the lower part of LVEW III (2220-2853m) were measured at confining pressures from 0-400 MPa, and ambient temperature. No measurements were made of highly fractured rocks recovered from the hole due to

experimental limitations. Sample density varies from 2.60-2.76 g/cc, all with porosity <0.5%. P-wave velocity at 100 MPa varies from 5.28-5.72 km/sec; Vs 3.22-3.63 km/sec, with a strong linear correlation between velocity and density. Vp/Vs varies between 1.52-1.72. Measured values are consistent with logging-based estimates of Vp to within 4%. Anisotropy in Vs (based on orientation of compositional layering) ranges from 0.5-9%. Intra-caldera volcanic deposits have heterogeneous seismic velocities that vary linearly with density (1.20-2.76 g/cc). P-wave velocities at 100 MPa for rhyolites (including early rhyolite, Bishop Tuff, and moat rhyolite) range from 2.52-5.24 km/sec, and show complete overlap with experimental results for rhyolite melt; Vs for the same samples range from 1.51 to 3.34 km/sec. Late intra-caldera basalt, have Vp of 2.59-5.72 km/sec, and Vs 1.59 to 3.08 km/sec. A detailed seismic velocity study of the Bishop Tuff (up to 250 meter thick) from both intra-caldera and outflow samples, suggests that porosity, density, and therefore velocity are all functions of compaction and welding. Densely welded samples with porosities between 2 and 4%, have Vp > 4.65-4.88 km/sec and Vs >2.8 km/sec, whereas those showing little welding (up to 30% porosity), have Vp from 2.64-4.46 km/sec and Vs 1.53-2.79 km/sec. Vp/Vs varies from 1.58 to 1.82. P-wave anisotropy varies systematically relative to compaction foliation, and ranges up to 4% (Vs

V52C MCC: 3006 Friday 1340h

The Stromboli and Etna Eruptions of 2002-2003

Presiding: **S Falsaperla,** Istituto Nazionale Geofisica e Vulcanologia, Sezione Catania**; M Patrick,** University of Hawaii, Manoa

V52C-01 1340h

Long Term Geochemical Monitoring of Stromboli Volcano (Italy): Clues On 2002-2003 Eruption From Gas Chemistry, Helium And Carbon Isotopes

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Since 1999, a geochemical monitoring has been carried out on both the hydrothermal system and the crater fumaroles of Stromboli volcano. A few (3) thermal waters as well as a low temperature (98°C) fumarole, located on the "Pizzo sopra La Fossa" area, are monthly sampled and analysed for their chemical and isotope (He and C) composition until the onset of 2002-2003 eruption. CO_2 is the main gas species dissolved in thermal waters, with concentrations ranging from 30 to 160 cc/l STP. The sampled fumarole showed a CO_2 dominant composition (about 100% vol.). Measured $^3He/^4He$ ratios are in the range of 3.6-4.3 Ra (corrected for air contamination), which represents the higher magmatic marker recently recognised at Stromboli (Inguaggiato & Rizzo, 2003). Since June 2002, synchronous variations in the dissolved CO_2 and $^3He/^4He$ ratios were observed among the sites. Such variations occurred before and during the main periods of volcanic unrest, displaying similar trends with those observed at the crater fumarole. Such findings suggest that episodes of magma degassing and ascent occurred in the plumbing system some months before the onset of the 2002-2003 eruption (28th December), inducing a pressure increase in the shallow levels of the volcano. Similar variations, although with a different range, were recognized before and during the 5th April 2003 explosive event, suggesting again a new input of gas-rich magma batches which induced a pressure increase in the shallow feeding system. Gaseous CO_2 of the fumarole showed a $\delta^{13}C$ average value of -2, which represents the typical magmatic marker for this volcano, falls in the range of Mediterranean volcanoes area (0 to -2 $^o/_{oo}$, Inguaggiato et al., 2000). The CO_2 gas isotope data of thermal waters, recalculated from TDIC values, highlighted a wide range of variation, from -9 to 0 $^o/_{oo}$ versus PDB linked to a mixing between magmatic and atmospheric end-members(-2 $^o/_{oo}$ -7 $^o/_{oo}$ respectively). Since June 2002, temporal variations of recalculated $\delta^{13}C$ values showed more homogeneous isotope data around -2$^o/_{oo}$, suggesting an increased magmatic contribution of CO_2 in the hydrothermal system. After 5th April, the absence of new input of undegassed magma determined a progressive trend towards more negative isotope values in the thermal waters. The long term monitoring of Stromboli volcano allowed us to recognise signals of magma degassing before and during the main episodes of volcanic unrest, thus representing an important tool in forecasting volcanic activity. Inguaggiato S., G. Pecoraino, and F. D'Amore. Chemical and isotopical characterization of fluid manifestations of Ischia Island (Italy). J.Volcanol.Geoth.Res. 99:151-178, 2000. Inguaggiato S. & A.Rizzo. Dissolved helium isotope ratio in ground-waters: A new technique based on gas-water re-equilibration and an application to a volcanic area" Appl. Geochem. Accepted. 2003

V52C-02 1355h

FLIR Thermography and Heat/Mass Budgets Bounding the 2002-2003 Effusive Period at Stromboli Volcano

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The remarkably consistent behavior of Stromboli Volcano, involving small intermittent explosive events, abruptly shifted to lava effusion from December 2002 to July 2003. Encompassing periods before, during and after the months of effusion we used a hand-held FLIR (Forward Looking Infrared Radiometer) camera to characterize heat loss from the volcanic vent system. We present new methods to estimate mass and heat flux of explosive events, as well as radiative and convective heat losses from the summit vents, using the FLIR imagery and image processing techniques. These results complement data from previous studies to comprise a comprehensive heat and mass budget covering the period around the 2002-2003 effusive stage. The pre-effusive heat flux totaled 420 MW, while the co-effusive value reached about 2100 MW, equating to an approximate increase in heat loss by a factor of five. Pre-effusive eruptive mass flux averaged about 150 kg/s, while the co-effusive value was about 1450 kg/s, meaning an increase in mass output by approximately a factor of ten. The eruptive mass output during the effusive period is roughly equivalent to the inferred subsurface magma flux (approx. 1350 kg/s) feeding the shallow system, which remained relatively constant throughout the pre and co-effusive stages according to gas flux measurements from other studies. Unlike the pre-effusive period when only a small portion of this magma influx was erupted, the effusive stage exhibited a balance between the subsurface influx and the erupted output. These observations suggest that the magma system at Stromboli remained unchanged at depth, and the effusive episode was simply a function of processes in the shallow conduit.

V52C-03 1410h

Seismo-Acoustic Monitoring of the Dec. 2002 Eruption of Stromboli Volcano

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On December 28, 2002, after several days of sustained strong explosive activity, an extremely fast lava flow run over the NE crater rim along the flank of Sciara del Fuoco partially filling the small basin at 650 m a.s.l. and reaching the sea in few minutes. A couple of days later, on December 30, with the lava still flowing out, a large landslide affected the subaerial and the underwater flank of the Sciara del Fuoco. The landslide produced tsunami waves which have severely damaged the San Vincenzo village and were observed all around the southern Tyrrhenian sea. The volcanic activity, following the landslide, was characterized by effusive activity from a lava field at 650 m, with no visible explosions from the summit crater. Since January 4, 2003 a seismo-acoustic network of 5 stations and a five-elements infrasonic array were deployed on the summit of Stromboli volcano. Each station consists on a 5 channel 16 bits A/D converter, a Guralp CMG-40T broadband seismometer and an infrasonic microphone. Digital data are radio-transmitted from the summit to the recording site in the village of Stromboli, at 9600 baud rate. Seismic activity during the effusive activity after the Dec. 30 landslide was characterized by a low amplitude tremor and by seismic transients with a clear VLP component (3-20 s) evidencing the internal magma dynamics. In spite of the absence of visible explosions at the craters, number of VLP per hour was high (10-15 events) and their waveform was typical of the pre-eruptive explosive activity. Location of the VLP after the eruption was not changed and remained stable indicating that source dynamics and conduit geometry were not affected by the collapse of the Sciara del Fuoco. This frequent seismic activity was seldom accompanied by weak (3-10 Pa) acoustic signals, revealed and located by the infrasonic array mainly in the NE crater. The presence of infrasound associated to seismic VLP indicated that the conduit were still opened and active even if the craters were thermically cold. However, the low infrasound and VLP amplitude was a clear evidence that the gas exsolved in the magmatic system and hence the explosive energy was reduced. This was also confirmed by the extremely large time delays (up to 30 s) between the seismic and acoustic onset. This general trend was interrupted by the strong April 5 explosion. After the minimum values recorded in May-June 2003, amplitude is now increasing toward the level of the typical strombolian explosive activity.

V52C-04 1425h

ENERGETIC TREND in EXPLOSIVE ACTIVITY of STROMBOLI

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The typical activity of Stromboli consists of intermittent mild explosions lasting a few seconds, which take place at different vents and at variable intervals, the most common time interval being 10-20 minutes. However, the routine activity can be interrupted by more violent, paroxysmal explosions, that eject m-sized scoriaceous bombs and lava blocks to a distance of several hundreds of meters from the craters, endangering the numerous tourists that watch the spectacular activity from the volcano's summit located about two hundreds meters from the active vents. On average, 1-2 paroxysmal explosions occurred per year over the past century, but this statistic may be underestimated in absence of continuous monitoring. For this reason from summer 1996 a remote surveillance camera works on Stromboli recording continuously the volcanic activity. It is located on Pizzo Sopra la Fossa, 100 metres above the crater terrace where are the active vents. Using image analysis we seeks to identify any change of the explosive activity trend that could precede a particular eruptive event, like paroxysmal explosions, fire fountains, lava flows. The analysis include the counting of the explosions occurred at the different craters and the parameterization in classes of intensity for each explosion on the base of tephra dispersion and kinetics energy. Associating at each class a corresponding Index of energy in order to compute an heuristic value of the Average Daily Energy Released (ADER) of the explosive activity at Stromboli and plotting this value for each crater versus time, the diagram shows a cyclic behavior with max and min of explosive activity ranging from a few days to a month. Often the craters show opposite trends so when the activity decreases in a crater, increases in the other. Before every paroxysmal explosions recorded, the crater that produced the event decreased and then stopped its activity from a few days to weeks before. The other crater tried to compensate increasing its activity and when it declined the paroxysmal explosion occurred suddenly at the former site. From September 2001 an on-line image analyzer called VAMOS (Volcanic Activity MOnitoring System) operates detection and classification of explosive events in real-time. The system has automatically recorded and analyzed the change in the energetic trend that preceded the 20 October 2001 paroxysmal explosion that killed a woman and the strong explosive activity that preceded the onset of 28 December 2002 lava flow eruption.

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