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 endmembers(-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.

V

V52C-05 1440h

Volcanic Activity Evaluation by the Mean of Soil Temperature Continuous Monitoring During the 2002-2003 Eruption at Stromboli Volcano (Eolian Islands, Italy)

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Stromboli volcano is characterised by both strombolian activity and periodic isolated paroxysmal events of mayor intensity, the more recent of which started on December 27th, 2002 and terminated on August, 2003. The eruptive event may be subdivided into two major phases, separated by a big explosion that took place in April 5th, 2003. During the first phase we observed a lack of activity at the top craters, due to the opening of some eruptive fractures at altitudes between 500 and 600 m a.s.l., along the so called "Sciara del fuoco", on the northern flank of the edifice. The April 5th explosion, from crater #1, occurred under condition of partial obstruction of the vent, caused launching and fall-down of lava fragments and rock blocks of several hundreds of kilograms in an area of about 1 km around the mountain top. After the explosion the eruption evolved towards a progressive renewal of activity at top craters, accompanied with a diminution of the lava flow rates from the fractures, until their complete closure occurred during August, 2003. These different phases were well detected by a network of soil temperature monitoring stations, composed of two multi-parametric (CO2 fluxes-soil temperature-meteorological parameters) stations, located in the top area (STR02) and at sea level (STR01), with continuous operations from January 2003, and other 3 provisory temperature-only dataloggers, placed at different altitudes between the two previous cited stations, that operated in a time range of 1 to 3 months. In particular, during the first phase we observed several cycles of cooling-warming of the soil at STR02, with frequencies of few days. The April explosion occurred just after a thermal anomaly of 3-4°C, that interrupted the seasonal soil warming, well detected at STR01. The final phase of the eruption was characterized by stable temperatures at STR02 and little well-defined thermal anomalies detected either at STR01 either at the other temperature dataloggers. The acquired thermal data seem to represent a useful tool in volcanic activity monitoring but, on the other hand, they need to be validated also under different seasonal conditions. The major detected anomalies, in fact, did not occurred during the warmest months (June-July), when the strong soil warming, due to high solar irradiance, may mask the volcanic-induced effects.

V52C-06 1455h

The 2002-2003 Mt. Etna Eruption: Insights From Volcanic Tremor Analysis

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The unrest of Mt. Etna in Fall 2002 marked a renewal of effusive activity shortly after the previous eruptive episode, which occurred between July and August 2001. The brief time span between the two eruptions and the similarities in the composition of the volcanic products erupted have led to surmise their strict link, which is supported by several geophysical evidence as well. Seismic swarms and remarkable changes in volcanic tremor at the beginning of both eruptions characterized seismic activity recorded at the permanent seismic network. We analyze the main features of volcanic tremor between the 2002-2003 eruption, providing a characterization of this signal in the time and frequency domains. We discuss the amplitude and frequency variations at several seismic stations, which are located at different distances with respect to the volcanic source. Besides, we propose a comparison with the previous eruptive episode, during which remarkable changes in the amplitude of volcanic tremor accompanied and marked different styles of eruptive activity.

V52C-07 1510h

Analyses of Etna Eruptive Activity From 18th Century and Characterization of Flank Eruptions

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Etna explosive activity has usually been considered subordinate with respect to the effusive eruptions. Nevertheless, in the last decade and overall after the 2001 and 2002 flank eruptions, explosive activity has drawn the attention of the scientific and politic communities owing to the damages that the long-lasting ash fall caused to Sicily's economy. We analyzed the eruptions from the 18th century to find some analogous behavior of Etna in the past. A study of the Etna historical record (Branca and Del Carlo, 2003) evidenced that after the 1727 eruption, there are no more errors in the attribution of the year of the eruption. Furthermore from this time on, the scientific quality of the chronicles allowed us to obtain volcanological information and to estimate the magnitude of the major explosive events. The main goal of this work was to characterize the different typologies of Etna eruptions in the last three centuries. Meanwhile, we have tried to find the possible relationship between the two kinds of activity (explosive and effusive) in order to understand the complexity of the eruptive phenomena and define the short-term behavior of Etna. On the base of the predominance of the eruptive typology (effusive or explosive) we have classified the flank eruptions in three classes: i) Type 1: almost purely effusive; ii) Type 2: the intensity of explosive activity comparable with the effusive; iii) Type 3: almost purely explosive with minor lava effusion (only the 1763 La Montagnola and 2002 eruptions belong to this class). Long-lasting explosive activity is produced by flank eruptions with continuous ash emission and prolonged fallout on the flanks (e.g. 1763, 1811, 1852-53, 1886, 1892, 2001 and 2002 eruptions). At summit craters continuous activity is weaker, whereas the strongest explosive eruptions are short-lived events. Furthermore, from the 18th to 20th century there were several years of intense and discontinuous summit explosive activity, from high strombolian to fire fountain. This activity produced abundant ash fall in the whole volcano area reaching the Calabria region and Malta Island. Generally, some of these periods preceded important flank eruptions. Concerning the occurrence of the higher magnitude explosive events, we observe that at least one subplinian eruption occurred both in the 18th and 19th centuries. In the 20th century the increased quality of the scientific reports has allowed to recognize 6 subplinian eruptions from summit craters.

V52D MCC: 3008 Friday 1340h

Mantle Geochemistry

Presiding: **K Cooper,** University of Washington**; F Frey,** Massachusetts Institute of Technology

V52D-01 1340h

Nb-U-Th-La Tracers of Basalt Sources Revisited

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Oceanic basalts from mantle upwellings (MORB, OIB) have typically much higher Nb abundances relative to other highly incompatible elements than do island arc and continental rocks, and this serves as one of the chief geochemical discriminants between the two tectonic environments. Hofmann et al. (1986) quantified this and claimed, on the basis of 28 MORB and 41 OIB analyses (from 11 oceanic islands), that Nb/U ratios are surprisingly uniform at 47 ± 10 (=± 21%) in MORB and OIB. They further argued that mantle melting in the MORB-OIB environment does not change Nb/U, so that this ratio also characterizes the mantle source(s) of these rocks, in contrast with a much lower average Nb/U =10 of the continental crust. Finally, they concluded that this rules out recycling of continental crust as an explanation for the trace element enrichment of OIB sources. Subsequently, local correlations between Nb/U and 87Sr/86Sr in EM-type OIBs indicated at least some admixture of recycled continental material to those sources (Chauvel et al., 1992, Hofmann, 1997), so that specific source contributions of OIBs can be identified. Sims & DePaolo (1997) reanalyzed the 1986 database and concluded that the Nb-U relationships (as well as Ce-Pb, not discussed here) are consistent with recycling of continental material to explain the entire isotopic heterogeneity of OIB sources. Seventeen years later, the amount of relevant data has increased dramatically, and their assessment is facilitated by the GEOROC and PetDB databases (http://www.earthchem.org/). Even now, a major difficulty lies in filtering out data of poor quality, due to either alteration or analytical errors. This can be done using criteria of analytical technique and data scatter, but a subjective judgment is unavoidable. I present a survey of about 450 OIB analyses from 20 (non-EM-2 type) hotspots and 170 MORB analyses from the three major oceans. Elements forming a globally uniform concentration ratio should be linearly correlated on a logA-logB plot with a slope of 1.0. Thorium, U, and La in MORBs form tightly linear correlations with Nb, with slopes changing systematically from 1.06 through 0.99 to 0.71, respectively. For OIBs, the respective slopes are 1.11, 1.06, and 0.93. Thus, for both MORBs and (non-EM-2) OIBs, the logNb-logU correlations have slopes closest to unity, with mean values of Nb/U = 47±24% (MORB) and 52±25% (OIB). R.S.D. values of Nb concentrations are 100 % (MORB) and 123% (OIB). Although no attempt has so far been made to weight the data, e.g. by location, this evaluation of a greatly expanded dataset provides remarkable confirmation of the original conclusions, with the important modification that most EM-2 (and at least some EM-1) type OIBs have significantly lower Nb/U ratios, which correlate with 87Sr/86Sr ratios, consistent with significant input of recycled sediment or other continental material in their sources. Other OIB sources contain little or no recycled continental source components. Chauvel, C. et al. (1992) Earth Planet. Sci. Lett. 110, 99-119. Hofmann, A.W. et al. (1986) Earth Planet. Sci. Lett. 79, 33-45. Hofmann, A.W. (1997) Nature 385, 219-229. Sims, K.W.W. & DePaolo, D.J. (1997) Geochim. Cosmochim. Acta 61, 765-784.

V52D-02 1355h

Trace Element Composition of the Depleted Upper Mantle

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The trace element composition of the depleted upper mantle (DMM) is a crucial parameter in modelling the generation of mid-ocean ridge basalts (MORBs), calculating the crust-mantle mass balance, and establishing the chemical and thermal evolution of the stratified Earth. Although MORBs have some degree of heterogeneity in radiogenic isotope ratios (Sr-Nd-Pb-Hf), they are focused within a small range of values relative to ocean island basalts and are, with few exceptions, depleted from bulk earth values in $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$. We interpret DMM to be a reservoir residual to variable degrees of melt depletion from a primitive mantle, and offer a method of estimating the trace element composition of a depleted mantle given any degree of depletion at any time. This method is based on the following: (1) Trace element compositions of clinopyroxenes from a global suite of abyssal peridotites with known modal abundances (compiled from the literature), (2) Parent/daughter ratios needed to evolve to today's average isotopic ratios of DMM based on segregation from bulk silicate Earth (BSE) at 1.8 Ga and (3) Canonical trace element ratios of MORBs. Trace element compositions (Sr, Zr, Ce, Nd, Sm, Eu, Dy, Er and Yb) of cpx grains in abyssal peridotites have been converted into bulk rock compositions using modal abundances and mineral/mineral partition coefficients. We have excluded samples containing more than 1% modal plagioclase. The relationship between the concentrations of two elements, A and B, in the residue of fractional melting can be linearized as follows:

$$\ln(C_s^A) = R\ln(C_s^B) + \ln\left(\frac{C_o^A}{(C_o^B)^R}\right)$$

Where R is a function of the bulk partition coefficients:

$$R = \frac{D_B(1 - D_A)}{D_A(1 - D_B)}$$

Calculated bulk rock compositions were plotted as ln([A]) vs. ln([B]) and fit with a two-error regression. Most regressions involving two REE intersect the primitive upper mantle (PUM) coordinates of McDonough and Sun (1995) within error of the regression, reinforcing the assumption that the starting composition for DMM was PUM, and suggesting that bulk partition coefficients have been very nearly the same throughout the melt depletion process. Since this regression scheme only provides relationships between elements, the absolute concentration of one or more elements must be determined from an additional constraint. For