PROJECT TITLE

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ACTIVITY REPORT –2nd YEAR

PROJECT PARTICIPANTS

RU#	AFFILIATION	RESPONSIBLE
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	INGV Catania	M. Pompilio
	Dip. Scienze della Terra Univ. Firenze	
	Istituto Geolgia Marina Bologna	L. Francalanci
	CIRCFT Università di Padova	M. Marani
	Dip. Sc. Geol. Geotecniche Univ. Milano-Bicocca	A. Vettore
	Dip. Fisica Univ. Bologna	A. Tibaldi
	Dip. Scienze della Terra Univ. Parma	S. Tinti
	INGV Roma	G. Serri
	CNRS-CEA Gif/Yvette Francia	M. L. Carapezza
		P. Allard

GENERAL OBJECTIVES

The project is aimed at the integrated collection of geology, petrology, geochemistry and marine geology data such to permit a substantial upgrading of knowledge for the potentially dangerous phenomena produced by the eruptive activity of the volcano. The project is also aimed at the acquisition of data, relevant to the definition of the hazards associated to the catastrophic failure of the Sciara del Fuoco slope. Such a scenario includes explosive phenomena induced by landslide decompression and tsunami wave generated by the entrance to the sea of the debris avalanche and to the identification of areas exposed to hazards. The project also intends to contribute to the risk mitigation at Stromboli by developing and testing of new techniques for the forecasting of dangerous phenomena.

TASK 1 -:Major explosions and paroxysms

- (RU PARTICIPANTS : Rosi, Francalaci, Pompilio, Allard)

- 2nd YEAR OBJECTIVES

The aim of this task was to improve the knowledge of how the shallow magmatic system works and develop a conceptual model of paroxysms

2nd YEAR RESULTS

The UR Rosi studied pumice emitted during two major paroxysms, in order to collect new data on the deepest part of Stromboli's feeding system. Comparison between the new data on mineralogy, major, volatile and trace element geochemistry of olivine-hosted melt inclusions (MI) and those presented by Metrich et al. (2001), indicate that MI of paroxysms have recorded true primary melts rich in CaO (up to 14.5 wt%) but low in FeO (6-7 wt%). They demonstrate recurrent variations in the chemistry of the primary magmas distinct with respect to their K_2O content and S/Cl ratios that enter the deep-system. Their volatile concentrations indicate crystal fractionation and storage between 3 and 4 kb fluid pressure. Data on MI suggest a conceptual model involving high-pressure differentiation of limited volume of CaO-rich FeO-poor primary magmas at the origin of the HK-basaltic pumice produced at Stromboli. Interactions between primary melts and olivine crystals inherited from pre-existing crystal-mush and mixing with the HK-basaltic magmas resident at high pressure are recorded at the scale of the micrometer, only. Based on olivine growth-rate calculations, the volatile-rich magma blobs possibly ascent within few hours to few tenths of hours. Rapid ascent rate combined with restricted temperature gradient and limited crystal

The crystal-rich magma feeding the persistent activity of the volcano have been investigated by studying plagioclase crystals host in scoriae emitted during normal activity, and lava effusion over the period 1985-2000. Detailed study of the compositional and textural zoning of plagioclase grains reveals the existence of alternating shells of An-rich and An-poor compositions. An-poor shells are thinly zoned, inclusion-free and likely form during crystal growth episodes in

equilibrium with the volatile-poor liquid. In contrast the An-rich shells bear large number of inclusions and reflect rapid, non in equilibrium growth episodes which immediately followed the interaction between the volatile-rich melts with the crystal-rich, volatile poor mush. The high H_2O content of the volatile-rich melt cause corrosion of the An-poor shells followed by the growth on an An-rich shell. The exolution of H_2O is accompanied by the further crystallization of plagioclase and its gradual change in composition towards An-poor composition. Crystallization induced by degassing rapidly changes the crystal-poor, volatile-rich magma into the crystal-rich, volatile-poor magma.

- Analyses of both mineralogy and MI (≈ 80 inclusions and their host) have been done on three selected samples of the activity before 1800 years ago. Preliminary results suggest a different crystallization history in terms of temperature and possibly pressure with respect to the present day activity. The most primitive melt inclusions have typically low K content close to 1 wt.% that clearly indicates that they evolved from a parental magma poorer in potassium also typical of the San Bartolo activity.

The Ur of Francalanci conducted Sr isotope analyses (27 analyses in total) that strengthened the data base on the recent activity of the volcano. Sr isotope ratios have been analysed in whole rock samples of scoriae and pumice erupted from 1998 to 2001. The same isotopes have been also measured in glassy groundmasses from a 1998 pumice and a 2000 scoriae. Scoriae samples, up to 1999, confirm the general tendency of Sr isotope ratios to slightly decrease with time since a period around 1980-85. Samples from 2000 eruptions show higher values, for decreasing again towards 2001. The glassy groundmass of the 2000 scoriae sample with the highest Sr isotope ratio shows a value similar to the whole rock.
Pumice samples, on the other hand, show lower Sr isotope ratios than scoriae and a slight smooth increase of $^{87}Sr/^{86}Sr$ from 1996 to 2000. Sr isotope ratios of whole rock – groundmass pairs in pumice suggest the occurrence of syn-eruptive mingling between scoria and pumice magmas.
In order to investigate the variations of $^{87}Sr/^{86}Sr$ in the recent past and to correlate them with the present values, Sr isotope ratios have been also analyzed in pumice and pumice-scoriae pairs from different stratigraphic levels of Trench 1 and Trench 2 of Rosi et al. (2000, *Bull. Volcanol.*). In both trenches, Sr isotope ratios of pumice samples show similar values, with general decreases from bottom to top (from about 0.706265±7 to 0.706194±7). Scoriae samples, which are only available from Trench 2, also display a general decrease of Sr isotope ratios from bottom to top of the sequence, ranging from 0.706265±6 (groundmass value) to 0.706229±8. Analyses of $^{87}Sr/^{86}Sr$ for some glassy groundmasses of scoriae and pumice have given values nearly similar to those of the respective whole rocks. A pumice sample coming from another outcrop has shown the highest value of 0.706317±9.

Analyses of Nd isotope ratios in samples erupted from the present day activity (10 pumice and scoriae samples and in 2 glassy groundmass) were performed. They do not show any significant variations with time; $^{143}Nd/^{144}Nd$ have been also analysed in 5 samples of pumice and scoriae from Trench 2. They show a quite constant value of about 0.512550.

Complete sets of trace elements have been analysed in about 70 glassy groundmasses of a large number of scoriae and pumice samples from 1996 to 2000 A.D. activity. The analyses have been performed at the CNR - "Istituto di Geoscienze e Georisorse - Sezione di PAVIA", by a Laser Ablation Microprobe.
Results indicate that scoriae glasses have higher incompatible and lower compatible element contents than pumice glasses. All trace element contents form good correlations with Rb, which will allow us to better define processes of evolution and to quantify the role of different mineral phases involved. Small but systematic differences of trace element contents are found between the scoriae glasses of different eruptions.

TASK 2 -: Flank collapses
(RU PARTICIPANTS : Tbaldi, Marani, Rosi)
The problem of flank collapses is addressed by two main actions: Assessment of the present stability of the NW flank of the volcano and collection of marine geology data for the identification, mapping and dating of past debris avalanche deposits ad associated volcanogenic turbidite deposits.

- 2nd YEAR OBJECTIVES

During the second year research the UR Tibaldi intended to provide a geological and geotechnical model of stability of the north–western flank of the volcano. The model includes stratigraphic, lithologic and structural data plus geotechnical and geomechanical parameters of the previously identified lithotechnical units. The model addresses three types of instabilities: 1) stability of the recent loose deposits which fill up the Sciara del Fuoco depression, 2) "local" instability along the Sciara scarps and flanks and 3) stability related to dip failure surfaces, "large scale sector collapses" like those recognized in the past volcano history:
Objectives of the UR Marani include geophysical investigation of the structure and depositional setting of the submarine Stromboli edifice and distal, deep-water regions. Sea-bottom sampling transects (gravity coring, box coring and dredging) in both the submerged Stromboli edifice and distal, deep-water regions. The latter activities were conducted in collaboration with the Ur Rosi.

The objective of the UR Serri was a petrologic investigation of the basement and subvolcanic rocks included in the pyroclastic deposits linked to the sector collapses of Stromboli occurred in the last 5-6 ka. An evaluation of the degree of hydrothermal alteration of the shallow-level volcanics of Stromboli through the systematic study of lithic ejecta erupted during recent or present-day activity.

- 2nd YEAR RESULTS

TheUR Tibaldi performed the following activities:
- geotechnical characterization of the soil like materials, filling up the Sciara del Fuoco depression, by:
  - sampling of loose materials,
  - measure of their physical and mechanical properties by standardised laboratory tests;
- rock mass characterization and engineering classification by:
  - structural and geomechanical surveys,
  - sampling of rock (intact rocks and joints),
  - measure of physical and mechanical properties by standardised laboratory tests on intact rocks and joints,
  - evaluation of rock mass strength and elastic parameters by empirical failure criteria (in progress)

stability analysis (in progress)

- ***Geotechnical characterization of the soil like materials, filling up the Sciara del Fuoco depression***

The collected samples are representative of the loose deposits related to the present activity of the Sciara del Fuoco. All the samples are mainly gravel and sands, with no silt. The natural water content is W<6.3%; the grain bulk volume Gs=2.91÷3.08 g/cm^3; the maximum and minimum bulk volume, determined on the grain size fraction minor than 9.5 mm, are respectively: $\gamma_{d\ min}$ = 1.32 ÷ 1.51 g/cm^3 and $\gamma_{d\ max}$=1.70 ÷1.78 g/cm^3 from which porosity have been computed n=40 ÷ 55 %. Consolidated-undrained triaxial compression tests have supported the peak and residual shear strength parameters, cohesion and shear strength angle: c_p = 0 , ϕ_p'= 43.5°÷50.8° and c_r = 0 , ϕ_r' = 39.2 ° ÷ 48.9°.

- ***Rock mass characterization and engineering classification***

Among the 52 sites of structural survey, 20 outcrops, mainly in lithotechnical units where lava deposits are dominant, were chosen to perform rock mechanics characterisation, according to the I.S.R.M. procedure. This procedure enabled to recognise the number of joint sets and their representative orientation, to determine the geometry of each joint (strike, dip and inclination), set spacing, type of movement, dilation amount, degree of alteration, roughness coefficient, presence and nature of infill. The rock masses are classified according to Rock Mass Rating, (Bieniawsky, 1979) and mainly results of "good quality" RMR=66÷80. Less "quality" may be expected for rock masses where breccia layers dominant on lava ones. In case of weak masses the GSI (Geological Strength Index, Hoek, 2000) appears to be a better tool of characterisation. As concerns the physical and mechanical properties of "intact rock", samples either represent tmassive lava layers or single clasts from breccia layers belonging to the following units: Lave di Petrazza, Lave del Vancori superiore and Lave di Vignavecchia.

The combination of in situ rock mechanics properties with intact rock characters allows to calculate the rock masses strength and elastic properties at low geostatic stress (elastic modulus E_m, bulk modulus K_m, shear modulus G_m, friction angle ϕ_m) and enables to estimate these parameters at growing stresses. The effect of confining pressure on strength and elastic modules will be detected by Triaxial Compressive Tests, which are undergoing.

- ***Stability of the recen loose deposits which fill up the Sciara del Fuoco depression***

<u>Limit equilibrium analysis: plane transactional slide of a granular mass at depth minor than 7.5 m</u>

The analysis is carried out with the following assumptions:
- homogeneous loose deposits fill up the Sciara del Fuoco depression at least up to the depth of 7.5 m;
- their geotechnical properties are those measured on the tested sample: c'= 0 kg/cm^2 ; _'= 35.9 °, γ_{min} = 1.511 g/cm^3, γ_{max} = 1.76 g/cm^3 , γ_{med} = 1.635 g/cm^3 .
- the average slope dip is _=35.3°.

Three cases are examined:

a) plane transactional slide of a granular mass at depth of 2.5 m; bulk volume assumed equal to γ_{med} = 1.635 g/cm^3
   The Safety factor is calculated as function of shear strength angle and cohesion c. (fig.4).
b) Plane transactional slide of a granular mass at depth of 7.5 m; bulk volume assumed equal to γ_{max} = 1.76 g/cm^3
   The Safety factor is calculated as function of shear strength angle and cohesion c.
c) The Safety factor is calculated as function of slope dip in the case of cohesion c=0.

The study of the deep-sea surrounding the Stromboli edifice was undertaken in order to evaluate the possibility of extending our knowledge about the eruption style and history of the volcano. In many cases in fact, the preservation

potential of certain horizons, and particularly those connected with explosive activity, is higher in the deep-sea environment than on land.
The interpretation of already available deep-tow sidescan sonar data over the distal part of the Stromboli volcano flanks and over the Marsili basin was carried out in order to better plan the summer research cruise for new data acquisition. These detailed seafloor image, moreover, will be merged with the newly acquired data in order to define the sedimentary and volcanic processes active in the sudy area
A preliminary interpretation of the Chirp sonar lines, has been aimed at determining the distribution of the acoustic facies over the study area. The results show that the Stromboli canyon and a smaller one, descending the western flank of Stromboli edifice feed a deep-sea channalised fan with depositional lobes that extend over much of the Marsili basin as far as the base of the Marsili seamount. Some of the channels appear abandoned and the main sedimentary pathways and coarse-grained depositional bodies appear to lie on the southern portion of the fan. All the cores have been cut and described. The preliminary interpretation of the sedimentary structures has allowed to evidence that high-density turbidity currents and debris flows are the predominant in the flank of the volcano an in the proximal part of the deep sea fan and, while low-density turbidity current deposits are present in the distal portions. Mineralogical, petrographic geochemical and textural analysis of some of the sandy portion of these sediment-gravity flow deposits is underway with the aim of determining if some of them can represent primary or secondary volcaniclastic deposits that could be directly related to pyroclastic flow entering the sea from the Stromboli volcano.
Some of the cores have been deliberately collected away from the main sediment-gravity flow pathways in order to obtain an undisturbed record of hemipelagic sedimentation where the potential of tephra layers preservation is the highest. Analysis of some already identified air-fall layer is ongoing.
Lava samples have been dredged in a submarine cone to the southwest of the island and are at present under geochemical analysis. The freshness of the lavas indicates that recent volcanic activity has occurred in a satellite cone at a water depth of around 1000 m, away from the summit craters of the Stromboli edifice

In cooperation with the UR Marani, the UR Rosi has started, in September 2002, a sedimentological and compositional study on the marine extension of the Sciara del Fuoco structure and the lowermost sector of the Stromboli canyon. This research will combine data on submarine morphology, sedimentology, grain-size, and composition of sediments to make inferences on the sedimentation processes active in the lower sector of the canyon of Stromboli. 50 samples of sediment-gravity flow deposits and tephra beds from 5 gravity cores have been so far selected for grainsize and componentry analysis. The main goual of this research is to come up with a generalized stratigraphy and sedimentation model of the last sector of the Stromboli canyon. We hope to classify different types of sediment-gravity flow deposits and, and possibly recognize and date, incursions of volcanogenic turbidites related to major the flank collapse episodes of the Sciara del Fuoco.

The UR Serri performed a detailed sampling and study of the sub-volcanic lithic component of the “Secche di Lazzaro” pyroclastics, the formation linked to the Sciara del Fuoco sector collapse occurred at the end of the Neostromboli period. New data came from intrusive clasts sampled in the debris flows belonging to the “Secche di Lazzaro” formation, discovered during 2002 in the northern (i.e. Punta Labronzo) and eastern (i.e. Rina Grande) sectors of the island. All the studied sub-volcanic rocks consist of monzonites and closely match, those already found in the “Secche di Lazzaro” proximal debris flows facies. Textural, mineralogical and geochemical evidence prove that the monzonites are cogenetic with the Neostromboli lavas and represent the crystalline materials slowly “frozen” from a shoshonite liquid composition in a shallow subvolcanic environment. New petrologic data furtherly support the hypothesis of violent decompression of the shallow magmatic plumbing system during the Sciara del Fuoco sector collapse which occurred at about 5 ka.
As regard the evaluation of the hydrothermal alteration of the Stromboli edifice the UR carried out a petrologic study on lithic ejecta of the recent/present day activity. In particular detailed mineralogy and compositional information were obtained on large-sized high-T, low-P glassy hornfels xenoliths (“buchites”) sampled at about 200 m from the SW active crater of Stromboli. Petrologic data indicate that “buchite” protoliths were volcanic rocks altered to argillaceous material, belonging to a hydrothermal system of Stromboli. These xenoliths are therefore the results of high-T, low-P transformations at the magma/hydrothermal system interface and may suggest that the recent/present-day basaltic magmas pass through shallow-level, altered volcanic rocks characterised by an “intermediate argillic” mineralogy. The identification of the hydrothermal system of Stromboli through the lithic ejecta has important implications in (i) rock weakening evaluation of the volcano interior and therefore in (ii) the condition ripe to flank collapses.

TASK 3 -: Tsunami
(RU PARTICIPANTS : Tinti, Vettore

2nd YEAR OBJECTIVES
Development of a 2D numerical code to simulate landslide evolution
Sensitivity analysis: effect of grid resolution in computation of tsunami the near-field and in the far-field
During the 2nd year, the research Unit of Padua has carried out several bathymetric surveys, in the south – south east sector of Stromboli island, between Ficogrande and Punta Lena.

- 2nd YEAR RESULTS

A 2D-block model to compute the landslide evolution has been developed by the UR Tinti. The initial slide body is subdivided into a matrix of blocks. The blocks are allowed to deform during the motion, but they maintain the volume constant and remain contiguous. Each block moves under the action of the effective gravity and the bottom friction, both depending upon the local topographical slope, the water buoyancy and water (frontal and lateral) resistance. Moreover, blocks interact through normal and tangential forces, that tend to change the distance between the blocks centres of mass and may induce block rotation. The model has been applied to study flank collapse at Stromboli. The assumed slide body has a volume of about 1 km^3 and its initial geometry is equal to that one assumed in previous studies. Cells having quadrilateral basis form the grid. At the onset time all the bases have supposedly equal horizontal projections. The model computes positions of the slide at different times, the blocks trajectories, the instantaneous shape of the slide and all other dynamical variables. It is found that both longitudinal shortening and transversal widening of the slide occur during the motion. The block trajectories are originally in NW direction and then tend to bend towards N in deeper waters. The resulting block velocities have peak values exceeding 40 m/s and 50 m/s for a few blocks. The heights of the blocks tend on average a general to increase with time.

Tsunami simulation

The simulation of the tsunami is carried out by means of a shallow water approximation finite-element (FE) model. Proper computations are needed to interface results of the slide model with the tsunami model: the instantaneous slide height, which is known at the block-grid nodes (changing position with time), has to be computed at the FE Eulerian grid nodes. Then on such nodes the impulses imparted by the slide to the water are calculated by applying proper transfer-function filtering of the shorter wavelengths to the local sea depth changes induced by the slide. The almost elliptical shape of the volcanic edifice dominates the bathymetry around Stromboli. The tsunami is studied in the near-field around the island over a local grid. The effect of grid resolution on the computed model has been explored. It is found that grids with typical element length larger than 300-400 m in the coastal belt are too coarse and tend to artificially damp the local solution around Stromboli. Here the main tsunami signal consists of a large central trough comprised between a leading and a trailing crest. When the main system of waves leaves the near-field, local waves persist travelling around the island. Wave trapping is known to be quite effective around ocean islands with steep flanks. As was already observed in previous simulations the largest waves are computed in correspondence of the Sciara del Fuoco, that is located on the trajectory of the failing mass, and of Malpasseddu, that is exactly on the opposite side of the island. The tsunami propagation in the southern Tyrrhenian sea has been computed by using a specific larger FE mesh including, which fits rather well the complex coastal boundaries of the Aeolian island archipelago and of promontories and peninsulas of western Calabria and northern Sicily. Analysis of tsunami grid has shown that the tsunami propagation in the intermediate (Aeolian islands, except Stromboli) and in the far field can be computed correctly even on a coarser grid since the signal is dominated by the longer wavelengths. Tsunami fronts radiate outward from Stromboli and approach the mainland, which is reached after about 800 s. Stronger fronts travel eastward (heading to Capo Vaticano) and westward rather than southward (towards Sicily). Fronts loose coherence on approaching the coast. The largest signals are computed on the exposed coasts of Panarea and Salina, rather close to the source. However also the records computed at Gioia Tauro, though it is found more distant on the Calabrian coast, have significant amplitude. The gauge at Punta Faro at the northern entrance of the Straits of Messina shows only a small perturbation, and even weaker are the signals at Messina and Reggio Calabria inside the Straits.

Bathymetric survey. Although the data acquisition software developed in the first year allowed a real-time approach, the analysis of the island morphology revealed that in some areas receiving GPS differential correction data could be shadowed by natural obstructions. Therefore, the UR choosed to perform kinematic GPS surveys with differential data post-processing. The ecosounder data stream acquisition has been synchronized with GPS positioning information by mean of PPS pulse, output from the rover GPS receiver.

Both GPS receivers were double frequency Trimble 4000 Ssi, while the Hmex SonarLite portable ecosounder system has been employed to record depth data. GPS logging interval has been set always to 1 sec. All GPS data were differentially corrected respect with a master station, located on two control points of the GPS network established during first year. The master station has beeen moved between these two vertices, in order to hold the radio link between the surveyors on the island and on the boat.

Combining differentially corrected GPS positions with ecosounder data, several depth profiles were obtained. These profiles are, on average, 10 m spaced, with a density of positions within each profile ranging from 50 cm to 1.5 m.. The distance from the coastline ranges from 200 to 300 m.. A transformation of the acquired data was then performed between WGS-84 and the Roma40 reference systems, in order to determine the 3D coordinates of combined data (planimetric positions + depths) in the national cartographic projection (Gauss-Boaga). The whole data set has been further processed in ArcView GIS, an ESRI software product, where a 10m x 10m cell size grid (DTM) was generated To this aim three different interpolation methods were applied, with different parameter setup, i.e. Inverse Distance

Weight (IDW), Spline and Nearest Neighbour. Although different choices for weight parameters (2-5) for the 2nd method and number of neighbours (6-15) for 3rd one resulted in a more smoothing effect of depth data, the IDW method has given the best results (12 points per group, power factor of 2 for distance weight).

TASK 4 -: Experimentation of monitoring techniques
(RU PARTICIPANTS : Carapezza

2nd YEAR OBJECTIVES)

Systematically collect chemical and isotopic data on soil gas emissions, on weak fumaroles of the crater rim, on thermal water wells, on rain water collected at the summit and at the base of the volcano. To use these data to ascertain the origin of the thermal manifestations of Stromboli and to develop a geochemical conceptual model of the volcano to be used for identifying possible anomalies related to the volcanic activity. (b) to develop and test automatic continuous stations to monitor CO_2 soil flux, together with some relevant environmental parameters, in two pre-selected anomalous sites on the crater rim and at the base of the volcano and to monitor physico-chemical parameters in some thermal water wells.

- 2nd YEAR RESULTS

The thermal waters of wells selected during the first year of activity as the most interesting from a geochemical view point, have been monthly sampled and analysed for chemical and isotopic composition and dissolved gas content . The latter confirmed to be an excellent geochemical tracer. The control for over two years of the chemical composition shows seasonal variations with different influence of the meteoric and marine components. It confirms the process of interaction with hot and acid (mainly CO_2) gases of deep origin. Of particular interest are the recorded variations of the dissolved gas content (CO_2 and He) whose isotopic compositions (_ ^{13}C and $^3He/^4He$) are near to those of the crater rim fumaroles, with a R/Ra ratio even higher. In the Spring-Autumn 2002 a significant increase, with fluctuation, was observed in the quantity of dissolved CO_2. This was followed particularly in November by an increase of CO_2 soil flux recorded at the permanent station of the crater area. In the same period the level of eruptive activity has been particularly high with the magma column near to the surface that produced small lava overflows and numerous and frequent explosions. These data seem to indicate that at the periphery of the volcano early phenomena are recorded of anomalous upraise of deep gases that prelude to a later intensification of the summit eruptive activity. In the light of these data it appears of relevant interest the continuous monitoring of the thermal water well (Cusolito) where the highest compositional anomalies have been recorded. To this scope we request again an additional financial contribution (see annex).
In order to have a total coverage of the island two new pluviometric stations were installed in the Ginostra side that complement the other three stations (Crater rim, GNV-Centre and Sirenetta) already installed in December 2002. Chemical and isotopic analyses of the rain water are presently under complesion.
The continuous recording of CO_2 soil flux (accumulation chamber method) suffered during 2002 because of several problems. The peripheral Pizzillo station had to be dismantled because the authorization to use the site was denied from the land owners. For some months it was reinstalled in another anomalous site (Piscità) where, however, several operational difficulties occurred because of the ground instability. Only recently authorization was obtained to use again the Pizzillo site. Unfortunately those problems caused a prolonged interruption in the data record that however covers a time interval of about two continuous years. The station for CO_2 flux and concentration measurements with different techniques, previously installed at Pizzillo, have been transferred to the crater rim but the data record have been only partial because of repeated damages caused by the eruptive activity. During the second year the sampling, with nearly monthly frequency , has been carried out on the crater rim fumarole. Analyses confirm the presence of a deep (magmatic) component with small but significant variation in the $^3He/^4He$ isotopic ratio that fluctuated between 2.9 and 3.4 R/Ra.
Two scientific papers have been almost completed dealing respectively on the influence of environmental parameters on CO_2 soil flux and on the geochemical significance of the compositional variations observed in the Stromboli fluids during two years of observations.

TASK 5 -: Eruptive history

- (RU PARTICIPANTS : Rosi, Pompilio)

2nd YEAR OBJECTIVES
Final objective: Reconstruction of the eruptive history of the last period of Stromboli's activity

- 2nd YEAR RESULTS

Stratigraphic studies conducted by the UR Pompilio has confirmed the existence of the "Lower Pyroclastic Sequence" identified by Rosi et al (2000) in the mid, NE flank of the volcano. The succession overlies the "Nel Cannestrà" lavas and comprises primary tephra, partially reworked volcanics and paleosoils. Radiometric dating of organic sediment and charcoals fragments indicates that these deposits have been emplaced 1840±40 and 2270±40 (conventional radiocarbon age) years ago. Ages, lithology and stratigraphic position of these tephra are thus fully comparable with that of the "Lower Sequence" described by Rosi et al, (2000).

The two successions have slightly different petrographic and compositional features. Products of the upper succession range in composition from basalt to shoshonitic basalt. All tephra beds include both crystal-poor golden pumices (BP) and crystal-rich black scorias (BS). The composition of these rocks are slightly different from the volcanics erupted during the last two decades. In particular present-day bulk rocks show higher SiO2 and are Ni and Cr-depleted with respects to volcanics of the upper succession. Pumices of the upper succession, are among the most primitive magmas erupted by Stromboli and contain fosteritic olivines (up to Fo89) with Cr-spinel inclusions, and Cr-Diospide pyroxenes. Composition of rocks of the lower succession ranges from basalt to HKCA-basaltic andesite. These rocks show, on the whole, size and abundance of phenocrysts (P.I.) lower than those observed in volcanics of the upper succession (BS-type). Basaltic andesites (P.I.~20%) form the bottom of the exposed succession whereas less evolved crystal-poor (~10%) basalts repeatedly fed the explosive eruptions that produced the overlying tephra layers. Thus observed stratigraphic relationships and compositional features of products indicate that in the last century a high number of large paroxysms occurred. These paroxysmal eruptions have been fed/triggered by the rise of a deep un-degassed and primitive magma. Alternatively these powerful eruptions drained deep portions of the plumbing system filled by pristine magmas. Further investigation on intra-eruptive compositional variations would resolve this ambiguity.

Dating of recent stratigraphic units were attempted using different archeomagnetic techniques by the Urs of Rosi and Pompilio. The UR Rosi addressed the archaeomagnetic dating of: i) the onset of the spattering activity; ii) the lava flow of San Bartolo and iii) the overflows on the eastern rim of the Sciara del Fuoco in order to constrain the age of the more recent flank collapse of the Sciara del Fuoco. Preliminary results indicate that the large spattering episode on the western flank of the volcano occurred in the sixth century A.D. This age is good agreement with the age of the onset of the present persistent activity, between the third and seventh centuries A.D. (Rosi et al., 2000). The lava flow of San Bartolo has been dated at the first century A.D. The UR Pompilio focused on the sampling of spatter emitted during the recent paroxysms and which were deposited materials on the two sides of the Sciara del Fuoco. .Coring of spatter was performed in 17 sites.

TASK 6 -: Xenoliths

2nd YEAR OBJECTIVES

Petrological study of volcanic products of Stromboli and their magmatic inclusions with quenched trapped liquids, in order to take "snapshots" of the pre-eruptive plumbing system.

Characterization of the Stromboli basement through the petrologic study of crustal xenoliths transported to the surface by the magmas of the past 100 ka (Paleostromboli to the the present-day activity). The expected final results are to highlight the nature of the continental crust below the volcano and to unravel the composition of acid liquids as potential contaminants of the basic lavas of the present-day activity.

- 2nd YEAR RESULTS

The UR Serri carried out a petrologic investigation on the high-grade hornfels xenoliths sampled in the 60 ka old calcalkaline basaltic andesite lava flows of Stromboli (Omo lavas; Paleostromboli II period). This study provide insights into the thermobaric history of pieces of contact aureole below the volcano, which were rapidly brought to the surface by the uprising magmas. These xenoliths consist of fine- to medium-grained holocrystalline rocks (anorthoclase + cordierite are *ca.* 85 vol% of the modal mineralogy) formed by contact metamorphism at a pressure range of 2-3.5 kbar and a peak temperature close to 800°C. Major, trace element and isotopic (Sr, Nd, Pb) compositions show that the xenoliths may well represent an *in situ* sampling of a contact aureole, compatible with metapelites belonging to the upper continental crust basement of Stromboli. TEM (Transmission Electron Microscopy) studies on feldspars support a fast cooling of the hornfels xenoliths (of the order of degrees per hour), compatible with cooling of the host lava flow.

The UR8 (Serri) also carried out a systematic sampling of gabbroic inclusions in the pyroclastic deposits of Stromboli. These gabbros are characterised by various amounts of trapped interstitial material (vesicular glass and quench minerals) and represent an important tool to understand the magmatic processes occurring in the feeding system of the volcano. Gabbroic nodules having such textures are particularly abundant in the Petrazza pyroclastic sequence (Paleostromboli I period) and the cumulate minerals are also characterized by the presence of abundant fluid and melt inclusions. The modal mineralogy, the mineral chemistry and the chemical and isotopic composition of the cumulate gabbros show that these nodules are fragments of cumulate rocks (cognates) disrupted from pre-existing solidification zones (magma chambers wall-rocks *lato sensu*) of the Stromboli magmas. Textural evidence, Fe-Mg mineral/liquid partioning and mass

balance calculations indicate that the interstitial material (quench crystals and vesicular glass) derived from infiltrated hydrous basaltic liquid, different from the host evolved high-K andesite (Petrazza) magma. Due to rapid decompression of the nodules followed by their ejections together with the Petrazza pyroclastics, the infiltrated hydrous basaltic liquid exsolved volatiles producing a high vesicular texture; in addition various quench crystals and glasses with variable degree of *in situ* differentiation were generated. The glasses represent the residual liquids of this interstitial material produced by crystallisation of quench *pl + amph ± cpx ± ol ± bi ± opq* from batches of basaltic magmas with variable serial affinity from high-K calcalkaline to shoshonitic. Microthermometric investigations on fluid inclusions and on the shrinkage bubble of the melt inclusions within cumulus minerals of the gabbroic nodules suggest that their parental magma contained CO_2. Petrological constraints and the occurrence of daughter biotite- and amphibole-bearing inclusions show that the H_2O activity in the magma was sufficiently high to allow calcic plagioclase (An_{95-87}) crystallisation from a high-alumina basaltic magma containing 3-4 wt % of water, at pressure ≤ 2 kbars and a temperatures of 1050-1100°C. The content of sulphur in the melt inclusions within cumulus clinopyroxene and olivine is high (up to 0.41 wt %). The presence of Fe-Cu(-Ni)-rich blebs of sulphide in cumulus plagioclase, olivine, amphibole, and locally in the melt inclusions too, further supports an important role of sulphur in the primitive magmas of Stromboli.

- 2nd YEAR OBJECTIVES

Final objective: Reconstruction of the eruptive history of the last period of Stromboli's activity

2nd YEAR RESULTS

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- RESEARCH PRODUCTS OF THE PROJECT
  - n° of articles published on international journals; 12
  - n° of articles published on national journals, proceedings, technical reports. 3
  - invited papers and talks
  - Presentation at international meetings

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- Presentation at national meetings

Bertagnini A., Metrich N., Landi P., Rosi M., Stromboli volcano (Aeolian Archipelago, Italy): an open window on the deep-feeding system of a basaltic volcano. Annual project meeting (Stromboli, June 2002)

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M. L. Carapezza, S. Inguaggiato and F. Quattrocchi (2002). Search of possible geochemical precursors of major explosion of Stromboli. GNV Stromboli project annual meeting.

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Vaggelli G., Francalanci L., Ruggeri G. & Testi S. (2001) A persistent polibaric rest for calc-alkaline magmas of Stromboli: pressure data by a fluid inclusion study on restitic quartzites. G.N.V. - *Programma quadro per l'attività di sorveglianza e ricerca sui vulcani italiani 2000-2002 - Assemblea 1° anno, Abstracts, Roma*

COMPUTATIONAL CODES

Computation codes: development of a cross-platform software running in Java language, for real time data acquisition and GPS/EcoSounder synchronization

OTHER

Tibaldi A. e Pasquaré G., 2002. Geological Map of Stromboli. National Project on 1:50,000 Prototype Map Atlas, CNR-SGN-CARG, in press.

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Mattioli M., Serri G., Salvioli-Mariani E., Renzulli A., Holm P.M., Santi P., Venturelli G. (2002) Sub-volcanic infiltration and syn-eruptive quenching of liquids in cumulate wall-rocks: the example of the gabbroic nodules of Stromboli (Aeolian Islands, Italy). Mineralogy and Petrology, accepted for publication.

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Salvioli-Mariani E, Mattioli M, Renzulli A, Serri G (2002) Silicate melt inclusions in the cumulate minerals of gabbroic nodules from Stromboli Volcano (Aeolian Islands, Italy): main components of the fluid phase and crystallisation temperatures. Mineralogical Magazine, 66, 6, 969-984.

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Vaggelli G., Francalanci L., Ruggeri G. & Testi S. (2002). Persistent polybaric rests of calcalkaline magmas at Stromboli volcano, Italy: pressure data from fluid inclusions in restitic quartzite nodules. *"Bulletin of Volcanology" (Heidelberg, Germania), in press.*

Tibaldi A., Corazzato C., Apuani T. e Cancelli A., 2002. Anatomy of deformation at Stromboli Volcano, Italy: insights from rock mechanics and structural geology. Tectonophysics, in press.

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HAZARD ASSESSMENT OF STROMBOLI VOLCANO
Coordinator of the project: Mauro Rosi

RU Responsible
Mauro Rosi –Full Professor
Dipartimento di Scienze della Terra - University of Pisa

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name-Position	Affiliation	man/month
Mauro Rosi – Full Professor	DST – Pisa University	
Antonella Bertagnini – researcher	INGV – Pisa	
Patrizia Landi – researcher	INGV – Pisa	
Nicole Metrich- Senior researcher	CNRS- France	
Simone Arrighi PhD student	DST – Pisa University	

- 2nd YEAR OBJECTIVES

- dating by means of archaeomagnetic method of natural outcrops and their correlation with tephra sequences in trenches
- collection of new mineralogical, geochemical, volatile content data on products of the present activity
- selection and preliminary analysis of melt inclusions in samples older than 1800 years (trenches, San Bartolo)
- sedimentological and compositional study on the marine extension of the Sciara del Fuoco structure and the Stromboli canyon (in cooperation with the UR Marani)

- 2nd YEAR RESULTS **(max 1 page)**

- Sampling for archaeomagnetic data was done during two field trips with the main goal at dating: i) the age of the paroxysmal episodes which emplaced spatter deposits on the slopes of the volcano and the onset of this kind of activity; ii) the lava flow of San Bartolo, fed by an eccentric vent during the activity before the present one; iii) the overflows on the eastern rim of the Sciara del Fuoco in order to constrain the age of the effusive activity before the last collapse of the Sciara del Fuoco. Preliminary results indicate that the large spattering episode on the western flank of the volcano occurred in the sixth century A.D. This age is fully consistent with the age of the onset of the present persistent activity, between the third and seventh centuries A.D. (Rosi et al., 2000). The lava flow of San Bartolo has been dated at the first century A.D.
- Pumices emitted during two paroxysms of the last period of activity of the volcano were studied in order to collect new data on the deepest part of Stromboli's feeding system. The new data on mineralogy, major, volatile and trace element geochemistry of olivine-hosted melt inclusions (MI) compared with previous results (Metrich et al., 2001) indicate that in all the studied paroxysms, MI have recorded true primary melts rich in CaO (up to 14.5 wt%) but low in FeO (6-7 wt%). They demonstrate recurrent variations in the chemistry of the primary magmas distinct with respect to their K_2O content and S/Cl ratios that enter the deep-system. Their high volatile concentrations indicate crystal fractionation and storage between 3 and 4 kb fluid pressure.

Data on MI suggest a model involving high-pressure differentiation of limited volume of CaO-rich FeO-poor primary magmas at the origin of the HK-basaltic pumice produced at Stromboli. Interactions between primary melts and olivine crystals inherited from pre-existing crystal-mush and mixing with the HK-basaltic magmas resident at high pressure are recorded at the scale of the

micrometer, only. Based on olivine growth-rate calculations, the volatile-rich magma blobs possibly ascent within few hours to few tenths of hours. Rapid ascent rate combined with restricted temperature gradient and limited crystal nucleation quite account for the emission of highly-vesicular glassy basaltic pumices.
Crystal-rich scoriae have been investigated by sampling products emitted during normal activity, major explosions and lava effusion over the period 1985-2000 in order to study crystallization history and magma dynamics of the shallow magma body. All the products, both scoriae and lavas, contain 50-58 wt% euhedral phenocrysts of plagioclase (26-37 wt%), clinopyroxene (12-19 wt%) and olivine (3-9 wt%) in a glassy to hypocrystalline groundmass. The whole rocks display rather homogeneous HK-basaltic/basaltic-shoshonitic compositions and their glassy groundmasses are quite homogeneous shoshonites. Plagioclase crystals consist of alternating, concentric layers af An-rich and Ab-rich plagioclase. Ab-rich layers (An64-An70) are characterized by a small-scale (1-5 _m) oscillatory zoning and appear to be in equilibrium with a liquid with the composition of the glassy matrix. The An-rich zones (An70-An88) are patchy zoned, show sieve texture with abundant micrometric glass inclusions and overgrow on dissolution surfaces. Sieve textures result from rapid crystallization occurring under supercooling conditions, which are induced by rapid degassing of the volatile-rich melts when they enter, react and crystallize with the shallow crystal-rich magma, at low pressure. We propose that compositional and textural zoning of the plagioclase reflects different intrusions of volatile-rich melts in the shallow crystal-rich, volatile poor mush. The high H_2O content of new melt blobs stabilizes An-rich plagioclase. Several lines of evidence suggest that degassing of the crystal-poor magma likely occurs in a few minutes (1-15 min). Crystallization induced by degassing rapidly changes the crystal-poor, volatile-rich magma into the crystal-rich, volatile-poor magma.
- Analyses of both mineralogy and MI (≈ 80 inclusions and their host) have been done on three selected samples of the activity before 1800 years ago. Preliminary results suggest a different crystallization history in terms of temperature and possibly pressure with respect to the present day activity. The most primitive melt inclusions have typically low K content close to 1 wt.% that clearly indicates that they evolved from a parental magma poorer in potassium also typical of the San Bartolo activity.
- In cooperation with the UR Marani, a sedimentological and compositional study on the marine extension of the Sciara del Fuoco structure and the Stromboli canyon has begun in September 2002. These research activities will combine data on submarine morphology, sedimentology, grain-size, and composition of sediments to make inferences on the sedimentation processes active in the lower sector of the canyon of Stromboli. We have at present selected 50 samples of sediment-gravity flow deposits and tephra beds from 5 gravity cores. Mineralogical, petrographic and textural analyses are underway.

- RESEARCH PRODUCTS
  - presentations at national meetings:
    Landi P., Métrich N., Bertagnini A., Rosi M.' Magma missing and degassing recorded in plagioclase from the shallow magma body at Stromboli (Aeolian Archipelago, Italy). Annual project meeting (Stromboli, June 2002)
    Bertagnini A., Metrich N., Landi P., Rosi M., Stromboli volcano (Aeolian Archipelago, Italy): an open window on the deep-feeding system of a basaltic volcano. Annual project meeting (Stromboli, June 2002)

- PUBLICATIONS LIST
    Bertagnini A., Metrich N., Landi P., Rosi M., Stromboli volcano (Aeolian Archipelago, Italy): an open window on the deep-feeding system of a steady-state basaltic volcano. Submitted to Journal Geophysical Research

PROJECT TITLE

The dynamics of the feeding system of Stromboli and its relationship with the eruptive activty

RU Responsible Massimo Pompilio I ricercatore
Name-Position
Affiliation Istituto Nazionale di Geofisica e Vulcanologia – Sez. Catania

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name-Position	Affiliation	man/month
Errore. L'origine riferimento non è stata trovata. – I Ricercatore	INGV-CT	4
Lucia Miraglia – Art. 23	INGV-CT	2
Simona Caruso – Ext. Collab.	INGV-CT	3
Fabio Speranza - Ricercatore	INGV- RM 1	2

- 2nd YEAR OBJECTIVES

a) Classification of paroxysmal eruptions

b) *Definition of the compositional characteristics of magmas residing in the feeding system*

2nd YEAR RESULTS **(max 1 page)**

Methodologies : Tefrostratigraphy, Radiometric (C14) and paleomagnetic age determination, Petrological, mineralogical (SEM-EDS) and geochemical (XRF-ICP-AES and MS) methods

Data acquisition: The deposits related to recent paroxysmal eruptions of Stromboli have been investigated by measuring stratigraphic sections in more than 40 hand-digged trenches located in the middle and higher flanks all around the volcano. Six C14 age determination of charchoal intebedded in the investigated volcanic succession. Coring of lava and spatter have been performed in 17 sites for paleomagnetic investigation. More than 100 samples of volcanics have been collected for grain size and petrological investigation. Major elements have been determined for 70 samples. Trace elements (43 elements) have been analysed in 35 selected samples. Mineral and glass chemistry have been anaysed in more then 20 samples.

Data processing and interpretation. In the most of the studied sections, we identified 2 distinct successions. The upper succession includes mainly reworked volcanic material in which at least 4 layers with characters of primary tephra are recognisable. These layers show a good spatial continuity in the upper and mid North-Eastern flank of the volcano. The tephra bed at the top shares lithological features with the hot-avalanches deposit, emplaced during the 1944 eruption that crops out at the foot of the Forgia Vecchia: On this basis we attributed this tephra layer to the 1944 paroxysm. The two underlying layers have areal distributions and thickness compatible with the two large paroxysms occurred respectively in the 1930 and 1919 Radiometric dating of charcoals, sampled in the same stratigraphic section immediately beneath these tephra beds, indicates a consistent time gap of about 10 years. However, due to the shape of the calibration curve and relative closeness in age to recent times, the conventional radiocarbon ages gives results that can have many interpretations (ex. AD 1530 to 1560, AD 1630 to 1680, AD 1740 to 1800 and AD 1930 to 1950 for the upper beds). Preliminary paleomagnetic investigation carried out on spatter of the northern flak data indicates magnetic properties (dip and declination) compatibile with those of the XVIII century. The lower succession overlies “Nel Cannestrà” lavas and comprises primary tephra, partially reworked

volcanics and paleosoils. In this succession two distinct tephra beds show a good spatial continuity along the mid-flank of the volcano: Radiometric dating of organic sediment and charcoals indicates that these deposits have been emplaced 1840±40 and 2270±40 (conventional radiocarbon age) years ago. Ages and stratigraphic position of these tephra are comparable with that of the "Lower Sequence" described by Rosi et al, (2000).

The two successions have distinct petrographical and compositional features. Products of the upper succession range in composition from basalt to shoshonitic basalt. All tephra beds include both crystal-poor golden pumices (BP) and crystal-rich black scorias (BS). The composition of these rocks are slightly different from the volcanics erupted during the last two decades. In particular present-day bulk rocks show higher SiO2 and are Ni and Cr-depleted with respects to volcanics of the upper succession. Pumices of the upper succession, are among the most primitive magmas erupted by Stromboli and contain fosteritic olivines (up to Fo89) with Cr-spinel inclusions, and Cr-Diospide pyroxenes. Composition of rocks of the lower succession ranges from basalt to HKCA-basaltic andesite. These rocks show, on the whole, size and abundance of phenocrysts (P.I.) lower than those observed in volcanics of the upper succession (BS-type). Basaltic andesites (P.I.~20%) form the bottom of the exposed succession whereas less evolved crystal-poor (~10%) basalts repeatedly fed the explosive eruptions that produced the overlying tephra layers. Thus observed stratigraphical relatioships and compositional features of products indicate that in the last century a high number of large paroxysms occurred. These paroxysmal eruptions have been fed/triggered by the rise of a deep un-degassed and primitive magma. Alternatively these powerful eruptions drained deep portions of the plumbing system filled by pristine magmas. Further investigation on intra-eruptive compositional variations would resolve this ambiguity.

- RESEARCH PRODUCTS
  - n° of articles published on international journals
  - n° of articles published on national journals, proceedings, technical reports
  - invited papers and talks
  - presentations at international meetings
  - 2 presentations at national meetings;
  - 1 Data base
  - Computation codes
  - Other

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Reconstruction of Holocene deformation and quantitative analysis of the stability of Sciara del Fuoco, Stromboli

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ACTIVITY REPORT–2nd YEAR

UR PARTICIPANTS

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Prof. Alessandro Tibaldi	Univ. Milano-Bicocca, Dip. Scienze Geologiche e Geotecnologie	6
Dott.ssa Tiziana Apuani - researcher	Univ. Milano-Bicocca, Dip. Scienze Geologiche e Geotecnologie	2
Dott.ssa Claudia Corazzato - PhD student	Univ. Milano-Bicocca, Dip. Scienze Geologiche e Geotecnologie	5
Dott. Mauro Ferraris – external cooperator		1
Dott.ssa Evamaria Graziotto - external cooperator		1
Dott.ssa Sonia Calvari - researcher	INGV-Catania	2

II YEAR OBJECTIVES

The second year research is intended to provide a geological and geotechnical model of the north–western flanks of the volcano (Sciara del Fuoco and surrounding areas). The model includes stratigraphic, lithologic and structural characters plus geotechnical and geomechanical parameters of the recognised lithotechnical units.
This model represents the main input data for any stability analysis.
The volcano slope stability is evaluated considering different problems and approaches:

1) stability of the recent loose deposits which fill up the Sciara del Fuoco depression:
   - limit equilibrium analysis: plane transactional slide of a granular mass at depth minor than 7.5 m;
   - limit equilibrium analysis, Junbu method: non-circular slip surface developed for different geological models;
2) "local" instability along the Sciara scarps and flanks:
   - limit equilibrium analysis, Sarma method: along structural controlled probable slip surfaces;
3) stability related to dip failure surfaces, "collapses" like those recognised in the past volcano history:
   - limit equilibrium analysis, Sarma method: along hypothetical dip structural controlled slip surfaces;
   - displacements and strain analysis by two-dimensional finite difference numerical modelling (FLAC)

II YEAR RESULTS

Methodology

The purpose is particularly ambitious taking into account that logistic difficulties limit the feasibility and reliability of geotechnical, mechanical and physical prospecting, commonly applied in non-volcanic environment. This forces to a number of assumptions and hypotheses. With these preliminarily remarks, the research includes:

- geotechnical characterization of the soil like materials, filling up the Sciara del Fuoco depression, by:
  - sampling of loose materials,
  - measure of their physical and mechanical properties by standardised laboratory tests;

- rock mass characterization and engineering classification by:
  - structural and geomechanical surveys,
  - sampling of rock (intact rocks and joints),
  - measure of physical and mechanical properties by standardised laboratory tests on intact rocks and joints,
  - evaluation of rock mass strength and elastic parameters by empirical failure criteria (in progress)
- stability analysis (in progress)

Data acquisition, processing and interpretation

- ***Geotechnical characterisation of the soil like materials, filling up the Sciara del Fuoco depression***

The collected samples are representative of the loose deposits related to the present activity of the Sciara del Fuoco, (superficial materials at depth between 0÷1 m) and correspond to the grain size fraction smaller than gravel (fig. 1). All the samples are mainly gravel and sands, with no silt or clay (coefficient of uniformity CU<7.3), SP or SW according to the U.S.C.S. (Unified Soil Classification System) (fig.2).The natural water content is W<6.3%; the grain bulk volume Gs=2.91÷3.08 g/cm^3; the maximum and minimum bulk volume, determined on the grain size fraction minor than 9.5 mm, are respectively: $\gamma_{d\ min}$ = 1.32 ÷ 1.51 g/cm^3 and $\gamma_{d\ max}$=1.70 ÷1.78 g/cm^3 from which porosity have been computed n=40 ÷ 55 %. Consolidated-undrained triaxial compression tests have supported the peak and residual shear strength parameters, cohesion and shear strength angle: c_p = 0 , ϕ_p'= 43.5°÷50.8° and c_r = 0 , ϕ_r' = 39.2 ° ÷ 48.9° (Tab.1).

- ***Rock mass characterisation and engineering classification***

Among the 52 sites of structural survey, 20 outcrops, mainly in lithotechnical units where lava deposits are dominant, were chosen to perform rock mechanics characterisation, according to the I.S.R.M. procedure. This procedure enabled to recognise the number of joint sets and their representative orientation, to determine the geometry of each joint (strike, dip and inclination), set spacing, type of movement, dilation amount, degree of alteration, roughness coefficient, presence and nature of infill. The rock masses are classified according to Rock Mass Rating, (Bieniawsky, 1979) and mainly results of "good quality" RMR=66÷80. Less "quality" may be expected for rock masses where breccia layers dominant on lava ones. In case of weak masses the GSI (Geological Strength Index, Hoek, 2000) appears to be a better tool of characterisation. As concerns the physical and mechanical properties of "intact rock", samples collected up to now represent mainly the massive lava layers which alternate to breccia ones in the outcrops or single elements constituting the breccia layers belonging to the Lave di Petrazza, Lave del Vancori superiore and Lave di Vignavecchia units. The specific bulk volume is Gs=2.62÷2.93 g/cm^3; dry and saturated bulk volume are γ_d = 2.27÷2.58 g/cm^3 and γ_{sat}=2.34÷2.61 g/cm^3; void index and porosity e=0.033÷0.248, n=3÷26%. (Tab. 2). Uniaxial Compressive Strength (σ_c) and Elastic Modules have been determined by Uniaxial Compressive tests on lava sample , taking into account the petrographical and textural anisotropy - load parallel (//) and orthogonal (⊥) to the main textural elements (flow surfaces): $\sigma_{c//}$ =61÷100 (235) MPa $\sigma_{c\perp}$=50 ÷162 MPa. (Fig. 3) and $Et_{50\ //}$ =13÷36 GPa $Et_{50\ \perp}$=17÷35 GPa. To have a wide distribution of data, comparable to the uniaxial test results, 500 point load tests have been carried out with load parallel (//) and orthogonal (⊥) to the main textural directions.(Tab. 3). Diametral Compressive Strength have been determined on lava samples taking into account the petrographical and textural anisotropy: σ_t=21÷95 MPa and the relative anisotropy coefficient is CA<54%.(Tab.4). The weakness planes represented by joints in the lavas have been characterised in terms of apparent cohesion (c), friction angle (ϕ') and shear modulus (Ks) by means of direct shear strength tests at normal stress σ_n<4 MPa, obtaining the following results: c_p=0.03÷1.05 MPa, ϕ'_p=39°÷56°, Ks=11 38 GPa and c_r=0 MPa, ϕ'_r=25°÷46°. The basic friction angle provided by tilt test, is ϕ_b =22°÷32°.

The combination of in situ rock mechanics properties with intact rock characters allows to calculate the rock masses strength and elastic properties at low geostatic stress (elastic modulus E_m, bulk modulus K_m, shear modulus G_m, friction angle ϕ_m) and enables to estimate these parameters at growing stresses. The effect of confining pressure on strength and elastic modules will be detected by Triaxial Compressive Tests, which are undergoing.

- ***Stability of the recent loose deposits which fill up the Sciara del Fuoco depression***

Limit equilibrium analysis: plane transactional slide of a granular mass at depth minor than 7.5 m

The analysis is carried out with the following assumptions:

- homogeneous loose deposits fill up the Sciara del Fuoco depression at least up to the depth of 7.5 m;
- their geotechnical properties are those measured on the tested sample: c'= 0 kg/cm^2 ; ϕ'= 35.9 °, γ_{min} = 1.511 g/cm^3, γ_{max} = 1.76 g/cm^3 , γ_{med} = 1.635 g/cm^3 .
- the average slope dip is β=35.3°.

Three cases are examined:

a) plane transactional slide of a granular mass at depth of 2.5 m; bulk volume assumed equal to γ_{med} = 1.635 g/cm^3

The Safety factor is calculated as function of shear strength angle ϕ and cohesion c. (fig.4).

b) Plane transactional slide of a granular mass at depth of 7.5 m; bulk volume assumed equal to $\gamma_{max} = 1.76$ g/cm^3

The Safety factor is calculated as function of shear strength angle ϕ and cohesion c.

c) The Safety factor is calculated as function of slope dip(β) in the case of cohesion c=0.

RESEARCH PRODUCTS

- n° of articles published on international journals: 3
- n° of articles published on national journals, proceedings, technical reports: 4
- invited papers and talks:
- presentations at international meetings: 3
- presentations at national meetings:
- Data bases :
- Computation codes :
- Other: 1 geological map, 1 electronic publication

SCIENTIFIC PUBLICATION LIST

ARTICLES 2002

1. Tibaldi A., Corazzato C., Apuani T. e Cancelli A., 2002. Anatomy of deformation at Stromboli Volcano, Italy: insights from rock mechanics and structural geology. Tectonophysics, in press.
2. Tibaldi A., 2002. Major changes in volcano behaviour after a sector collapse: insights from Stromboli, Italy. Terra Nova, in press.
3. Tibaldi A., 2002. Influence of volcanic cone morphology on dikes, Stromboli, Italy. J. Volcanol. Geotherm. Res., in press.

GEOLOGICAL MAPS

4. Tibaldi A. e Pasquaré G., 2002. Geological Map of Stromboli. National Project on 1:50,000 Prototype Map Atlas, CNR-SGN-CARG, in press.

ELECTRONIC PUBLICATIONS

5. Tibaldi A. e Pasquaré G., 2002. 1:10.000 scale Geological Map of Stromboli. National Project on 1:50,000 Prototype Map Atlas, CNR-SGN-CARG, in publication on S.G.N. web site.

PROCEEDINGS

6. Tibaldi A. and C. Corazzato, 2002. Pre-and post-sector collapse interplay between basement tectonics and magmatic-gravity deformations, Stromboli, Italy. Proceed. Int. Symposium on Basement-Volcano Interplay, Santiago del Chile, 22-23 October 2002, UNESCO-IUGS-IGCP, Chile, 14 pp.

INTERNATIONAL CONGRESSES

7. Tibaldi A. and C. Corazzato, 2002. Present-day instability of Stromboli volcano and its inherited history. Proceed. Volcanological Group Meeting, London, January 2002.
8. Tibaldi A., 2002. The “suction force” of collapsed volcanoes: insights from Stromboli and Etna, Italy. Proceed. 100 ys Mt. Pelee Eruption Int. Meeting, Martinique Is., June 2002.
9. Tibaldi A. and C. Corazzato, 2002. Pre-and post-sector collapse interplay between basement tectonics and magmatic-gravity deformations, Stromboli, Italy. International Symposium on Basement-Volcano Interplay, Santiago del Chile, 22-23 October 2002, UNESCO-IUGS-IGCP, Chile.

PERICOLOSITÀ DEL VULCANO STROMBOLI

RU Responsible
Michael Marani
Istituto di Geologia Marina –ISMAR/CNR

ACTIVITY REPORT–2nd YEAR

RU IGM PARTICIPANTS

Name	Position	Affiliation	Man/mth
Michael Marani	Researcher	IGM, CNR, Bologna	24
Fabiano Gamberi	Researcher	IGM, CNR, Bologna	24
Luigi Vigliotti	Researcher	IGM, CNR, Bologna	6
Daniela Penitenti	Technician	IGM, CNR, Bologna	9
Vladimiro Landuzzi	Technician	IGM, CNR, Bologna	9
Giancarlo Serri	Professor	Parma University, Parma	3
Teresa Trua	Rresearcher	Parma University, Parma	8

2nd YEAR OBJECTIVES

Integrated analysis of the stability of the submerged portions of Stromboli
Geophysical investigation of the structure and depositional setting of the submarine Stromboli edifice and distal, deep-water regions.
Sea-bottom sampling transects (gravity coring, box coring and dredging) in both the submerged Stromboli edifice and distal, deep-water regions.

2nd YEAR RESULTS

Data acquisition. Since on the previous year, data acquisition was mainly devoted at the study of the shallow submerged portion of the Stromboli volcanic edifice (sidescan sonar data down to 1000 m water depth), the present year data collection was aimed at the coverage of the distal portions of the edifice and its surroundings. 200 miles of Chirp sonar high resolution seismic lines were acquired and 25 seafloor sites were sampled (1 dredge, 10 box cores and 14 gravity cores).
Data processing and interpretation.
The study of the deep-sea surrounding the Stromboli edifice was undertaken in order to evaluate the possibility of extending our knowledge about the eruption style and history of the volcano. In many cases in fact, the preservation potential of certain horizons, and particularly those connected with explosive activity, is higher in the deep-sea environment than on land.
The interpretation of already available deep-tow sidescan sonar data over the distal part of the Stromboli volcano flanks and over the Marsili basin was carried out in order to better plan the summer research cruise for new data acquisition. These detailed seafloor image, moreover, will be merged with the newly acquired data in order to define the sedimentary and volcanic processes active in the sudy area
A preliminary interpretation of the Chirp sonar lines, has been aimed at determining the distribution of the acoustic facies over the study area. The results show that the Stromboli canyon and a smaller one, descending the western flank of Stromboli edifice feed a deep-sea channalised fan with depositional lobes that extend over much of the Marsili basin as far as the base of the Marsili seamount. Some of the channels appear abandoned and the main sedimentary pathways and coarse-grained depositional bodies appear to lie on the southern portion of the fan. All the cores have been cut and described. The preliminary interpretation of the sedimentary structures has allowed to evidence that high-density turbidity currents and debris flows are the predominant in the flank of

the volcano an in the proximal part of the deep sea fan and, while low-density turbidity current deposits are present in the distal portions. Mineralogical, petrographic geochemical and textural analysis of some of the sandy portion of these sediment-gravity flow deposits is underway with the aim of determining if some of them can represent primary or secondary volcaniclastic deposits that could be directly related to pyroclastic flow entering the sea from the Stromboli volcano.
Some of the cores have been deliberately collected away from the main sediment-gravity flow pathways in order to obtain an undisturbed record of hemipelagic sedimentation where the potential of tephra layers preservation is the highest. Analysis of some already identified air-fall layer is ongoing.
Lava samples have been dredged in a submarine cone to the southwest of the island and are at present under geochemical analysis. The freshness of the lavas indicates that recent volcanic activity has occurred in a satallite cone at a water depth of around 1000 m, away from the summital craters of the Stromboli edifice

RESEARCH PRODUCTS
Depositional facies map of the Stromboli edifice and distal deepwater basin.

PUBLICATIONS LIST
Gamberi F., Marani M.P. Penitenti D., DallaValle G**.** (2002). Sedimentary dynamics offshore Sciara del Fuoco from shallow- to deep-water. GNV Stromboli project annual meeting (abstract and oral presentation).

RESEARCH UNIT N° 3

RU Responsible: Lorella FRANCALANCI – Associate Professor
DIPARTIMENTO DI SCIENZE DELLA TERRA

UNIVERSITA' DEGLI STUDI DI FIRENZE

ACTIVITY REPORT – 2nd YEAR

RU Partecipants: From Dipartimento di Scienze della Terra, Università di Firenze:
Sandro Conticelli - Ass. Prof. - 2 man/month
Simone Tommasini – Ass. Prof. – 5 man/month
Giulia Perini – Fellow – 6 man/month
Amos Anderini – Student – 8 man/month
Silvia Testi – Student – 8 man/month

From C.N.R. – Istituto di Geoscienze e Georisorse:
Gloria Vaggelli – Researcher – 4 man/month
Giovanni Ruggieri – Researcher – 2 man/month

From University of Amsterdam:
Arnt Heumann – Researcher – 2 man/month

2nd YEAR OBJECTIVES:

1) To increase the data base of Sr isotope data in samples from present day and recent activity, included those coming from trenches, in collaboration with the Research Unit of M.Rosi.
2) Analyses of Nd isotope ratios in samples erupted from the present day activity, in order to check eventual variations
3) Trace element analyses in glassy groundmasses of samples from present day activity.
4) Search of fluid inclusions in xenoliths of rocks from more recent activity.
5) Interpretation and discussion of CO_2 fluid inclusion data in quartzite nodules.

2nd YEAR RESULTS:

Objective 1): All the following Sr isotope ratios (27 analyses in total) have been analysed at the Dipartimento di Scienze della Terra of University of Florence by a Thermal Ionisation Mass Spectrometer (Finnigan -Triton TI).

Sr isotope ratios have been analysed in whole rocks samples of scoriae and pumice erupted from 1998 to 2001 period of activity. The same isotopes have been also measured in glassy groundmasses from a 1998 pumice and a 2000 scoriae.

Scoriae samples, up to 1999 rocks, confirm the general tendency of Sr isotope ratios to slightly decrease with time since a period around 1980-85 (constant value before this period was around 0.706260; Francalanci et al., 1999, *E.P.S.L*). In fact, they pass from 0.706165±0.000008 (*hereafter ±8*) in 1996 to 0.706157±5 in 1999. Samples from 2000 eruptions show higher values (average of 0.706188), for decreasing again towards 2001 (0.706159±9). The glassy groundmass of the 2000 scoriae sample with the highest Sr isotope ratio shows a value similar to the whole rock, indicating these high values of 2000 eruption do not come from possible xenocrysts enriched in radiogenic Sr.

Pomice samples, on the other hand, show lower Sr isotope ratios than scoriae and a slight smooth increase of $^{87}Sr/^{86}Sr$ from 1996 (0.706105±8) to 2000 eruptions (0.706123±6). One of the two pumice samples analysed from 1998 eruption has given a highest value of 0.706128±4, its glassy groundmass, however, has a Sr isotope ratio like that of the other pumice sample from the same eruption (0.706107±6). This probably means that the high value of whole rock pumice is due to syn-eruptive mingling processes between scoria and pumice magmas, whereas the real Sr isotope value

of pumice magma is the lowest one. These data, together with those already published on samples from previous activity, will be interpreted in the light of dynamic processes occurring between scoriae and pumice magmas.

In order to investigate the variations of $^{87}Sr/^{86}Sr$ in the recent past and to correlate them with the present values, Sr isotope ratios have been also analysed in pumice and pumice-scoriae pairs from different stratigraphic levels of Trench 1 and Trench 2 of Rosi et al. (2000, *Bull. Volcanol*.). In both trenches, Sr isotope ratios of pumice samples show similar values, with general decreases from bottom to top (from about 0.706265±7 to 0.706194±7). Scoriae samples, which are only available from Trench 2, also display a general decrease of Sr isotope ratios from bottom to top of the sequence, ranging from 0.706265±6 (groundmass value) to 0.706229±8. Thus, a decoupling between Sr isotope ratios of pumice and scoriae appears towards the top of the stratigraphic column. Analyses of $^{87}Sr/^{86}Sr$ for some glassy groundmasses of scoriae and pumice have given values nearly similar to those of the respective whole rocks. A pumice sample coming from an other outcrop has shown the highest value of 0.706317±9. The results obtained in samples from trenches will be compared with Sr isotope ratios of present day rocks for understanding their relationships and the behaviour of the present magmatic system.

Finally, during the 2° year, more rocks have been sampled, both from recent and present period of activity.

Objective 2): Also all the following Nd isotope ratios have been analysed at the Dipartimento di Scienze della Terra of University of Florence by a Thermal Ionisation Mass Spectrometer (Finnigan -Triton TI).

Nd isotope ratios have been analysed in 10 pumice and scoriae samples and in 2 glassy groundmass from 1996 to 2000 eruptions. They do not show any significant variations with time; pumice samples, however, generally display slightly higher values than scoriae samples (0.512562±5 – 0.512575±7 and 0.512550±8 – 0.512562±6, respectively).

$^{143}Nd/^{144}Nd$ have been also analysed in 5 samples of pumice and scoriae from Trench 2. They show a quite constant value of about 0.512550.

Objective 3): Complete sets of trace elements (about 30 elements) have been analysed in about 70 glassy groundmasses of a large number of scoriae and pumice samples (18 samples in total) from 1996 to 2000 A.D. activity. The analyses have been performed at the CNR - "Istituto di Geoscienze e Georisorse - Sezione di PAVIA", by a Laser Ablation Microprobe.

Results indicate that scoriae glasses have higher incompatible and lower compatible (e.g. Cr, Sc, Co) element contents than pumice glasses. All trace element contents form good correlations with Rb, which will allow us to better define processes of evolution and to quantify the role of different mineral phases involved. Small but systematic differences of trace element contents are found between the scoriae glasses of 1996-1998 and 1999-2000 eruptions. This characteristic is also observed for some trace elements in whole rock samples of scoriae and seems to suggest small changes in the steady state conditions of shallow magma reservoir, which occur in a short time span.

Objective 4): The main objective of our research unit regarding to the xenolith study was the investigation of fluid inclusions in order to obtain rest pressures of magmas. Since now, the only available fluid inclusions found in Stromboli rocks are in quartzite nodules included in calc-alkaline rocks of about 200 and 60 ka.

In order to search fluid inclusions in more recent rocks, for better relating the eventual pressure obtained to the present day magmatic system, fluid inclusions have been investigated in nodules included in more recent rocks (e.g. S. Bartolo lavas and Lazzaro pyroclatic deposits).

After a detailed investigation on several polish sections, made ad hoc for fluid inclusion study, very small or no fluid inclusions have been found until now.

Objective 5): Data on CO_2 fluid inclusions in quartzite nodules have been better interpreted and discussed. It has been pointed out a correlation between nodule textures and type of fluid inclusion and the presence of fluid inclusion re-equilibration. In particular, the latter process has been better interpreted in the light of an isobaric heating (magma rest) or an isothermal decompression (fast ascent of magma) of host crystals. Furthermore, the trapping temperatures have been also better defined. All these data and considerations have allowed us to suppose the presence of two magma rests (magma chambers), one at 290 MPa (11 km with a density of 2.7 g/cm^3) and the other at around 100 MPa (about 3.5 km). The place of these magma rests did not change passing from 200 ka (Strombolicchio) to 60 ka (Paleostromboli II). According to the latter evidence there is no reason to believe that a similar polybaric evolution is not still under way in the current volcanic system.

RESEARCH PRODUCTS:

2 articles submitted on an international journal
1 article submitted on a national journal
1 presentation at an international meeting
6 presentation at national meetings

PUBLICATION LIST:

Abstracts

- FRANCALANCI L., TOMMASINI S., CONTICELLI S., DAVIES G.R. & ANDERINI A. (2001). Magma dynamics of the present day activity at Stromboli: evidence from new chemical data and Sr isotope microdrilling. *"Geoitalia 2001, 3° Forum italiano di Scienze della Terra", Riassunti, 722-723.*
- FRANCALANCI L., TOMMASINI S., CONTICELLI S., DAVIES G.R. & ANDERINI A. (2001). Magma dynamics of the present day activity at Stromboli: evidence from new chemical data and Sr isotope microdrilling. G.N.V. - *Programma quadro per l'attività di sorveglianza e ricerca sui vulcani italiani 2000-2002 - Assemblea 1° anno, Abstracts, Roma.*
- FRANCALANCI L., TOMMASINI S., CONTICELLI S., DAVIES G.R. & ANDERINI A. (2002). Magma dynamics of the present day activity at Stromboli volcano. *Mount Pelèe 1902-2002, Explosive volcanism in subduction zones, Ile de la Martinique, Maggio, Program and abstracts, 79.*
- FRANCALANCI L., TOMMASINI S., CONTICELLI S., VAGGELLI G., RUGGIERI G. & ANDERINI A. (2002). The present day activity of Stromboli: considerations on the plumbing system. *Annual Meeting per "Coordinated Project: Hazard Assessment of Stromboli volcano", GNV, INGV, Stromboli, Giugno, Programma e Riassunti.*
- FRANCALANCI L., TOMMASINI S., LANDI P., BERTAGNINI A. & ROSI M. (2002). Isotopic variations in the magmas feeding the persistent activity at stromboli*. Annual Meeting per "Coordinated Project: Hazard Assessment of Stromboli volcano", GNV, INGV, Stromboli, Giugno, Programma e Riassunti.*
- VAGGELLI G., FRANCALANCI L., RUGGIERI G. & TESTI S. (2001). Steady-state polibaric rest for calc-alkaline magmas of Stromboli at 200 ky and 60 ky: pressure data by fluid inclusions. *"Geoitalia 2001, 3° Forum italiano di Scienze della Terra", Riassunti, 744-745.*
- VAGGELLI G., FRANCALANCI L., RUGGIERI G. & TESTI S. (2001) A persistent polibaric rest for calc-alkaline magmas of Stromboli: pressure data by a fluid inclusion study on restitic quartzites. G.N.V. - *Programma quadro per l'attività di sorveglianza e ricerca sui vulcani italiani 2000-2002 - Assemblea 1° anno, Abstracts, Roma*

Articles

- FRANCALANCI L., TOMMASINI S. & CONTICELLI S. (2002). The volcanic activity of Stromboli in the 1906-1998 A.D. period: evidences from mineralogical, geochemical and isotope data. *Sottomesso per la pubblicazione a "Journal of Volcanology and Geothermal Researches" (Amsterdam, Olanda).*
- FRANCALANCI L., ANDERINI A., TOMMASINI S. & CONTICELLI S. (2002). Mineralogy, geochemistry and isotope data of the 1998-2001 activity at Stromboli volcano: inferences on the plumbing system. *Sottomesso per la pubblicazione al "Periodico Mineralogia".*

VAGGELLI G., FRANCALANCI L., RUGGIERI G. & TESTI S. (2002). Persistent polybaric rests of calcalkaline magmas at Stromboli volcano, Italy: pressure data from fluid inclusions in restitic quartzite nodules. *"Bulletin of Volcanology" (Heidelberg,*

PETROLOGICAL, GEOCHEMICAL AND ISOTOPIC STUDY OF VOLCANIC PRODUCTS OF STROMBOLI, THEIR XENOLITHS AND COGNATE INCLUSIONS: A CONTRIBUTION TO THE KNOWLEDGE OF THE MAGMATIC PLUMBING SYSTEM

RU Responsible: Serri Giancarlo (Dipartimento di Scienze della Terra Università di Parma)

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

G. Serri	University of Parma	5
A.Renzulli	University of Urbino	8
M.Mattioli	University of Urbino	4
P.Santi	University of Urbino	6
E.Salvioli-Mariani	University of Parma	4
G.Venturelli	University of Parma	1
P.M. Holm	University of Copenhagen	1

- 2nd YEAR OBJECTIVES

1) **Objective**: (i) Characterization of the Stromboli basement through the petrologic study of crustal xenoliths transported to the surface by the magmas of the past 100 ka (Paleostromboli to the the present-day activity); (ii) characterization of liquids formed by partial melting of the continental crust, in order to define compositional variations of the potential acid end-members which could be involved in the magmatic feeding system of Stromboli. The expected final results are to highlight the nature of the continental crust below the volcano and to unravel the composition of acid liquids as potential contaminants of the basic lavas of the present-day activity. These results are of paramount importance to detect little compositional change of erupting magmas toward crustal end-members, which could foresee a change in the eruptive style of a basaltic volcano.
2) **Objective**: Petrological study of volcanic products of Stromboli and their magmatic inclusions with quenched trapped liquids, in order to take "snapshots" of the pre-eruptive plumbing system. The expected final results are to understand: (i) the relationships among the composition of the liquids involved in the genesis of magmatic inclusions, trapped glass and host-rocks; (ii) the pre-eruptive crystallization processes which occur on the solidification boundary layers of the magma chamber (crystal mush of the side-walls) and on the interior of the reservoir.
3) **Objective**: Involvement (and disruption) of basement and/or subvolcanic rocks during sector collapses of Stromboli. This objective is attained through the petrologic investigation of the sub-volcanic lithic component within the deposits of the last 5-6 ka triggered by flank collapses of the volcano. The expected final results are to achieve information about the disruption of shallow magma chamber side-walls and generally, sub-volcanic or basement portions of the stratovolcano during significant lateral collapses. Since weakening of the rocks of the stratovolcano may also promote this kind of collapses, it is important to evaluate the degree of hydrothermal alteration through the systematic study of lithic ejecta erupted during recent or present-day activity.

- 2nd YEAR RESULTS

Petrologic investigations of high-grade hornfels xenoliths in the 60 ka old calcalkaline basaltic andesite lava flows of Stromboli (Omo lavas; Paleostromboli II period) provided insights into the thermobaric history of pieces of contact aureole below the volcano, which were rapidly brought to the surface by the uprising magmas. These xenoliths consist of fine- to medium-grained holocrystalline rocks (anorthoclase + cordierite *ca.* 85 vol%) formed by contact metamorphism at a pressure range of 2-3.5 kbars and a peak temperature close to 800°C. Chemical and isotopic (Sr, Nd, Pb) compositions show that the source rocks are metapelites compatible with upper continental crust-derived materials. TEM (Transmission Electron Microscopy) studies on feldspars support a fast cooling of the hornfels xenoliths (of the order of degrees per hour) compatible with cooling of the host lava flow.
During 2002 we studied some large-sized xenoliths sampled at about 200 m from the SW active crater of Stromboli and erupted during a recent major explosion. Mineralogical, petrographic and geochemical data of representative samples indicate that they are high-T, low-P glassy hornfelses ("buchites"). SEM-EDS and microprobe analyses, powder XRD, TEM investigations and ICP-OES-MS bulk rock major-trace elements analyses were carried out on the various portions of the xenoliths which are characterised by ubiquitous cordierite (± indialite), Ca-rich plagioclase, mullite, tridymite, orthopyroxene, clinopyroxene, pseudobrookite and rutile. Glass varies in composition from rhyolite to andesite. Petrographic and geochemical data allowed to suppose that the "buchite" protoliths were volcanic rocks altered to argillaceous material, probably belonging to a hydrothermal system of Stromboli. The studied xenoliths could have been formed by the thermal action of high-temperature magmas, either intruded into an hydrothermal system characterized by an "intermediate argillic" mineralogy or on blocks of stoped hydrothermally altered rocks.

We also carried out a systematic mineralogic, petrographic and geochemical study of the gabbroic inclusions characterised by various amounts of trapped interstitial material (vesicular glass and quench minerals). They are abundant in the Petrazza pyroclastic sequence (Paleostromboli I period) and are characterised by cumulate textures and low-P modal mineralogy (plagioclase + clinopyroxene + olivine ± amphibole ± opaque minerals); in addition they contain variable amounts of interstitial material, represented by newly crystallised microlites of plagioclase + amphibole + clinopyroxene ± olivine ± biotite ± opaques and highly variable amount of residual glasses (with variable degree of vesicularity) ranging in composition from shoshonite and high-K basaltic andesite to high-K andesite and latite. The petrologic data (including Sr-Nd-Pb isotopic ratios) show that these nodules are fragments of cumulate rocks (cognates) disrupted from pre-existing solidification zones (magma chamber wall-rocks *lato sensu*) of the Stromboli magmas. Textural evidence, Fe-Mg mineral/liquid partioning and mass balance calculations indicate that the interstitial material (quench crystals and vesicular glass) derived from infiltrated hydrous basaltic liquid, different from the host evolved high-K andesite (Petrazza) magma. Microthermometric investigations on fluid inclusions and on the shrinkage bubble of the melt inclusions suggest that the cumulate-forming magma contained CO_2. Petrological constraints and the occurrence of daughter biotite- and amphibole-bearing inclusions show that the H_2O activity in the magma was sufficiently high to allow calcic plagioclase (An_{95-87}) crystallisation from a high-alumina basaltic magma containing 3-4 wt % of water, at pressure ≤ 2 kbars and a temperatures of 1050-1100°C. The content of sulphur in the melt inclusions within cumulus clinopyroxene and olivine is high (up to 0.41 wt %). The presence of Fe-Cu(-Ni)-rich blebs of sulphide in cumulus plagioclase, olivine, amphibole, and locally in the melt inclusions too, further supports an important role of sulphur in the primitive magmas of Stromboli.

A detailed sampling of the sub-volcanic lithic component of the "Secche di Lazzaro" pyroclastics (the formation linked to the Sciara del Fuoco sector collapse occurred at the end of the Neostromboli period; i.e. 5 ka) was also carried out. New petrologic data came from lithics sampled in the debris flows belonging to the "Secche di Lazzaro" formation, discovered during 2002 in the northern (i.e. Punta Labronzo) and eastern (i.e. Rina Grande) sectors of the island. All the studied sub-volcanic rocks consist of monzonites and closely match, on a mineralogic, petrographic and geochemical point of view, those already found in the "Secche di Lazzaro" proximal debris flows facies (i.e. less than 1 km southwards from the source vent). They are holocrystalline, with a medium grain-size, and an orthocumulate-poikilitic texture. Mineral assemblage consists of poikilitic Na-K feldspar (sanidine), plagioclase, clinopyroxene, olivine and phlogopite in decreasing order of abundance. Major and trace elements of both the monzonite and the juvenile component directly underlying the debris flows (greenish pumiceous scoriae) at the Rina Grande outcrop clearly indicate cogenetic relations with the erupted KS Neostromboli lavas. Textural, mineralogical and geochemical evidences prove that the monzonites represent the crystalline materials slowly "frozen" from the shoshonite liquid composition in a shallow subvolcanic environment. This furtherly supports the hypothesis of violent decompression of the shallow magmatic plumbing system during the Sciara del Fuoco sector collapse occurred at about 5 ka.

- RESEARCH PRODUCTS

  - articles published on international journals: 3
  - articles published on national journals, proceedings, technical reports: 2
  - presentations at international meetings: 1
  - presentations at national meetings: 1

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Mattioli M., Serri G., Salvioli-Mariani E., Renzulli A., Holm P.M., Santi P., Venturelli G. (2002) Sub-volcanic infiltration and syn-eruptive quenching of liquids in cumulate wall-rocks: the example of the gabbroic nodules of Stromboli (Aeolian Islands, Italy). Mineralogy and Petrology, accepted for publication.

Mattioli M., Renzulli A., Serri G., Salvioli-Mariani E. (2002) High-T shear zones in the Stromboli feeding system: evidence from highly deformed gabbroic nodules. GNV, Annual Meeting, Stromboli 17-19 June 2002.

Renzulli A., Serri G., Tribaudino M., Santi P., Salvioli-Mariani E. (2002a) Large-sized buchite xenoliths erupted during the recent activity of Stromboli: do they provide insights into the shallow magma-hydrothermal system interface ? GNV, Annual Meeting, Stromboli 17-19 June 2002.

Renzulli A., Tribaudino M., Salvioli-Mariani E., Serri G., Holm P.M. (2002b) Cordierite-anorthoclase hornfels xenoliths in Stromboli lavas (Aeolian Islands, Sicily): an example of a fast cooled contact aureole. European Journal of Mineralogy, accepted for publication.

Renzulli A., Tribaudino M., Salvioli-Mariani E., Serri G., Holm P.M. (2002) Cordierite-anorthoclase hornfels xenoliths in Stromboli lavas (Aeolian Islands, Sicily): an example of a fast cooled contact aureole. In: "International symposium on interaction between volcanoes and their basement and related geological hazards" Second workshop of the IGCP project n.455. VII Congreso Internacional de Ciencias de la Tierra, Santiago del Cile, 21-23 october 2002.

Salvioli-Mariani E, Mattioli M, Renzulli A, Serri G (2002) Silicate melt inclusions in the cumulate minerals of gabbroic nodules from Stromboli Volcano (Aeolian Islands, Italy): main components of the fluid phase and crystallisation temperatures. Mineralogical Magazine, 66, 6, 969-984.

HAZARD ASSESSMENT OF STROMBOLI VOLCANO
Coordinator of the project: Mauro Rosi

RU Responsible
Maria Luisa Carapezza – Researcher
INGV RM1

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name-Position	Affiliation	man/month
M. L. Carapezza,	INGV RM1	
S. Inguaggiato (INGV-PA),	INGV – PA	
L. Brusca (INGV-PA),	INGV – PA	
M. Longo (INGV-PA),	CNRS- PA	
L. Pruiti (GNV).	INGV - GNV	

- 2nd YEAR OBJECTIVES

(a) to systematically collect chemical and isotopic data on soil gas emissions, on weak fumaroles of the crater rim, on thermal water wells, on rain water collected at the summit and at the base of the volcano; these data are to be used to ascertain the origin of the thermal manifestations of Stromboli and to develop a geochemical model of the volcano to be used for identifying possible anomalies related to the volcanic activity. (b) to develop and test automatic continuous stations to monitor CO_2 soil flux, together with some relevant environmental parameters, in two pre-selected anomalous sites on the crater rim and at the base of the volcano and to monitor physico-chemical parameters in some thermal water wells.

- 2nd YEAR RESULTS

The thermal waters of wells selected during the first year of activity as the most interesting from a geochemical view point, have been monthly sampled and analysed for chemical and isotopic composition and dissolved gas content . The latter confirmed to be an excellent geochemical tracer. The control for over two years of the chemical composition shows seasonal variations with different influence of the meteoric and marine components. It confirms the process of interaction with hot and acid (mainly CO_2) gases of deep origin. Of particular interest are the recorded variations of the dissolved gas content (CO_2 and He) whose isotopic compositions ($\delta^{13}C$ and $^3He/^4He$) are near to those of the crater rim fumaroles, with a R/Ra ratio even higher. In the Spring-Autumn 2002 a significant increase, with fluctuation, was observed in the quantity of dissolved CO_2. This was followed particularly in November by an increase of CO_2 soil flux recorded at the permanent station of the crater area. In the same period the level of eruptive activity has been particularly high with the magma column near to the surface that produced small lava overflows and numerous and frequent explosions. These data seem to indicate that at the periphery of the volcano early phenomena are recorded of anomalous upraise of deep gases that prelude to a later intensification of the summit eruptive activity. In the light of these data it appears of relevant interest the continuous monitoring of the thermal water well (Cusolito) where the highest compositional anomalies have been recorded. To this scope we request again an additional financial contribution (see annex).

In order to have a total coverage of the island two new pluviometric stations were installed in the Ginostra side that complement the other three stations (Crater rim, GNV-Centre and Sirenetta) already installed in December 2002. Chemical and isotopic analyses of the rain water are presently under complesion.

The continuous recording of CO_2 soil flux (accumulation chamber method) suffered during 2002 because of several problems. The peripheral Pizzillo station had to be dismantled

because the authorization to use the site was denied from the land owners. For some months it was reinstalled in another anomalous site (Piscità) where, however, several operational difficulties occurred because of the ground instability. Only recently authorization was obtained to use again the Pizzillo site. Unfortunately those problems caused a prolonged interruption in the data record that however covers a time interval of about two continuous years. The station for CO_2 flux and concentration measurements with different techniques, previously installed at Pizzillo, have been transferred to the crater rim but the data record have been only partial because of repeated damages caused by the eruptive activity. During the second year the sampling, with nearly monthly frequency , has been carried out on the crater rim fumarole. Analyses confirm the presence of a deep (magmatic) component with small but significant variation in the $^3He/^4He$ isotopic ratio that fluctuated between 2.9 and 3.4 R/Ra.
Two scientific papers have been almost completed dealing respectively on the influence of environmental parameters on CO_2 soil flux and on the geochemical significance of the compositional variations observed in the Stromboli fluids during two years of observations. Results have been anticipated to the EGS – Nice and GNV – Stromboli meetings.

ß RESEARCH PRODUCTS

presentations at national/international meetings:

M. L. Carapezza and S. Inguaggiato (2001). Interaction between thermal waters and CO_2-rich fluids at Stromboli volcano (Italy). Proc. WRI-10 (R. Cidu ed.) Rotterdam, Balkema.

M. L. Carapezza and S. Inguaggiato (2001). Continuous and automatic geochemical monitoring at the Stromboli natural laboratory (Aeolian Islands, Italy). Geophys. Res. Abstract, EGS 26th General Assembly, Nice, March 2001.

M. L. Carapezza and S. Inguaggiato (2001). Search of possible geochemical precursors of major explosions of Stromboli. GNV Stromboli project annual meeting.

M. L. Carapezza , M. Guidi and S. Inguaggiato (2002). Soil CO_2 degassing on Stromboli Island: influence of environmental parameters and insights on volcanic activity. Geophys. Res. Abstract, EGS 27th General Assembly, Nice, March 2002.

M. L. Carapezza, S. Inguaggiato and F. Quattrocchi (2002). Search of possible geochemical precursors of major explosion of Stromboli. GNV Stromboli project annual meeting.

PUBLICATIONS LIST

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F. Barberi and M. L. Carapezza (2001). Stromboli (Italy) - Major explosion of Stromboli kills a tourist on 20 October 2001. Bull. Global Volc. Network, 26-10, Oct. 2001.

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PRECISION BATHYMETRIC SURVEY
ALONG STROMBOLI ISLAND COASTLINE

RU Responsible
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ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name-Position	Affiliation	man/month
Antonio Vettore	University of Padua – Dept. TESAF	3
Alberto Guarnieri	PhD – University of Bologna	3
Marco Pontin	University of Padua	2
Francesco Pirotti	University of Padua	2

- 2nd YEAR OBJECTIVES

During the 2nd year, the research Unit of Padua has carried out several bathymetric surveys, within the south – south east portion of stromboli island, ranging from Ficogrande to Punta Lena, as depicted in fig. 1.

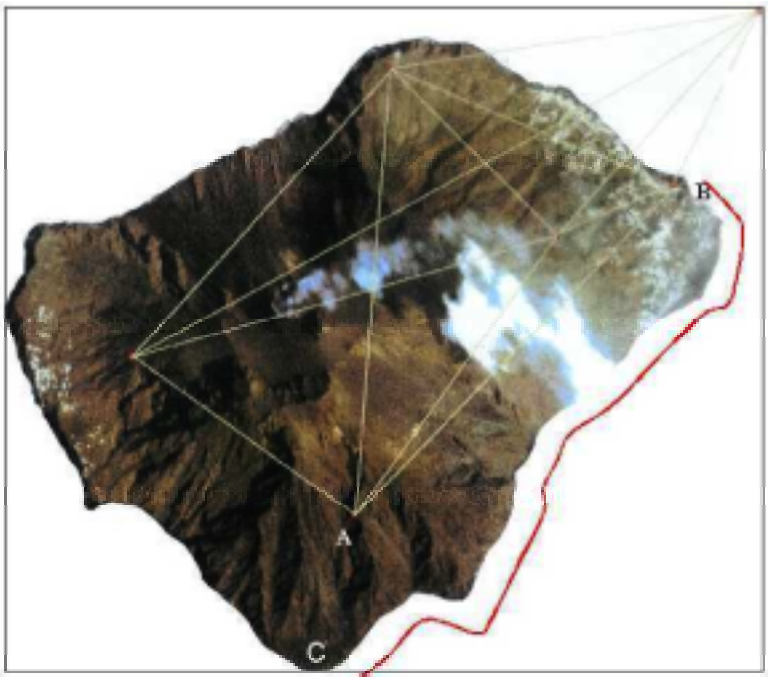

Fig.1: Surveyed area during 2nd project year

- 2nd YEAR RESULTS
  - **Methodologies**: although the data acquisition software developed in the first year allowed a real-time approach, the analysis of the island morphology revealed that in some areas receiving GPS differential correction data could be shadowed by natural obstructions. Therefore, the UR choosed to perform kinematic GPS surveys with differential data post-processing. The ecosounder data stream acquisition has been synchronized with GPS positioning information by mean of PPS pulse, output from the rover GPS receiver.

  - **Data acquisition**: both GPS receivers were double frequency Trimble 4000 Ssi, while the Hmex SonarLite portable ecosounder system has been employed to record depth data. GPS logging interval has been set always to 1 sec. All GPS data were differentially corrected respect with a master station, located on two control points of the GPS network established during first year. The master station has beeen moved between these two vertices, in order to hold the radio link between the surveyors on the island and on the boat.

  - **Data processing and interpretation**: Combining differentially corrected GPS positions with ecosounder data, several depth profiles were obtained. These profiles are, in average, 10 m spaced, with a density of positions within each profile ranging from 50 cm to 1.5 m. The distance from the coastline ranges from 200 to 300 m. A datum transformation was then performed between WGS-84 and the Roma40 reference systems, in order to determine the 3D coordinates of combined data (planimetric positions + depths) in the national cartographic projection (Gauss-Boaga). The whole data set has been further processed in ArcView GIS, an ESRI software product, where a 10m x 10m cellsize grid (DTM) was generated (Fig. 2). To this aim three different interpolation methods were applied, with different parameter setup, i.e. Inverse Distance Weight (IDW), Spline and Nearest Neighbour. Although different choices for weight parameters (2-5) for the 2nd method and number of neighbours (6-15) for 3rd one resulted in a more smoothing effect of depth data, the IDW method has given the best results (12 points per group, power factor of 2 for distance weight).

Fig.2: Resulting DTM from bathymetric surveys performed within the 2nd year

- **Others**: The main obstacle encountered over the bathymetric surveys was the weather condition. In most cases, even in presence of a moderate breeze, the motion of the waves heavily affected the capability of the processing software to filter out such motion in order to provide a more as possible stable reference level for depth measurements. Furthermore, the geometric GPS satellite configuration should be taken into account, which sometimes was poor (high PDOP values) mainly due to the high slope of the volcano, overall within the area between Punta Lena and Malpasso (points A and C in fig. 1). This limited the maximum surveying distance from the shoreline to 50 m.

ß RESEARCH PRODUCTS

- presentations at international meetings: 1
- Computation codes: development of a cross-platform software running in Java language, for real time data acquisition and GPS/EcoSounder synchronization

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

- "Batimetric Survey of Stromboli Island" to be presented at 11th International FIG Symposium on Deformation Measurements, Santorini, Greece, May 2003

PROJECT TITLE

RU Responsible
Name-Position Stefano Tinti (Associate Professor)
Affiliation Dipartimeto di Fisica, Settore di Geofisica, Università di Bologna

ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

Name	Position	Affiliation	Man/month
Stefano Tinti	Professore Associato	Università di Bologna	2
Armigliato Alberto	Dottorato di Ricerca	Università di Genova	1
Anna Manucci	Dottorato di Ricerca	Università di Bologna	3
Gian Luca Pagnoni	Borsista	Università di Bologna	6
Filippo Zaniboni	Dottorato di Ricerca	Università di Bologna	5

1) 2nd YEAR OBJECTIVES

Development of a 2D numerical code to simulate landslide evolution
Sensitivity analysis: effect of grid resolution in computation of tsunami the near-field and in the far-field

- 2nd YEAR RESULTS **(max 1 page)**
  - methodologies
  - Data acquisition
  - Data processing and interpretation
  - Others

Landslide evolution

A 2D-block model to compute the landslide evolution has been developed. It is the enhancement of a previous 1.5-D model, developed by the same research group. The initial slide body is discretised into a matrix of blocks. The blocks are allowed to deform during the motion, but they maintain the volume constant and remain contiguous. Each block moves under the action of the effective gravity and the bottom friction, both depending upon the local topographical slope, the water buoyancy and water (frontal and lateral) resistance. Moreover, blocks interact each other through normal and tangential forces, that tend to change the distance between the blocks centres of mass and may induce block rotation. The model has been applied to study flank collapse at Stromboli. The assumed slide body has a volume of about 1 Km^3 and its initial geometry is equal to that one assumed in previous studies. The grid is formed by cells having quadrilateral basis. At the onset time all the bases have supposedly equal horizontal projections. The model computes positions of the slide at different times, the blocks trajectories, the instantaneous shape of the slide and all other dynamical variables. It is found that both longitudinal shortening and transversal widening of the slide occur during the motion. The block trajectories are originally in NW direction and then tend to bend towards N in deeper waters. The resulting block velocities have peak values exceeding 40 m/s and 50 m/s for a few blocks. The heights of the blocks tend on average a general to increase with time.

Tsunami simulation

The simulation of the tsunami is carried out by means of a shallow water approximation finite-element (FE) model. Proper computations are needed to interface results of the slide model with the tsunami model: the instantaneous slide height, which is known at the block-grid nodes (changing position with time), has to be computed at the FE Eulerian grid nodes. Then on such nodes the impulses imparted by the slide to the water are calculated by applying proper transfer-function filtering of the shorter wavelengths to the local sea depth changes induced by the slide. The bathymetry around Stromboli is dominated by the almost elliptical shape of the volcanic edifice. The tsunami is studied in the near-field around the island over a local grid. The effect of grid resolution on the computed model has been explored. It is found that grids with typical element length larger than 300-400 m in the coastal belt are too coarse and tend to artificially damp the local solution around Stromboli. Here the main tsunami signal consists of a large central trough comprised between a leading and a trailing crest. When the main system of waves leaves the near-field, local waves persist travelling around the island. Wave trapping is known to be quite effective around ocean islands with steep flanks. As was already observed in previous simulations the largest waves are computed in correspondence of the Sciara del Fuoco, that is located on the trajectory of the failing mass, and of Malpasseddu, that is exactly on the opposite side of the island. The tsunami propagation in the southern Tyrrhenian sea has been computed by using a specific larger FE mesh including, which fits rather well the complex coastal boundaries of the Aeolian island archipelago and of promontories and peninsulas of western Calabria and northern Sicily. Analysis of tsunami grid has shown that the tsunami propagation in the intermediate (Aeolian islands, except Stromboli) and in the far field can be computed correctly even on a coarser grid since the signal is dominated by the longer wavelengths. Tsunami fronts radiate outward from Stromboli and approach the mainland, which is reached after about 800 s. Stronger fronts travel eastward (heading to Capo Vaticano) and westward rather than southward (towards Sicily). Fronts loose coherence on approaching the coast. The largest signals are computed on the exposed coasts of Panarea and Salina, rather close to the source. However also the records computed at Gioia Tauro, though it is found more distant on the Calabrian coast, have significant amplitude. The gauge at Punta Faro at the northern entrance of the Straits of Messina shows only a small perturbation, and even weaker are the signals at Messina and Reggio Calabria inside the Straits.

- RESEARCH PRODUCTS

- 1 n° of articles published on international journals
- n° of articles published on national journals, proceedings, technical reports
- invited papers and talks
- 2 presentations at international meetings
- 1 presentations at national meetings;
- Data bases
- Computation codes
- Other

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Tinti S., F.Zaniboni, A.Manucci, E.Bortolucci, 2002, A 2D block model for landslide simulation: an application to the 1963 Vajont case, Geophysical Research Abstracts, EGS 27th General Assembly, Vol. 4, CDROM.

Tinti S., F.Zaniboni, G.Pagnoni, E.Bortolucci , 2002, Tsunami Generation in Stromboli island and impact on south Tyrrhenian coasts, Geophysical Research Abstracts, EGS 27th General Assembly, Vol. 4, CDROM.

Tinti S., G. Pagnoni, F. Zaniboni, E. Bortolucci, 2002, Tsunami generation in Stromboli and impact on the south-east Tyrrhenian coasts, *Natural Hazards and Earth System Sciences*, (in press).