PROJECT TITLE

# STUDY AND CONSTRAINTS ON INTERMEDIATE STORAGE, MAGMA UPRISE AND CONDUITS THROUGH MODELLING OF STRAIN FIELDS, VELOCITY AND ATTENUATION TOMOGRAPHY AT MT. ETNA

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## ACTIVITY REPORT –2nd YEAR

PROJECT PARTICIPANTS

| RU# | AFFILIATION | RESPONSIBLE |
|---|---|---|
| 1 | INGV Sez. di Catania (ex IIV) | Dr. Alessandro Bonaccorso |
| 2 | Dipartimento di Fisica - Univ. Bologna | Prof. Maurizio Bonafede |
| 3 | INGV Sez. di Catania (ex IIV) | Dr. Domenico Patane` |
| 4 | Ist. di Macchine, Fac. Ingegneria - Univ. di Catania | Prof. Guido La Rosa |
| 5 | Dipartimento di Scienze Geologiche - Univ. Catania | Prof. Stefano Gresta |
| 6 | Dip. Scienze della Terra - Univ. Messina | Prof. Giancarlo Neri |
| 7 | INGV Sez. di Catania (ex IIV) | Dr. Eugenio Privitera |
| 8 | INGV - Centro Nazionale Terremoti, Roma | Dr. Claudio Chiarabba |

PRELIMINARY REMARKS

The RU's of the Project are still awaiting for the second tranche of funds due for the second year of activity.
Since september 2002, several RU of the project were severely engaged in monitoring and civil protection activities due to the intense eruptive and seismic activity at Mt. Etna.
Delayed funding and the eruption made it impracticable convening a Project mid-term Meeting originally scheduled in novembre 2002, deferred after the end of the still-ongoing eruption.
While perturbing several research activities, the 2002 eruption is providing a host of new data and observations which hold promises of greatly improving our understanding of the structure, feeding system, and stress transfer mechanisms accompanying Mt. Etna eruptions.
Collaborations with RU's included in the Remote Sensing Project, recommended from the Evaluation Committee, are already active (e.g. see the RU#3 Report and related publications). Collaboration with the Gravity and Magnetism Project (Coordinator C. Del Negro), also envisaged from the Evaluation Committee, will be possibly discussed during the mid term Meeting referred to above.

GENERAL OBJECTIVES

*Description of the main objectives must follow the Task scheme container in the approved project*

The aim of the project consists in employing geodetic, seismological, petrological and geological data (already available or new acquisitions) pertinent to the Etna region in order to improve our knowledge of the structure, of the stress and strain fields, of magma uprise mechanisms. To this end, comparisons are made among results separately provided by the different approaches in order to test the compatibility of the different interpretations.
More specifically, the detailed **3D structure of the Etna region**, obtained from seismic tomography, the accurate **relocation of earthquakes** connected to volcanic activity, obtained employing the 3D velocity structure, the **focal mechanisms** of a host of selected earthquakes, the **strain field** provided by magma injection and the **location and geometry of magma intrusions**, inferred from deformation data, are employed synergetically to provide a comprehensive picture of

the dynamical behaviour of Mt. Etna, focussing on **the relationships between the regional and local stress field and the eruptive and seismic activity**.
The ultimate target is integrating most of the different data sets in joint inversion procedures. In this framework the project should provide **realistic numerical models** of Mt. Etna, suitable for studies of deformation events and seismicity associated with intrusive events, taking into account the role of **topography** and layering of **elastic and inelastic properties** as inferred from seismic tomography.

In the following pages, results are listed according to the 8 tasks proposed originally within the present project and the 4 tasks added in the negotiation phase following the suggestions of the Evaluation Committee. The overall 12 tasks are formally coincident with the research programs of different Research Units (RU), so that the description of task objectives and results is practically coincident with the separate RU reports: however it may be mentioned that several tasks focus on closely related topics and synergetic interactions have been promoted from this project among different RU's. According to a higher order classification, tasks 1, 2, 5-A and 6 can be grouped together under the title "Deformation Modelling", tasks 3 and 4 under title "Analysis and integration of different deformation data", tasks 5-B, 6, 7, 9 and 10 under title "Knowledge of the physical properties of the medium below Etna", tasks 11 and 12 under title "Seismogenic stress and strain fields in the Etna region".

***Tasks 1-4 are intimately linked to each other and carried on by UR1 in cooperation with other RU's and Institutes. Objectives and results are reported below altogether.***

**TASK # - 1** TITLE: **Modelling strain fields caused by action of vertically elongated conduits and final mechanisms of uprising**

- (RU PARTICIPANTS) (RU1- RU3-RU7, subcontractor UCLA)

**TASK # - 2** TITLE: **Analysis and study of the coseismic and aseismic tilt variations**.

- (RU PARTICIPANTS) (RU1-RU3)

**TASK # - 3** TITLE: **Verification of the SAR results taken in the 1992-93 eruption by the integration of geodetic data (tilt, levelling, EDM and GPS)**

- (RU PARTICIPANTS) (RU1, subcontractor IRECE-NA)

**TASK # - 4** TITLE: **"Real time continuous monitoring implementation"** (task added as suggested by the Evaluation Committee in the report of the first year of activity).

- **2nd YEAR OBJECTIVES**

1. **Objective 1 -** Modelling strain fields caused by action of vertically elongated conduits and final mechanisms of uprising
2. **Objective 2** – Analysis and study of the coseismic and aseismic tilt variations.
3. **Objective 3** – Verification of the SAR results taken in the 1992-93 eruption by the integration of geodetic data (tilt, levelling, EDM and GPS)
4. **Objective** "real time continuous monitoring implementation" (point added as suggested by the Evaluation Committee in the report of the first year of activity)

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

- methodologies, data processing and interpretation

Conduits : Application of analytical models for ground deformation produced by the action of vertically elongated volcanic conduits. Deformation constraints on Etna summit craters geometry inferred by tilt variations during explosive activities (Bonaccorso, meeting 2002; Bonaccorso, in preparation).

Final uprising mechanisms :
Study of the intrusive mechanisms at Mt. Etna forerunning the July-August 2001 eruption from seismic and ground deformation data (Bonaccorso et al., submitted, 2002).
Modeling of the dike emplacement forerunning the Etna July 2001 eruption through continuous tilt and GPS data (Bonaccorso et al., 2002). Analysis of the two main lateral eruptions classes of intrusion on Mt. Etna on the basis of the modeling results of the recent eruptions (Bonaccorso and Davis, 2002).

Aseismic tilt : Investigations on the location area of aseismic variations. We verified that this area has been affected, during the last 14 years, by strong seismic releases at a depth of 7-12 km. The occurrence of the seismicity, furthermore, on many occasions, follows the deformations by a few days suggesting a cause-effect. The analyses currently on-going are aimed at characterizing the source mechanisms of the seismicity and their end result is to define the possible relationships between the source of the tilt variations (low velocity stress discharge) and the seismicity (fast velocity stress discharge).

Intermediate storage : Comparison of integrated geodetic data and satellite radar interferograms to infer magma storage during the 1991-93 Mt. Etna eruption. We compared the results obtained from the modelling of EDM, GPS, levelling and tilt data measured in the first part of the 1991-93 eruption at Etna to the InSAR data acquired during the second part. The geodetic changes are very marked in the first half of the eruption and constrain a deflation source located at a few kilometres of depth (≈ 3 km b.s.l.). SAR interferograms, available during the second part of the eruption, reveal a large-scale, but less marked, deflation of the volcano that could be caused by a deeper source. The combination of geodetic data modelling and SAR images suggests a complex plumbing system composed at least of two possible storage regions located at different depths (Bonaccorso et al., submitted, 2002).
Moreover, we conducted an integrated study between an advanced seismic tomography and ground deformation allowing to define the recent dynamic process inside the crust and in the shallow plumbing system (Patanè et al., submitted, 2002)

Real time analysis implementation : this is a point raised by the Evaluation Committee. Even if, from the RU's point of view, this does not belong within the scope of a modelling research project but to a specific and focussed project, we utilized the resources of INGV-CT to continue to implement the real time automatic analysis. The main details are reported below in the paragraph "Others".

- Data acquisition

The SAR data have been provided by the ESA project ERS AO3. 359 entitled "Development of SAR Techniques aimed at managing Natural Disasters in geodynamically active areas ".
The GPS, tilt and EDM data are collected by the Catania Section of INGV in the frame of its monitoring and surveillance activities.

- Others

We realized an automatic software, "EOLO", which allows the management of data from a GPS network using a "near-real time" automatic acquisition (Amore et al., 2002). The software is the

fruit of five years experience of working with continuous GPS and has been designed with a modular object-based structure to be extremely flexible and adaptable to different needs.
Following also the Evaluation Committee suggestion, we experimented with acquisition methods, transmission and data elaboration by the setting up of a real-time GPS network with a further implementation of the EOLO software (in acquisition mode of 1 session/day). We devised and tested software aimed at the acquisition of GPS data in real-time by TCP/IP protocol; the acquisition of GPS data in real-time by LAN and WLAN networks, and the comparison with traditional radio and telephone systems. We have carried out tests and estimates of repeatability and accuracy of GPS networks in real-time using Crnet software; comparison between the estimate of values of precision of GPS data elaborated in real-time averaged over 24 hours, and the values obtained by traditional software (GAMIT).

- **RESEARCH PRODUCTS**

- n° of articles published on international journals : 5 (accepted) and 4 (submitted) in 2002
- n° of articles published on national journals, proceedings, technical reports ==
- invited papers and talks: 1
- presentations at international meetings 5
- presentations at national meetings; 4
- Data base
- Computation codes 1
- Other

- **PUBLICATIONS LIST (inclusive of papers in prints and accepted)**


Amore M. Bonaccorso A., Ferrari F., Mattia M., Eolo : software for the automatic on-line treatment and analysis of GPS data for environmental monitoring, Computer and Geosciences, 28, 271-280, 2002

Bonaccorso A. and Davis P., Models of ground deformation from vertical volcanic conduits with application to eruptions of Mount. St. Helens and Mount Etna, J. Geophys.Res., 104, 10531-10542, 1999

Bonaccorso A. and Patanè D**7 .,** Shear response to an intrusive episode at Mt. Etna volcano (January 1998) inferred through seismic and tilt data, Tectonophysics, 334/2, 61-75, 2001.

Bonaccorso A., Mt Etna volcano : modelling of ground deformation patterns of recent eruptions and considerations on the associated precursors, Special Number on "Mechanics and Thermalfluid Dynamics of the Volcanic Processes", Journal of Volcanology and Geothermal Research, 109, 99-108, 2001.

Bonaccorso A., Aloisi M., Mattia M., Dike emplacement forerunning the Etna July 2001 eruption modelled through continuous tilt and GPS data, Geophysical Research Letters, v.29, n.13, 2002

Bonaccorso A. and Davis P.M. Modeling of ground deformation associated with recent lateral eruptions: Mechanics of magma ascent and intermediate storage at Mt.Etna, submitted to the monograph of American Geophysical Union "Etna Volcano Laboratory" , accepted, 2002a

Bonaccorso A., Campisi O., Falzone G., Gambino S., Continuous tilt monitoring: a lesson from 20 years experience at Mt. Etna, submitted to the monograph of American Geophysical Union "Etna Volcano Laboratory", accepted, 2002b

Patanè D., De Gori P., Chiarabba C., and Bonaccorso A., Uprising mechanisms and magma re-pressurization at Mt. Etna volcano, Science, 2002, accepted.

Gambino S., Coseismic and aseismic tilt variations on Mount Etna. Pure and Applied Geophysics, 159, 2751-2762, 2002.

Bonaccorso A., D'Amico S., Mattia M., Patanè D.Intrusive Mechanisms at Mt. Etna Forerunning the July-August 2001 Eruption from Seismic and Ground Deformation Data, submitted to Pageoph, 2002a

Bonaccorso A., Sansosti E., Berardino P., Modelled deformation pattern from integrated geodetic data and observed pattern from SAR for inferring magma storage sources at Mt. Etna during the 1991-93 eruption, submitted to Pageoph, 2002b

Elia M., Occhipinti R., Bonaccorso A., La Rosa G., Finite element analysis of round deformation due to dike intrusion, submitted to Annals of Geophysics, 2002

- invited papers and talks:

Bonaccorso A., Ground deformation modelling and associated precursors of recent eruptions at Mt. Etna volcano, 18th symposium of the International School of Geophysics, Advances in the assessment of earthquake and volcanic hazard, Erice, Sicily, 5-154 July 2001

- presentations at international meetings 5

Bonaccorso A., Patanè D., Shear response to an intrusive episode at Mt. Etna volcano (January 1998) inferred through seismic and tilt data, poster presented at annual meeting of the American Geophysical Union, S. Francisco, December 2000.

Bonaccorso A. and the whole scientific staff of INGV, The Evolution of the State of Mt. Etna Volcano in the Last Ten Years Inferred Through Multidisciplinary Investigations, poster at annual meeting of the American Geophysical Union, San Francisco, December 2001

Bonaccorso A., D' Amico , Mattia M., Patanè D. , Intrusive Mechanisms Evidence Occurred During January-April 2001 at Mt. Etna and Preceding the July 2001 Eruption, poster at annual meeting of the American Geophysical Union, San Francisco, December 2001

Bonaccorso A., Summit explosive activity and deformation: constraints on the Etna SE crater through tilt variations during the 1998-2000 lava fountains, spoken presentation at annual assembly of the European Geophysical Society, Nice, France, April, 2002

Gambino S., Bonaccorso A., Ferrari F., Patanè D. Integrated seismic and deformation data for inferring the July 2001 dike emplacement at Mt. Etna. AGU Meeting 2002.

- presentations at national meetings; 4

Bonaccorso A., Aloisi M., Mattia M., modelling of the dyke emplacement leading to the Etna July 2001 eruption : preliminary results from continuous tilt and gps data, poster at meeting of the Gruppo Nazionale di Vulcanologia, Roma, November, 2001

Bonaccorso A., Aloisi M., Berardino P., Davis P., Gambino S., Lanari R., Sansosti E, Modelling strain fields associated with uprising mechanisms (conduits and intrusion) and intermediate storage at Mt. Etna volcano, poster at meeting of the Gruppo Nazionale di Vulcanologia, Roma, November, 2001

Bonaccorso A., Etna eruption 2001 : investigations on ground deformation, spoken presentation at meeting of the Gruppo Nazionale di Vulcanologia, Roma, November, 2001

Gambino S. Coseismic and aseismic deformation at Etna. Workshop of the coordinated project GNV-Poseidon, Catania 19-20 July 2001.

- Computation codes 1

VISUAL BASIC code of the "TCP/IP Connect" software for GPS data acquisition in real-time via LAN and WLAN.

**TASK #** 5 A - TITLE **Influence of structural discontinuities on gravity changes, strain and stress fields.**

- (RU PARTICIPANTS) (RU2, RU1, RU3, RU4, RU8)

**TASK #** 5 B - TITLE **Laboratory measurements of "static" and "dynamic" elastic constants**

- (RU PARTICIPANTS) (RU2, RU5)

- **2nd YEAR OBJECTIVES**
  A) Modelling the influence of the structural discontinuities, inferred from seismic tomography, on deformation, gravity changes and seismicity induced by magma intrusion at mount Etna.
  B) Application to Etna lavas of experimental procedures developed to analyze over a range of nine frequency decades differences between static and dynamic elastic constants.

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

A) The ground deformation produced by a spherical overpressure source in a heterogeneous elastic and/or viscoelastic medium was investigated employing numerical models based on the finite element method. Spherical overpressure sources were assumed to be located at different depths beneath Mount Etna, the structure of which was approximated as axially symmetric. Finite element modelling allows to incorporate in the analysis realistic features such as the topographic relief and the laterally heterogeneous multi-layered structure inferred from seismic tomography. In order to avoid introducing artifacts in the solution, great care was taken to calibrate the computational domain necessary to reproduce analytical results accurately. An elastic analysis, performed initially, shows significant changes of the deformation field with respect to homogeneous half-space solutions: topography induces slight but detectable changes in the deformation field; in particular the maximum value of the vertical component is shifted slightly away from the symmetry axis. When introducing the elastic heterogeneities into the model, ground deformation is found to be more confined to the proximity of the axis and its amplitude is mostly sensitive to the presence of low rigidity layers above the source. The ratio of maximum radial to vertical deformation is significantly larger for deeper sources. The model was further developed to include the study of inelastic properties, assuming a Maxwell viscoelastic rheology for different layers. If the viscoelastic rheology is applied only to layers deeper than the source, the solutions are affected in different ways according to the distance of the source from the viscoelastic layer. If a viscoelastic layer is present above the source, a very large amplification (by more than 100%) of the surface deformation is predicted by the model; moreover, uplift transients are found to be followed by subsidence, without invoking any decrease in source overpressure. The most striking effects are found when the source is embedded within a viscoelastic layer: in this case a static equilibrium configuration is not attained and, in the long term, both components of deformation reverse their signs in proximity to the axis. Furthermore, the surface deformation becomes nearly independent of source depth, in the long term. Simple physical explanations were proposed for the different cases.
The results obtained from these models show that rheological properties of buried layers play a very important role in governing the deformation history following an intrusion episode within Mt. Etna. In particular, the interpretation of a high velocity body (inferred from seismic tomography) as a diapir of quenched mantle material, endowed with enhanced rheological properties, allows large horizontal deformation through mechanical decoupling of the shallow elastic layer along its base; such a mechanism is consistent with deformation data (GPS and SAR) collected during the july 2001 eruption (Trasatti, Giunchi and Bonafede, 2002).
The influence of inelastic constitutive relationships in near-surface layers has been investigated in terms of Von Mises (perfectly plastic) or Mohr-Coulomb (frictionally dominated) yield

conditions. The deformation pattern induced by a buried inflating source in plastic media is found to be significantly different than in elastic media: in particular, the depth of the source inferred from surface deformation may differ by a factor of "two" (Trasatti, Giunchi and Bonafede, in preparation).

B) We established an experimental procedure to analyze over a range of nine frequency decades any difference between the static and the dynamic method of measuring the elastic constants. We tested it with applications to reference materials, including a reference rock, Calcare Massiccio. No dependence whatsoever on the measurement method was found for non-rheologic materials. The method is now being applied to Etna lava rocks.

- **RESEARCH PRODUCTS**
  - n° of articles published on international journals: 6 + 2 submitted
  - n° of articles published on national journals, proceedings, technical reports ==
  - invited papers and talks: 2
  - presentations at international meetings: 3
  - presentations at national meetings; 5
  - Data bases ==
  - Computation codes ==
  - Other ==

- **PUBLICATIONS LIST (inclusive of papers in prints and accepted)**

Bonafede, M., Parenti, B. and Rivalta, E., 2002. On strike slip faulting in layered media, Geophys. J. Int., 149, 698-723.

Rivalta, E., Mangiavillano, W. and Bonafede, M., 2002. The edge dislocation problem in a layered elastic medium, Geophys. J. Int., 149, 508-523..

Trasatti, E., Giunchi, C. and Bonafede, M., 2002. Effects of topography and rheological layering on ground deformation in volcanic regions, J. Volcanol. Geotherm. Res., in press, 2002.

Ciccotti M., 2000. A realistic finite-element model for the Double Torsion loading configuration. *J. Am. Ceram. Soc*. **83** [11], pp. 2737-44.

Ciccotti M., Negri N., Gonzato G., Mulargia F., 2001. Practical application of an improved methodology for the Double Torsion load relaxation method. *Int. J. of Rock Mech. Min. Sci*.**38**, 569-576.

Ciccotti M., Gonzato G., and Mulargia F., 2000. The Double Torsion loading configuration for fracture propagation: an improved methodology for the load-relaxation at constant displacement. *Int. J. Rock Mech. Min. Sci*., **37**, pp. 1103-1113.

SUBMITTED PAPERS

Ciccotti M., Almagro R. and Mulargia F.. Static and dynamic moduli of the seismogenic layer in Italy. Rock Mech. and Rock Eng., submitted, July 2002.

Ciccotti M. and Mulargia F.. Experimental differences between static and dynamic measurements of the elastic moduli in a typical seismogenic rock. Geophys. J. Int., submitted, September 2002.

INVITED TALKS

Bonafede M., 2000. Modelling Ground Deformation and Gravity Residuals at "Campi Flegrei " Caldera (Italy): Constraints on Source Processes, EOS Trans. AGU, 81 (48), Fall Meet. Suppl. Abstract G21A-02, 2000. (invited paper)

Bonafede, M., 2001. Modelling ground deformation and gravity residuals in volcanic regions, EGS 26-th General Assembly, Geophys. Res. Abstract, 3, GRA3-1069. (invited paper).

PRESENTATIONS AT INTERNATIONAL MEETINGS

Trasatti, E., Giunchi, C. and Bonafede, M., 2002. Effects of elastic and rheological heterogeneities on sorce depth extimation at Campi Flegrei, Italy. XXVII EGS General Assembly, Nice (F) 21-26/4/2002.

Rivalta, E. and Bonafede, M., Inclined dikes in layered media. XXVII EGS General Assembly, Nice (F) 21-26/4/2002.

Trasatti, E., Giunchi, C. and Bonafede, M., Effects of topography and buried structures below Mt. Etna on the deformation field induced by overpressure sources. XXVII EGS General Assembly, Nice (F) 21-26/4/2002.

PRESENTATIONS AT NATIONAL MEETINGS

Bonafede M., 2001. Deformazioni del suolo e variazioni di gravita` in aree vulcaniche: contributo di sorgenti immerse in mezzi elastici e visco-elastici, Convegno di medio termine del Progetto GNV-POSEIDON, Catania 19-20 luglio 2001.

Ciccotti M. e Mulargia F. 2001. Costanti elastiche statiche e dinamiche: relazione sui primi mesi di attività, Convegno di medio termine del Progetto GNV-POSEIDON, Catania 19-20 luglio 2001.

Trasatti, E., Bonafede M., Giunchi C., Cianetti S. 2001. Modellazione numerica di aree vulcaniche e studio dell'effetto delle eterogeneita` strutturali del mezzo nelle deformazioni causate, Convegno di medio termine del Progetto GNV-POSEIDON, Catania 19-20 luglio 2001.

Bonafede M., "Studi e costraints su stoccaggi intermedi, risalita e condotti attraverso la modellizzazione dei campi di strain, e tomografia in velocità e attenuazione all' Etna", Assemblea Annuale del GNV (Gruppo Nazionale per la Vulcanologia), Roma 9-11 ottobre 2001.

Trasatti E., Giunchi C., e Bonafede M. "Influence of topography and heterogeneities on stress and deformation patterns in volcanic areas" (poster), Assemblea Annuale del GNV (Gruppo Nazionale per la Vulcanologia), Roma 9-11 ottobre 2001.

**TASK # 6** TITLE **A new approach for velocity seismic tomography at Etna**

- ( UR PARTICIPANTS) (RU 3, Virginia Politech.) (1°, 2° years)

**TASK # 7** - TITLE :**Attenuation tomography at Mt. Etna**

- ( UR PARTICIPANTS) (RU3, University of Granada) (2°, 3° years)

- **2nd YEAR OBJECTIVES**

This project and the research activity of U.R. INGV-CT2, VT and UG (SCM task) started later than the other GNV projects. This because the financial support (Poseidon funds) has been furnished only in January 2001. Moreover, the July-August, 2001, Mt. Etna flank eruption and the more recently flank eruption started in October, 2002, have caused temporary interruptions in the planned analyses and, consequently, in the regular development of the project.

The aim of the SCM task (INGV-CT2 and VT) is to carry out a new approach of velocity tomography at Mt. Etna area, using recent digital data (earthquakes recorded in the 1989-2001 period) with higher quality than the analogic ones used in previous tomographic studies. The new results and the comparison with those already published will also allow to evaluate the present limits of tomographic studies at Mt. Etna. It is noteworthy that, these studies have to be considered

as preparatory to the study of attenuation tomography, which will be carried out in a second phase (2° and 3° year) by INGV-CT in collaboration with UG.

Thus, the project has two main objectives: a) the velocity and b) the attenuation tomographic definition of the volcanic structure and crust beneath Mt. Etna.

We must take into account that some objectives of the first year have been shifted in the second year, with a consequent translation of all expected results. The main objectives for the 2001-2002 were:

- Optimization of the software modules developed during the first year for data analysis and elaboration;
- Earthquake data analysis at Mt. Etna;

**Objective a)**

- 3D velocity model ($V_P$ and $V_P/V_S$57 )
- Re-locations of earthquakes using the 3D velocity model.

**Objective b)**

- preliminary 3D attenuation model ($Q_P$ and $Q_S$)

- **2nd YEAR RESULTS**

As already indicated in the first year activity report, the several activities planned for the first year overlap with those planned for the second year, with a consequent shifting of the expected results in time. However, despite the various difficulties encountered some important results have been already reached.

***Objective a)***

- Several optimization on the software have been performed during the 2001-2002 period. This was done in order to integrate and improve the off-line analysis program ASDP (Patanè e Ferrari, 1999, Physics of the Earth and Planetary Interiors, 113/1-4, p. 57-74), which provide a common software for all R.U. for an interactive elaboration of the whole available data-set (1989-2001) recorded at both permanent (ex-IIV and ex-Poseidon) and temporary networks (OV), characterized by different recording formats.
- The dataset of local earthquakes recorded in the period 1994-2001 has been already finished, and the whole dataset (period 1989-2001) will be completed in the next months.

It is noteworthy that, after the July-August 2001 eruption we started the analysis of the intense seismic crises affecting the pre-eruptive period, which will help to better define a new detailed velocity model in the first 3 km of the crust beneath the volcano (Patanè et al., 2002).

- We also established a collaboration with the U.R. INGV-CNT in Roma (responsible Chiarabba C.) both for the attenuation studies at Mt. Etna and for the improvement of the Chiarabba et al. (2000) 3D velocity model (Chiarabba et al., 2002; Patanè et al., 2002).

We believe that, before the first half of 2003 the tomographic inversion using the finite difference method for the calculation of travel times and for the ray tracing (Hole, 1992) and the entire dataset will be available. Since the whole data set is not still available, our collaboration with the VT research unit was deferred to year 2003.

***Objective b)***

We are following and testing several methods to estimate the attenuation tomography at Etna volcano, by: 1) the coda waves, to obtain a block image of Etna attenuation; 2) the first pulse of the P waves, using both its amplitude and pulse duration (or rise time) and 3) the spectral ratio technique, applied on both P- and S-waves. All these analyses are in progress, for a part of the whole dataset. In particular, thanks to the use of the July-August 2001 eruption dataset we started the attenuation tomographic inversion, which help to better define an attenuation model in the first 3 km of the crust beneath the volcano (Arevalo et al., 2002; Patanè and Giampiccolo, 2002).

We believe that, a definitive tomographic inversion in attenuation will be made before the end of the project.

- **RESEARCH PRODUCTS (2001-2002)**
  - n° of articles published on international journals : 5 (1 submitted) + 2 in preparation
  - presentations at international meetings: 4
  - presentations at national meetings: 2
  - Data base: earthquake recordings in the period 1994-2001, suitable for tomographic studies;
  - Computation codes : different software modules

**PUBLICATIONS LIST (inclusive of papers in prints and accepted)**

**Year 2001**

1) Bonaccorso A. and Patanè D. (2001), *Shear response to an intrusive episode at Mt. Etna volcano (January 1998) inferred through seismic and tilt data.* Tectonophysics, 334, 61-75.

**Year 2002**

2) Patanè D., Chiarabba C., Cocina O., De Gori P., Moretti M. and Boschi E. (2002), *Tomographic images and 3D earthquakes locations of the seismic swarm preceding the 2001 Mt. Etna eruption: Evidence for a dyke intrusion*. Geophys. Res. Lett., Vol. 29, No. 19.
3) Chiarabba, C., De Gori, P., and Patanè D. (2002), *The Mt. Etna Plumbing System: The contribution of Seismic Tomography*, In: Etna Volcano Laboratory, Eds., Calvari S., Coltelli M., Bonaccorso S., Del Negro C., Falsaperla S., monograph of the American Geophysical Union, accepted.
4) Patanè D., De Gori P., Chiarabba C., and Bonaccorso A. (2002), *Uprising mechanisms and magma re-pressurization at Mt. Etna volcano* (2002). Science, accepted.

**Submitted**

5) Bonaccorso A., D'Amico S., Mattia M. and Patanè D. (2002), *Intrusive mechanisms evidence occurred at Mt. Etna during the year preceding the July-August 2001 Eruption*, Pure and Applied Geophysics, submitted.

**In preparation**

6) Patanè D. and Giampiccolo E. (2002). Attenuation of body waves at Mt. Etna volcano using shallow earthquakes recorded during the 2001
7) Arevalo M., Ibanez J. and Patanè D., Seismic attenuation tomography at Mt. Etna volcano by using first P-wave pulse.

**National meetings**

**Year 2001**

8) Patanè D., Chiarabba C., Cocina O., De Gori P., Ferrari F., Moretti M., 2001. *Tomographic images and 3D earthquake locations of the recent seismicity accompanying the 2001 Mt. Etna eruption.* Convegno Annuale GNV – INGV, Roma 9-11 ottobre 2001, poster presentation.
9) Puglisi G., Patanè D. , Bonforte A., Maiolino E. (2001) *Inferences on magma uprising at Mt. Etna (Italy) by seismic and GPS ground deformation data*, Convegno Annuale GNV dash INGV, Roma 9-11 ottobre 2001, poster presentation.

**International meetings**

**Year 2001**

10) Patanè D., Chiarabba C., Cocina O., De Gori P., Ferrari F., Moretti M., 2001. Tomographic images and 3D earthquake locations of the recent seismicity accompanying the 2001 Mt. Etna eruption. AGU, 10-14 December, 2001, S. Francisco, poster presentation.
11) Bonaccorso A., D'Amico S., Mattia M. and Patanè D. (2001) *Intrusive mechanisms evidence occurred durino January-April 2001 at Mt. Etna and preceding the July 2001 Eruption*, AGU, 10-14 December, 2001, S. Francisco, poster presentation.
12) Puglisi G., Patanè D. , Bonforte A., Maiolino E. (2001) *Inferences on magma uprising at Mt. Etna (Italy) by seismic and GPS ground deformation data*, AGU, 10-14 December, 2001, S. Francisco, poster presentation.

**Year 2002**

13) Gambino S., Bonaccorso A., Ferrari F., Patanè D. (2002). *Integrated seismic and deformation data for inferring the July 2001 dike emplacement at Mt. Etna*. AGU Fall Meeting, 6-10 December 2002, session T05, poster presentation.

**TASK #** 8 - TITLE **Modelling deformation sources by employing numerical methods**

- ( UR PARTICIPANTS) (UR4-UR1-UR2)

- **2nd YEAR OBJECTIVES**

During the second year multi-layer models were analysed in order to evaluate the strain-deformation state as a function of structural discontinuities and of the induced thermopressure. The analysis was carried out on the basis of the results obtained in omogeneous or stratified media (two layers) and the measurements acquired. The first approach is in static conditions and considers a limited number of homogeneous layers in order to verify the reliability of the results.

- **2nd YEAR RESULTS**

*-Methodologies*

A classic mechanism of the magma uprise is due to the action of the dykes. They are schematised by tensile dislocations.

The application of the theory of the dislocation to the case of tensile mechanisms has been often used and applied with success to the study of ground deformations.
But the real characteristics of the medium are different from the perfectly homogenous behaviour because, in the various layers of the subsoil, we have different values of rigidity.
Moreover the real topography is different from the flat free surface of the theory of dislocation, therefore the analysis of a real situation, with topography and stratification of the medium, is much more complex.
FEM analysis represents a valid alternative.
We have executed two-dimensional analysis in which the domain reproduces the topography of an east-west cross section of Mount Etna. In these analyses we have considered the intrusion that has characterized the recent lateral eruption of the Mount Etna in July-August 2001.
We have also considered the effects of the material and stratification of the medium in order to verify their influence on the surficial ground deformations.
Two different depths of the source for every type of analysis have been considered obtaining different behaviours of the ground deformations.

*-Data acquisition.*

We considered a perfectly elastic behaviour for the medium with condition $\lambda=\nu$. The boundary conditions have been assumed in the bottom surface for displacements (ux=uy=0), to the symmetry surface (ux=0) and leaving free the top surface without ties in order to respect the condition of null stress. The values of the Young's modulus of single layer have been obtained applying the theory of the P-waves propagation in linear elastic medium. In particular we have used the values of Vp from a recent tomography of Mount Etna. From this tomography we have found the layers thickness.

*-Data processing and interpretation*

The two models without topography have been used with different reference planes: 1500 m a.s.l. and 2000 m a.s.l. They have been used for two fundamental reasons: to obtain information about set-up of parameters for the more complex analyses with topography and to verify the correspondence with theoretical results.

We have executed also simulations for the same model varying the value of the Young's modulus, but in the condition of $\lambda=\nu$. From the results it emerges clearly that the values of vertical and horizontal deformation are equal with analytical values.
This allows to assert that the choice of the domain and of the type of FEM elements is correct, and to have further confirmation about the theory of the tensile dislocation.
The topography instead introduces some differences with theoretical models. In particular the distribution of vertical and horizontal displacements are not symmetric.
Compared with theoretical values there is a distribution of deformations on average more elevated and a shift of the maximum peaks of displacements. The differences evidenced from the previous comparison are repeated with a trend marked in the model with top dyke to 1920 m a.s.l..
This would confirm, in agreement with other studies (see Bonaccorso, 1998) that 1500m a.s.l. is the plane of reference that better is adapted to the studies with homogenous half-spaces.

From the previous models with topography we have introduced the stratification of medium considered homogeneous and stratified in seven layers of linear elastic material with condition $\lambda=\nu$.
The results obtained do not evidence particular differences with the values we have found in the condition of not stratified medium.

We have shown that in these conditions the effects of one-layer are equal to those provoked in presence of stratification.
It has instead importance on the displacements field, the effect of the topography mostly in the near-field of the topographic variations like usually the volcanoes top surface shows.
Therefore if we considerer deformations in far-field of top area (flanks of the Etna Mount to 3-4 km of distance) the analytical method shows effects similar to those obtained considering more realistic situations with stratification and topography.

- **RESEARCH PRODUCTS OF THE PROJECT**

  - Presentation at national meetings: Congresso nazionale INGV Roma
  - N. 6 two-dimensional finite element models.

- **PUBLICATIONS LIST:**

M. ELIA, R. OCCHIPINTI AMATO, G. LA ROSA - Finite element method applications in the study of deformation of volcano areas. Poster, Congresso nazionale GNV, Roma
M. ELIA, R. OCCHIPINTI AMATO, A. BONNACCORSO, G. LA ROSA - Finite element analysis of ground deformation due the dike intrusion – Submitted to *Annals of geophysics*

**TASK #** 9 - TITLE: **Magmatic feeding system and seismic deformation associated to magma uprising: application to italian volcanoes.**

- ( UR PARTICIPANTS) (UR8-UR3-UR7)

- **2nd YEAR OBJECTIVE**
  Definition of the magmatic feeding system of Mt. Etna employing seismological and petrological data, relationships between seismic deformation and stress field at regional and volcanic scale.
  A) Deep strucure: Vp, Vp/Vs, Qp models
  B) Seismic deformation: Focal mechanisms for the 1994-2000 seismicity
  C) Geophysical parameters of rocks: predict the resistivity of etnean rocks as a function of temperature and degree (and composition) of partial melting

- **2nd YEAR RESULTS (max 1 page)**
  - Seismology: The new data recorded during the present day activity have been analysed to refine P-wave and Vp/Vs velocity models, focused on the upper 5 km. A complete set of high quality focal mechanisms have been computed using the 3D velocity model to study the seismic deformation in recent years. The interesting results obtained have been compared with the mechanism of deformation of the volcano inferred from geodetic. A general radial compression around the main high Vp body has been recognized and related to strong re-pressurization of the volcano since 1994.
    The study of attenuation tomography is in progress. T-star estimates from the velocity spectrum of selected earthquakes have been computed to define a Qp model of the volcano. The technique of analysis has been developed and has been applied to a limited percentage of the available data.

  - Laboratory measurements of electric parameters: We investigated the physical properties of Etnean rocks performing experiments using a multi-anvil apparatus. We measured and compared the electrical conductivity of a primitive basalt and of an ultramafic nodule. The electrical conductivity of the two samples were measured *in situ* at pressures of 900 and 1500 MPa, temperatures ranging from 400 to 1100 °C and frequencies ranging from 0.1 to $10^5$ Hz. In order to investigate the electrical properties of the Etnean products as a function of partial melting, a few experiments were performed in the piston

cylinder apparatus prior to the electrical measurements (in the multianvil). The amount and the composition of the glasses in the experimental products were determined by using a scanning electron microscope and an electron microprobe, respectively.

The interpretation of impedance spectra indicates that the conductivity of basalt behaves Arrheniusly over the entire temperature range investigated with an activation energy of 0.75 eV. We confirmed that the conductivity is pressure independent. On the contrary, experiments performed using a partially molten sample indicate that conductivity significantly depends on the quantity of glass and is less dependent on the glass composition. However, when the amount of partial melt increases, the conductivity of the sample increases too. In particular, at the same temperature, the conductivity of sample having 80% of glass is a factor of four higher than the conductivity of a sample with 8% of glass.

- **RESEARCH PRODUCTS**
- n° of articles published on international journals: 4
- n° of articles published on national journals, proceedings, technical reports
- invited papers and talks:
- presentations at international meetings:1
- presentations at national meetings;

**PUBLICATIONS LIST (inclusive of papers in prints and accepted)**

Patane' D., Chiarabba C., Cocina O., De Gori P., Moretti M., and Boschi E., Tomographic images and 3D earthquake location of the seismic swarm preceding the 2001 Mt. Etna eruption: Evidence for dike intrusion, G.R.L., 29, 10,1029-10,1032, 2002.

Taddeucci J., Pompilio M., Scarlato P., Monitoring the esplosive activity of the July-August 2001 eruption of Mt. Etna (Italy) by ash characterization. Geophysical Research Letters., 29, (8), 10.1029/2001GL014372, 2002.

Chiarabba C., De Gori P., and Patane' D., The Mt. Etna plumbing system, The contribution of seismic tomography, AGU monograph "Etna Volcano Laboratory", in press.

Patanè D., De Gori P., Chiarabba C., and Bonaccorso A. (2002), Uprising mechanisms and magma re-pressurization at Mt. Etna volcano (2002). Science, accepted.

- presentations at international meetings:1

Scarlato P., Poe B., Freda C., Gaeta M.. *HP-HT measurements of electrical conductivity in basaltic rocks from Mt. Etna (Sicily, Italy)* Geophysical Research Abs. 4. 27th General Assembly of the European Geophysical Society. Nizza, 21-26 aprile 2002

**TASK #** 10 - TITLE **Definition of eruptive scenarios at Mt. Etna by employing integrated multidisciplinary studies.**

- (RU PARTICIPANTS) (RU5)

- **2nd YEAR OBJECTIVES**

– Integration of data for the validation (or rejection) of the scenarios based on single databases; dynamic scenarios (varying in time) based on relational dataset by approaching each single eruption onset;

– new data acquisition;

– application of the fluid filled tensile crack model to volcanic tremor recorded during lava fountainings;

– application of a method for the precise relocation of microearthquakes, to better define the brittle response of surrounding rocks to a magma dyke intrusion.

- **2nd YEAR RESULTS (max 1 page)**
  - methodologies: see references
  - Data acquisition: Seismotectonic and volcanological data relating the ground fractures occurred during the 2001 and 2002 eruptions; daily tremor spectra.
  - Data processing and interpretation: see references

The products related to the second year are the following:

The integration of seismotectonic and instrumental seimic data for the 2001 eruption allowed to evidence that the occurrence and the behaviour of the main flank eruption at Mt. Etna are strongly controlled by the regional tectonics.

The analysis of volcanic tremor amplitude in the period 1983-1999 dynamics has evidenced that during paroxysmal eruptive stages -- lava fountains -- the daily tremor amplitude assumes an intermittent character. These time intervals were also studied by means of low-dimensional chaos analysis. Moreover, the eruptive episodes of September 1989 have been studied also to find the behaviour of their source.
The Chouet's model as source of volcanic tremor at Mount Etna has been applied to other lava fountain episodes at the Northeastern Crater (1995). The model looks better satisfying in the description of the phenomenon than that was found the previous year.
The application of high precision locations techniques to seismic swarms associated to the first stages of the 1991-1993 eruption provided very good results. The comparison between the results and the deformation source models lead to several considerations on the passive brittle response of the medium to the ongoing intrusion of the eruptive dyke.
Good results have been also obtained at Mt. Saint Helens volcano, evidencing that a magma recharge may have occurred during recent seismic swarms.
Finally, the collecting of data, related to the observed and documented volcanic activity, continued.

- **RESEARCH PRODUCTS**
  - n° of articles published on international journals: 1 published + 2 accepted + 2 submitted
  - n° of articles published on national journals, proceedings, technical reports
  - invited papers and talks
  - presentations at international meetings: 6
  - presentations at national meetings: 1
  - Data base: 1

- **PUBLICATIONS LIST (inclusive of papers in prints and accepted)**

Musumeci C., Gresta S. and Malone S., 2002. Magma system recharge of Mount St. Helens (USA) from precise relative hypocenter location of microearthquakes. *J. Geophys. Res.*, 107, B10.

Privitera E., Sgroi T. and Gresta S., (in print). Statistical analysis of intermittent volcanic tremor associated with the September 1989 summit explosive eruptions at Mt. Etna, Sicily. *J. Volcanol. Geotherm. Res.*

Brancato A. and Gresta S., (in print). High precision relocation of microearthquakes at Mt. Etna (1991-93 eruption onset): a tool for better understanding the volcano seismicity. *J. Volcanol. Geotherm. Res.*

Catalano S., Cocina O., De Guidi G., Ferlito C., Gresta S., Monaco C., Musumeci C., Neri M. and Tortorici L. Tectonic control on the eruptive dynamics at Mt. Etna volcano (eastern Sicily) during the July-August 2001 eruption. *Geophys. J. Int*. (submitted September 2002)

Gresta S., Ripepe M., D'Amico S., Marchetti E., Coltelli M., Harris A.J.L. and Privitera E. A seismoacoustic experiment during the July-August 2001 eruption at Mt. Etna volcano, Italy. *J. Volcanol. Geotherm. Res.* (submitted November 2002)

Presentations at international meetings

Barbano M.S., Cosentino M., Lombardo G. , Intensity attenuation law in the eastern flank of Mt. Etna. W.G. "Seismic Phenomena Associated with Volcanic Activity", Montserrat (W.I.)

Cammarata L., Privitera E., Gresta S., Volcanic tremor spectra during a summit explosive eruption at Mount Etna, a critical application of the fluid filled crack source model European Geophysical Society, XXVII General Assembly, Nice, France, 21-26 April 2002.

Gresta S., Catalano S., Cocina O., De Guidi G., Ferlito C., Monaco C., Musumeci C., Neri M. and Tortorici L., Tectonic control on the eruptive dynamics at Mt. Etna (eastern Sicily) during the July-August 2001 eruption. AGU, San Francisco, USA, 6-10 December 2002

Leonardi S., Gresta M., Marzocchi W., Time evolution analysis of tremor amplitude at Mt. Etna: implications for magma dynamics, AGU, San Francisco, USA, 6-10 December 2002

Saccorotti G., Zuccarello L., Del Pezzo E., Ibanez J., Gresta S., Privitera E., Quantitative analysis of tremor wavefield at Etna volcano, Italy. European Geophysical Society, XXVII General Assembly, Nice, France, 21-26 April 2002.

Tusa G., Giampiccolo E., Gresta S., Malone S.D., Musumeci C., Source parameters and scaling relationships of microearthquakes at Mount St. Helens (USA), European Geophysical Society, XXVII General Assembly, Nice, France, 21-26 April 2002.

**TASK #** 11 - TITLE **Space-time distribution of seismogenic stresses**

- (RU PARTICIPANTS) (RU6-UR7)

- **2nd YEAR OBJECTIVES**

  Determination in a 3D local velocity structure of hypocenter parameters and fault-plane solutions of shear earthquakes occurring in the Etna area between 1988 and 1999, and evaluation of seismogenic stress and seismic deformation space-time patterns

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

We have performed the analysis of the space-time distribution of the seismogenic stress and seismic strain tensors in the Etna area, with the main purpose of preparing the final stage of the research, e.g. the comparison of stress and strain data with other geophysical and volcanological information available, in the framework of the Project and from outside. The analysis of stress and strain parameters has been performed by the methods of Gephart and Forsyth (1984 and 1990) and Wyss et al. (1992), respectively. The data used for this analysis came from the investigation of the focal parameters of the shear events that occurred in the study area between January 1988 and January 1999. A dataset of about 400 fault-plane solutions was collected, and this includes all the seismic events with magnitude over 2.7, and many additional events with magnitude between 2.0 and 2.7. The analysis of hypocentral locations and fault plane solutions was performed using the tridimensional local velocity structure recently proposed by this same research unit (Aloisi et al., Phys. Earth Planet. Interiors, 2002), a velocity structure which was also proven to be a useful

constraint for the interpretation of the stress and strain patterns in the study region. The fault-plane solution dataset resulted more than three times larger compared to those used in the previous investigations, and the average quality of the solutions resulted also significantly improved. This allowed us to increase the space resolution of the stress and strain estimates and to extend the analysis of the dynamic processes beneath the volcano to a nearly double time period compared to the previous studies. A cooperation has also recently started with the staff of Dr. G. De Natale at INGV-Naples for the application of stress propagation modelling algorithms to data and results produced in the framework of the activity of our Research Unit.

- **RESEARCH PRODUCTS**
  - n° of articles published on international journals 4
  - n° of articles published on national journals, proceedings, technical reports 0
  - invited papers and talks 0
  - presentations at international meetings 2
  - presentations at national meetings; 0
  - Data bases: dataset of about 400 fault-plane solutions with magnitude over 2.0;
  - Computation codes 0
  - Other 0

**PUBLICATIONS LIST (inclusive of papers in prints and accepted)**

Barberi G., Cocina O., Neri G., Privitera E., Spampinato S. (2000): Volcanological inferences from seismic strain tensor computations at Mt. Etna volcano, Sicily. *Bull. of Volcanology, Vol. 62, pp. 318-330.*

Aloisi M., Cocina O., Neri G., Orecchio B., Privitera E. (2002): Seismic tomography of the crust underneath the Etna volcano, Sicily. *Phys. Earth Planet. Int*, 134, 3-4, 139-155.

Aloisi M., D'Agostino M., Dean K.J., Mostaccio A., Neri G. (2002): Satellite analysis and physical modelling of the eruptive cloud generated by the Mount Etna big paroxysm of 22 July 1998. *Jour. Geophys. Res.*, accepted, in press.

Neri G., Barberi G., Orecchio B., Aloisi M. (2002): Seismotomography of the crust in the transition zone between the Southern Tyrrhenian and Sicilian tectonic domains. *Geophys. Res. Letters*., accepted, in press.

**TASK #** 12 - TITLE **Geophysical constraints on the dynamics of intrusive processes**

- ( UR PARTICIPANTS) (UR7-UR6)

- **2nd YEAR OBJECTIVES**

1) Integration of Mt. Etna Fault Plane Solution (FPS) databases in the period 1994 –2002.
2) Relevance of Volumetric (V) and CLVD seismic sources and their role in the dynamics of eruptive processes.
3) Mt. Etna Stress and Strain fields characterization in time and space domains.

- **2nd YEAR RESULTS (max 1 page)**
  - The delayed start of a fellowship influenced the operation linked to the integration of Mt. Etna FPS database available in the period 1994 – 2002, nevertheless a relevant amount of integrate FPSs are already available and only quality control checks are needed. The occurrence of 2001 and 2002 Mt. Etna eruptions induced us to modify our original programs in order to devote a great attention to the relevant scientific problems raised from these eruptive activities. A relevant amount of data was collected and processed in order to obtain FPSs able to determine the evolution of the stress and strain fields at Mt. Etna before and during the two eruptions.

- The entire database collected (1994 – 2002) is undergoing a relocation process using a 3D velocity model, in order to evaluate affordable ray paths in a representative media. Consequently, spurious effects due to unrealistic refraction do not affect evaluated FPSs. Obtained result will be used for inversion of stress (Gephart & Forsyth, JGR, 1984) and strain (Kostrov, IAS,1974) fields, in order to study their evolution in space and in time domains.
- Analyses on seismic activity that have preceded Mt. Etna 2001 eruption were completed and a paper is in preparation. Main result (obtained on the basis of seismicity time-space distribution, FPSs analyses and stress tensor inversion) evidenced a magma intrusion along the NNW-SSE structural trend. The local stress field induced by magma overpressure in the plumbing complex, induced a fragile response of ENE-WSW fault system in the western flank of the volcano at a depth of 5-10 km range. On the contrary, in the eastern flank fragile response occurred at shallower depth (0-5 km) and involved several structural systems.
- After the end of the 2001 eruption, seismicity remained at low level until the beginning of the October 2002 Mt. Etna eruption. The beginning of the eruption was heralded and followed by a powerful seismic swarm. Seismicity spread progressively on the whole eastern flank, involving several structures. Preliminary analyses on seismicity time-space distribution and FPSs, suggest a possible mechanism of the volcano east flank movement in eastward direction, triggered by magma injection in a c.a. N-S eruptive system.
- Data analyses related to moment tensor inversion encountered problems due to the delayed start of a fellowship. At this stage of the project, we were able only to select a data set related to the 2001 Mt. Etna eruption and perform preliminary analyses propaedeutic to data inversion.

- **RESEARCH PRODUCTS**
  - n° 1 of articles published on international journals
  - presentations at international meetings;
    EGS 2002 – Nice - France
  - presentations at national meetings;
    GNV 2001 - Roma
  - FPS Data bases (1988 –2002)

- **PUBLICATIONS LIST (inclusive of papers in prints and accepted)**

Aloisi M., Cocina O., Neri G., Orecchio B, Privitera E. (2002). Seismic tomography of the crust underneath the Etna volcano, Sicily. *Physics of the Earth and Planetary Interiors.* 134, 139-155.

Patané D., Cocina O., Falsaperla S., Privitera E., Spampinato S. (2002). Mt. Etna volcano: A seismological framework. Monograph of American Geophysical Union, “Etna Volcano Laboratory”. In print.

PROJECT TITLE

**STUDY AND CONSTRAINTS ON INTERMEDIATE STORAGE, MAGMA UPRISE AND CONDUITS THROUGH MODELLING OF STRAIN FIELDS, VELOCITY AND ATTENUATION TOMOGRAPHY AT MT. ETNA**

**RU #1 – INGV - CT1 - Responsible**
Name-Position: Alessandro Bonaccorso - researcher
Affiliation : Istituto Nazionale di Geofisica e Vulcanologia

# ACTIVITY REPORT–2nd YEAR

RU #1- INGV-CT1 - PARTICIPANTS

| Name-Position | | Affiliation | man/month |
|---|---|---|---|
| Bonaccorso Alessandro | Researcher | INGV-CT | 4 |
| Aloisi Marco | Researcher | INGV-CT | 3 |
| Gambino Salvatore | Researcher | INGV-CT | 3 |
| Sansosti Eugenio | Researcher | IREA – CNR | 1 |
| Berardino Paolo | Researcher | IREA-CNR | 1 |
| Davis Paul M. | Professor in Geophysics | UCLA - U.S.A. | 1 |
| Amore Mauro | Technologist | INGV-CT | 2 |
| Mattia | Technologist | INGV-CT | 2 |
| Rossi | Technicians | INGV-CT | 2 |

- **2nd YEAR OBJECTIVES**

5. **Objective 1 -** Modelling strain fields caused by action of vertically elongated conduits and final mechanisms of uprising
6. **Objective 2** – Analysis and study of the coseismic and aseismic tilt variations.
7. **Objective 3** – Verification of the SAR results taken in the 1992-93 eruption by the integration of geodetic data (tilt, levelling, EDM and GPS)
8. **Objective** "real time continuous monitoring implementation" (point added as suggested by the Evaluation Committee in the report of the first year of activity)

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

- methodologies, data processing and interpretation

Conduits : Application of analytical models for ground deformation produced by the action of vertically elongated volcanic conduits. Deformation constraints on Etna summit craters geometry inferred by tilt variations during explosive activities (Bonaccorso, meeting 2002; Bonaccorso, in preparation).

Final uprising mechanisms :
Study of the intrusive mechanisms at Mt. Etna forerunning the July-August 2001 eruption from seismic and ground deformation data (Bonaccorso et al., submitted, 2002).
Modeling of the dike emplacement forerunning the Etna July 2001 eruption through continuous tilt and GPS data (Bonaccorso et al., 2002). Analysis of the two main lateral eruptions classes

of intrusion on Mt. Etna on the basis of the modeling results of the recent eruptions (Bonaccorso and Davis, 2002).

Aseismic tilt : Investigations on the location area of aseismic variations. We verified that this area has been affected, during the last 14 years, by strong seismic releases at a depth of 7-12 km. The occurrence of the seismicity, furthermore, on many occasions, follows the deformations by a few days suggesting a cause-effect. The analyses currently on-going are aimed at characterizing the source mechanisms of the seismicity and their end result is to define the possible relationships between the source of the tilt variations (low velocity stress discharge) and the seismicity (fast velocity stress discharge).

Intermediate storage : Comparison of integrated geodetic data and satellite radar interferograms to infer magma storage during the 1991-93 Mt. Etna eruption. We compared the results obtained from the modelling of EDM, GPS, levelling and tilt data measured in the first part of the 1991-93 eruption at Etna to the InSAR data acquired during the second part. The geodetic changes are very marked in the first half of the eruption and constrain a deflation source located at a few kilometres of depth (≈ 3 km b.s.l.). SAR interferograms, available during the second part of the eruption, reveal a large-scale, but less marked, deflation of the volcano that could be caused by a deeper source. The combination of geodetic data modelling and SAR images suggests a complex plumbing system composed at least of two possible storage regions located at different depths (Bonaccorso et al., submitted, 2002).
Moreover, we conducted an integrated study between an advanced seismic tomography and ground deformation allowing to define the recent dynamic process inside the crust and in the shallow plumbing system (Patanè et al., submitted, 2002)

Real time analysis implementation : this is a point raised by the Evaluation Committee. Even if, from the RU's point of view, this does not belong within the scope of a modelling research project but to a specific and focussed project, we utilized the resources of INGV-CT to continue to implement the real time automatic analysis. The main details are reported below in the paragraph "Others".

- Data acquisition

The SAR data have been provided by the ESA project ERS AO3. 359 entitled "Development of SAR Techniques aimed at managing Natural Disasters in geodynamically active areas ".
The GPS, tilt and EDM data are collected by the Catania Section of INGV in the frame of its monitoring and surveillance activities.

- Others

We realized an automatic software, "EOLO", which allows the management of data from a GPS network using a "near-real time" automatic acquisition (Amore et al., 2002). The software is the fruit of five years experience of working with continuous GPS and has been designed with a modular object-based structure to be extremely flexible and adaptable to different needs.
Following also the Evaluation Committee suggestion, we experimented with acquisition methods, transmission and data elaboration by the setting up of a real-time GPS network with a further implementation of the EOLO software (in acquisition mode of 1 session/day). We devised and tested software aimed at the acquisition of GPS data in real-time by TCP/IP protocol; the acquisition of GPS data in real-time by LAN and WLAN networks, and the comparison with traditional radio and telephone systems. We have carried out tests and estimates of repeatability and accuracy of GPS networks in real-time using Crnet software; comparison between the estimate of values of precision of GPS data elaborated in real-time averaged over 24 hours, and the values obtained by traditional software (GAMIT).

- RESEARCH PRODUCTS

  - n° of articles published on international journals : 5 (accepted) and 4 (submitted) in 2002
  - n° of articles published on national journals, proceedings, technical reports ==
  - invited papers and talks:

Bonaccorso A., Ground deformation modelling and associated precursors of recent eruptions at Mt. Etna volcano, 18th symposium of the International School of Geophysics, Advances in the assessment of earthquake and volcanic hazard, Erice, Sicily, 5-154 July 2001

  - presentations at international meetings

Bonaccorso A., Patanè D., Shear response to an intrusive episode at Mt. Etna volcano (January 1998) inferred through seismic and tilt data, poster presented at annual meeting of the American Geophysical Union, S. Francisco, December 2000.

Bonaccorso A. and the whole scientific staff of INGV, The Evolution of the State of Mt. Etna Volcano in the Last Ten Years Inferred Through Multidisciplinary Investigations, poster at annual meeting of the American Geophysical Union, San Francisco, December 2001

Bonaccorso A., D' Amico , Mattia M., Patanè D. , Intrusive Mechanisms Evidence Occurred During January-April 2001 at Mt. Etna and Preceding the July 2001 Eruption, poster at annual meeting of the American Geophysical Union, San Francisco, December 2001

**Bonaccorso A., Summit explosive activity and deformation: constraints on the Etna SE crater through tilt variations during the 1998-2000 lava fountains, spoken presentation at annual assembly of the European Geophysical Society, Nice, France, April, 2002**

**Gambino S., Bonaccorso A., Ferrari F., Patanè D. Integrated seismic and deformation data for inferring the July 2001 dike emplacement at Mt. Etna. AGU Meeting 2002.**

  - presentations at national meetings;

Bonaccorso A., Aloisi M., Mattia M., modelling of the dyke emplacement leading to the Etna July 2001 eruption : preliminary results from continuous tilt and gps data, poster at meeting of the Gruppo Nazionale di Vulcanologia, Roma, November, 2001

Bonaccorso A., Aloisi M., Berardino P., Davis P., Gambino S., Lanari R., Sansosti E, Modelling strain fields associated with uprising mechanisms (conduits and intrusion) and intermediate storage at Mt. Etna volcano, poster at meeting of the Gruppo Nazionale di Vulcanologia, Roma, November, 2001

Bonaccorso A., Etna eruption 2001 : investigations on ground deformation, spoken presentation at meeting of the Gruppo Nazionale di Vulcanologia, Roma, November, 2001

Gambino S. Coseismic and aseismic deformation at Etna. Workshop of the coordinated project GNV-Poseidon, Catania 19-20 July 2001.

  - Computation codes

VISUAL BASIC code of the "TCP/IP Connect" software for GPS data acquisition in real-time via LAN and WLAN.

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Amore M. Bonaccorso A., Ferrari F., Mattia M., Eolo : software for the automatic on-line treatment and analysis of GPS data for environmental monitoring, Computer and Geosciences, 28, 271-280, 2002

Bonaccorso A. and Davis P., Models of ground deformation from vertical volcanic conduits with application to eruptions of Mount. St. Helens and Mount Etna, J. Geophys.Res., 104, 10531-10542, 1999

Bonaccorso A. and Patanè D**7 .,** Shear response to an intrusive episode at Mt. Etna volcano (January 1998) inferred through seismic and tilt data, Tectonophysics, 334/2, 61-75, 2001.

**Bonaccorso A., Mt Etna volcano : modelling of ground deformation patterns of recent eruptions and considerations on the associated precursors, Special Number on "Mechanics and Thermalfluid Dynamics of the Volcanic Processes", Journal of Volcanology and Geothermal Research, 109, 99-108, 2001.**

Bonaccorso A., Aloisi M., Mattia M., Dike emplacement forerunning the Etna July 2001 eruption modelled through continuous tilt and GPS data, Geophysical Research Letters, v.29, n.13, 2002

Bonaccorso A. and Davis P.M. Modeling of ground deformation associated with recent lateral eruptions: Mechanics of magma ascent and intermediate storage at Mt.Etna, submitted to the monograph of American Geophysical Union "Etna Volcano Laboratory" , accepted, 2002a

Bonaccorso A., Campisi O., Falzone G., Gambino S., Continuous tilt monitoring: a lesson from 20 years experience at Mt. Etna, submitted to the monograph of American Geophysical Union "Etna Volcano Laboratory", accepted, 2002b

Gambino S., Coseismic and aseismic tilt variations on Mount Etna. Pure and Applied Geophysics, 159, 2751-2762, 2002.

Patanè D., De Gori P., Chiarabba C., and Bonaccorso A., Uprising mechanisms and magma re-pressurization at Mt. Etna volcano, Science, 2002, accepted.

Bonaccorso A., D'Amico S., Mattia M., Patanè D.Intrusive Mechanisms at Mt. Etna Forerunning the July-August 2001 Eruption from Seismic and Ground Deformation Data, submitted to Pageoph, 2002a

Bonaccorso A., Sansosti E., Berardino P., Modelled deformation pattern from integrated geodetic data and observed pattern from SAR for inferring magma storage sources at Mt. Etna during the 1991-93 eruption, submitted to Pageoph, 2002b

Elia M., Occhipinti R., Bonaccorso A., La Rosa G., Finite element analysis of round deformation due to dike intrusion, submitted to Annals of Geophysics, 2002

**RU #2 – UNIBO - Responsible**
Name-Position: Maurizio Bonafede, Full Professor of Geophysics
Affiliation: Department of Physics, University of Bologna

# ACTIVITY REPORT–2nd YEAR

RU #2 – UNIBO - PARTICIPANTS

| Name-Position | Affiliation | | man/month |
|---|---|---|---|
| BONAFEDE Maurizio | Chair Professor. | Dept. Physics UniBO | 3 |
| MULARGIA Francesco | Chair Professor | Dept. Physics UniBO | 1 |
| GASPERINI Paolo | Associate Professor | Dept. Physics UniBO | 1 |
| BELARDINELLI Maria Elina | University Researcher | Dept. Physics UniBO | 1 |
| RIVALTA Eleonora | Post-doc fellow | Dept. Physics UniBO | 1 |
| CASTELLARO Silvia | Post-doc fellow | Dept. Physics UniBO | 1 |
| CICCOTTI Matteo | Post-doc fellow | Dept. Physics UniBO | 4 |
| TRASATTI Elisa | PhD student | Dept. Physics UniBO | 12 |
| ALMAGRO Riccardo | Postgraduate fellow | Dept. Physics UniBO | 7 |
| GIUNCHI Carlo | Researcher at INGV | INGV - Roma | 2 |
| CIANETTI Spina | Researcher at INGV | INGV - Roma | 2 |
| GUIDI Cristiano | Technician | Dept. Physics UniBO | 1 |

- 2nd YEAR OBJECTIVES
  - ***C) Modelling the influence of the structural discontinuities, inferred from seismic tomography, on deformation, gravity changes and seismicity induced by magma intrusion at mount Etna.***
  - ***D) Application to Etna lavas of experimental procedures developed to analyze over a range of nine frequency decades differences between static and dynamic elastic constants.***

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

A) The ground deformation produced by a spherical overpressure source in a heterogeneous elastic and/or viscoelastic medium was investigated employing numerical models based on the finite element method. Spherical overpressure sources were assumed to be located at different depths beneath Mount Etna, the structure of which was approximated as axially symmetric. Finite element modelling allows to incorporate in the analysis realistic features such as the topographic relief and the laterally heterogeneous multi-layered structure inferred from seismic tomography. In order to avoid introducing artifacts in the solution, great care was taken to calibrate the computational domain necessary to reproduce analytical results accurately. An elastic analysis, performed initially, shows significant changes of the deformation field with respect to homogeneous half-space solutions: topography induces slight but detectable changes in the deformation field; in particular the maximum value of the vertical component is shifted slightly away from the symmetry axis. When introducing the elastic heterogeneities into the model, ground deformation is found to be more confined to the proximity of the axis and its amplitude is mostly sensitive to the presence of low rigidity layers above the source. The ratio of maximum radial to vertical deformation is significantly larger for deeper sources. The model was further developed to include the study of

inelastic properties, assuming a Maxwell viscoelastic rheology for different layers. If the viscoelastic rheology is applied only to layers deeper than the source, the solutions are affected in different ways according to the distance of the source from the viscoelastic layer. If a viscoelastic layer is present above the source, a very large amplification (by more than 100%) of the surface deformation is predicted by the model; moreover, uplift transients are found to be followed by subsidence, without invoking any decrease in source overpressure. The most striking effects are found when the source is embedded within a viscoelastic layer: in this case a static equilibrium configuration is not attained and, in the long term, both components of deformation reverse their signs in proximity to the axis. Furthermore, the surface deformation becomes nearly independent of source depth, in the long term. Simple physical explanations were proposed for the different cases. The results obtained from these models show that rheological properties of buried layers play a very important role in governing the deformation history following an intrusion episode within Mt. Etna. In particular, the interpretation of a high velocity body (inferred from seismic tomography) as a diapir of quenched mantle material, allows large horizontal deformation through mechanical decoupling of the shallow brittle layer along its base; such a mechanism is consistent with deformation data (GPS and SAR) collected during the july 2001 eruption.
The influence of inelastic constitutive relationships in near-surface layers has been investigated in terms of Von Mises (perfectly plastic) or Mohr-Coulomb (frictionally dominated) yield conditions. The deformation pattern induced by a buried inflating source in plastic media is found to be significantly different than in elastic media: in particular, the depth of the source inferred from surface deformation may differ by a factor of "two" (Trasatti, Giunchi and Bonafede, in preparation).

B) We established an experimental procedure to analyze over a range of nine frequency decades any difference between the static and the dynamic method of measuring the elastic constants. We tested it with applications to reference materials, including a reference rock, Calcare Massiccio. No dependence whatsoever on the measurement method was found for non-rheologic materials. The method is now being applied to Etna lava rocks.

- RESEARCH PRODUCTS
  - n° of articles published on international journals **6**
  - n° of articles published on national journals, proceedings, technical reports -
  - invited papers and talks **2**
  - presentations at international meetings **3**
  - presentations at national meetings **5**
  - Data bases -
  - Computation codes -
  - Other -

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Bonafede, M., Parenti, B. and Rivalta, E., 2002. On strike slip faulting in layered media, Geophys. J. Int., 149, 698-723.

Rivalta, E., Mangiavillano, W. and Bonafede, M., 2002. The edge dislocation problem in a layered elastic medium, Geophys. J. Int., 149, 508-523..

Trasatti, E., Giunchi, C. and Bonafede, M., 2002. Effects of topography and rheological layering on ground deformation in volcanic regions, J. Volcanol. Geotherm. Res., in press, 2002.

Ciccotti M., 2000. A realistic finite-element model for the Double Torsion loading configuration. *J. Am. Ceram. Soc*. **83** [11], pp. 2737-44.

Ciccotti M., Negri N., Gonzato G., Mulargia F., 2001. Practical application of an improved methodology for the Double Torsion load relaxation method. *Int. J. of Rock Mech. Min. Sci*. **38**, 569-576.

Ciccotti M., Gonzato G., and Mulargia F., 2000. The Double Torsion loading configuration for fracture propagation: an improved methodology for the load-relaxation at constant displacement*. Int. J. Rock Mech. Min. Sci*., **37**, pp. 1103--1113.

SUBMITTED PAPERS

Ciccotti M., Almagro R. and Mulargia F.. Static and dynamic moduli of the seismogenic layer in Italy. Rock Mech. and Rock Eng., submitted, July 2002.

Ciccotti M. and Mulargia F.. Experimental differences between static and dynamic measurements of the elastic moduli in a typical seismogenic rock. Geophys. J. Int., submitted, September 2002.

INVITED TALKS

Bonafede M., 2000. Modelling Ground Deformation and Gravity Residuals at ”Campi Flegrei ” Caldera (Italy): Constraints on Source Processes, EOS Trans. AGU, 81 (48), Fall Meet. Suppl. Abstract G21A-02, 2000. (invited paper)

Bonafede, M., 2001. Modelling ground deformation and gravity residuals in volcanic regions, EGS 26-th General Assembly, Geophys. Res. Abstract, 3, GRA3-1069. (invited paper).

PRESENTATIONS AT INTERNATIONAL MEETINGS

Trasatti, E., Giunchi, C. and Bonafede, M., 2002. Effects of elastic and rheological heterogeneities on sorce depth extimation at Campi Flegrei, Italy. XXVII EGS General Assembly, Nice (F) 21-26/4/2002.

Rivalta, E. and Bonafede, M., Inclined dikes in layered media. XXVII EGS General Assembly, Nice (F) 21-26/4/2002.

Trasatti, E., Giunchi, C. and Bonafede, M., Effects of topography and buried structures below Mt. Etna on the deformation field induced by overpressure sources. XXVII EGS General Assembly, Nice (F) 21-26/4/2002.

PRESENTATIONS AT NATIONAL MEETINGS

Bonafede M., 2001. Deformazioni del suolo e variazioni di gravita` in aree vulcaniche: contributo di sorgenti immerse in mezzi elastici e visco-elastici, Convegno di medio termine del Progetto GNV-POSEIDON, Catania 19-20 luglio 2001.

Ciccotti M. e Mulargia F. 2001. Costanti elastiche statiche e dinamiche: relazione sui primi mesi di attività, Convegno di medio termine del Progetto GNV-POSEIDON, Catania 19-20 luglio 2001.

Trasatti, E., Bonafede M., Giunchi C., Cianetti S. 2001. Modellazione numerica di aree vulcaniche e studio dell'effetto delle eterogeneita` strutturali del mezzo nelle deformazioni causate, Convegno di medio termine del Progetto GNV-POSEIDON, Catania 19-20 luglio 2001.

Bonafede M., "Studi e costraints su stoccaggi intermedi, risalita e condotti attraverso la modellizzazione dei campi di strain, e tomografia in velocità e attenuazione all' Etna", Assemblea Annuale del GNV (Gruppo Nazionale per la Vulcanologia), Roma 9-11 ottobre 2001.

Trasatti E., Giunchi C., e Bonafede M. "Influence of topography and heterogeneities on stress and deformation patterns in volcanic areas" (poster), Assemblea Annuale del GNV (Gruppo Nazionale per la Vulcanologia), Roma 9-11 ottobre 2001.

**RU #3 - INGV-CT2 Responsible**
Name-Position : Domenico Patanè - I Researcher
Affiliation : Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Catania

# ACTIVITY REPORT–2nd YEAR

**Sub-projects**
6) A new velocity tomographic approach at Mt. Etna (*INGV-CT2, VT*)
7) Attenuation tomography at Mt. Etna ( *INGV-CT2, UG*)

UR INGV-CT2 PARTICIPANTS

INGV-CT2

| Name-Position | Affiliation | man/month |
|---|---|---|
| Patanè Domenico-Researcher | INGV-CT | 5 |
| Cocina Ornella-Researcher | INGV-CT | 4 |
| Torrisi Orazio-Technician | INGV-CT | 6 |
| Ferrari Ferruccio-Technician | INGV-CT | 3 |

VT

| Name-Position | Affiliation | man/month |
|---|---|---|
| Hole John-Assistant Professor | Department of Geological Sciences Virginia Tech (USA) | 3 |

UG

| Name-Position | Affiliation | man/month |
|---|---|---|
| Ibanez Jesus-Professor | University of Granada (Spain) | 3 |
| Arévalo C. Martínez -PhD | University of Granada (Spain) | 4 |

- 2nd YEAR OBJECTIVES

This project and the research activity of U.R. INGV-CT2, VT and UG (SCM task) started later than the other GNV projects. This because the financial support (Poseidon funds) has been furnished only in January 2001. Moreover, the July-August, 2001, Mt. Etna flank eruption and the more recently flank eruption started in October, 2002, have caused temporary interruptions in the planned analyses and, consequently, in the regular development of the project.

The aim of the SCM task (INGV-CT2 and VT) is to carry out a new approach of velocity tomography at Mt. Etna area, using recent digital data (earthquakes recorded in the 1989-2001 period) with higher quality than the analogic ones used in previous tomographic studies. The new results and the comparison with those already published will also allow to evaluate the present limits of tomographic studies at Mt. Etna. It is noteworthy that, these studies have to be considered as preparatory to the study of attenuation tomography, which will be carried out in a second phase (2° and 3° year) by INGV-CT in collaboration with UG.

Thus, the project has two main objectives: a) the velocity and b) the attenuation tomographic definition of the volcanic structure and crust beneath Mt. Etna.

We must take into account that some objectives of the first year have been shifted in the second year, with a consequent translation of all expected results. The main objectives for the 2001-2002 were:

- Optimization of the software modules developed during the first year for data analysis and elaboration;
- Earthquake data analysis at Mt. Etna;

**Objective a)**

- 3D velocity model ($V_P$ and $V_P/V_S$57 )
- Re-locations of earthquakes using the 3D velocity model.

**Objective b)**

- preliminary 3D attenuation model ($Q_P$ and $Q_S$)

- 2nd YEAR RESULTS

As already indicated in the first year activity report, the several activities planned for the first year overlap with those planned for the second year, with a consequent shifting of the expected results in time. However, despite the various difficulty encountered some important results have been already reached.

***Objective a)***

- Several optimization on the software has been performed during the 2001-2002 period. That in order to integrate and improve the off-line analysis program ASDP (Patanè e Ferrari, 1999, Physics of the Earth and Planetary Interiors, 113/1-4, p. 57-74), which provide a common software for all R.U. for an interactive elaboration of the whole available data-set (1989-2001) recorded at both permanent (ex-IIV and ex-Poseidon) and temporary networks (OV), characterized by different recording formats.
- The dataset of local earthquakes recorded in the period 1994-2001 has been already finished, and the whole dataset (period 1989-2001) will be completed in the next months.

It is noteworthy that, after the July-August 2001 eruption we started the analysis of the intense seismic crises affecting the pre-eruptive period, which will help to better define a new detailed velocity model in the first 3 km of the crust beneath the volcano (Patanè et al., 2002).

- We also established a collaboration with the U.R. INGV-Roma (responsible Chiarabba C.) both for the attenuation studies at Mt. Etna and for the improvement of the Chiarabba et al. (2000) 3D velocity model (Chiarabba et al., 2002; Patanè et al., 2002).

We believe that, before the first half of 2003 the tomographic inversion using the finite difference method for the calculation of travel times and for the ray tracing (Hole, 1992) and the entire dataset will be available. Since the whole data set is not still available, we did not start our collaboration with the VT research unit. We will start it during 2003.

***Objective b)***

We are following and testing several methods to estimate the attenuation tomography at Etna volcano, by: 1) the coda waves, to obtain a block image of Etna attenuation; 2) the first pulse of the P waves, using both its amplitude and pulse duration (or rise time) and 3) the spectral ratio technique, applied on both P- and S-waves. All these analyses are in progress, for a part of the whole dataset. In particular, thanks to the use of the July-August 2001 eruption dataset we started the attenuation tomographic inversion, which help to better define an attenuation model in the first 3 km of the crust beneath the volcano (Arevalo et al., 2002; Patanè and Giampiccolo, 2002).

We believe that, a definitive tomographic inversion in attenuation will be made before the end of the project.

- RESEARCH PRODUCTS (2001-2002)
  - n° of articles published on international journals : 5 (1 submitted) + 2 in preparation
  - presentations at international meetings: 4
  - presentations at national meetings: 2
  - Computation codes : different software modules

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

**Year 2001**

1) Bonaccorso A. and Patanè D. (2001), *Shear response to an intrusive episode at Mt. Etna volcano (January 1998) inferred through seismic and tilt data.* Tectonophysics, 334, 61-75.

**Year 2002**

2) Patanè D., Chiarabba C., Cocina O., De Gori P., Moretti M. and Boschi E. (2002), *Tomographic images and 3D earthquakes locations of the seismic swarm preceding the 2001 Mt. Etna eruption: Evidence for a dyke intrusion.* Geophys. Res. Lett., Vol. 29, No. 19.

3) Chiarabba, C., De Gori, P., and Patanè D. (2002), *The Mt. Etna Plumbing System: The contribution of Seismic Tomography*, In: Etna Volcano Laboratory, Eds., Calvari S., Coltelli M., Bonaccorso S., Del Negro C., Falsaperla S., monograph of the American Geophysical Union, accepted.

8) Patanè D., De Gori P., Chiarabba C., and Bonaccorso A. (2002), *Uprising mechanisms and magma re-pressurization at Mt. Etna volcano* (2002). Science, accepted.

**Submitted**

9) Bonaccorso A., D'Amico S., Mattia M. and Patanè D. (2002), *Intrusive mechanisms evidence occurred at Mt. Etna during the year preceding the July-August 2001 Eruption*, Pure and Applied Geophysics, submitted.

**In preparation**

Patanè D. and Giampiccolo E. (2002). Attenuation of body waves at Mt. Etna volcano using shallow earthquakes recorded during the 2001

Arevalo M., Ibanez J. and Patanè D., Seismic attenuation tomography at Mt. Etna volcano by using first P-wave pulse.

**NATIONAL MEETINGS**

**Year 2001**

8) Patanè D., Chiarabba C., Cocina O., De Gori P., Ferrari F., Moretti M., 2001. *Tomographic images and 3D earthquake locations of the recent seismicity accompanying the 2001 Mt. Etna eruption.* Convegno Annuale GNV – INGV, Roma 9-11 ottobre 2001, poster presentation.

9) Puglisi G., Patanè D. , Bonforte A., Maiolino E. (2001) *Inferences on magma uprising at Mt. Etna (Italy) by seismic and GPS ground deformation data*, Convegno Annuale GNV dash INGV, Roma 9-11 ottobre 2001, poster presentation.

**INTERNATIONAL MEETINGS**

**Year 2001**

10) Patanè D., Chiarabba C., Cocina O., De Gori P., Ferrari F., Moretti M., 2001. Tomographic images and 3D earthquake locations of the recent seismicity accompanying the 2001 Mt. Etna eruption. AGU, 10-14 December, 2001, S. Francisco, poster presentation.

11) Bonaccorso A., D'Amico S., Mattia M. and Patanè D. (2001) Intrusive mechanisms evidence occurred durino January-April 2001 at Mt. Etna and preceding the July 2001 Eruption, AGU, 10-14 December, 2001, S. Francisco, poster presentation.

12) Puglisi G., Patanè D. , Bonforte A., Maiolino E. (2001) Inferences on magma uprising at Mt. Etna (Italy) by seismic and GPS ground deformation data, AGU, 10-14 December, 2001, S. Francisco, poster presentation.

**Year 2002**

13) Gambino S., Bonaccorso A., Ferrari F., Patanè D. (2002). *Integrated seismic and deformation data for inferring the July 2001 dike emplacement at Mt. Etna.* AGU Fall Meeting, 6-10 December 2002, session T05, poster presentation.

**RU #4 – UNICT1 - Responsible**
Prof. Guido La Rosa
DIIM- CATANIA

# ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

| Name-Position | Affiliation | man/month |
|---|---|---|
| Marco Elia - Engineer | Contract Collaborator | 4 |
| Rosario Occhipinti Amato - Engineer | Contract Collaborator | 4 |

- 2nd YEAR OBJECTIVES

During the second year multi-layer models will be analysed in order to evaluate the strain-deformation state as a function of structural discontinuities and of the thermopressure induced. The analysis will be carried out on the basis of the results obtained in omogeneous or stratified media (two layers) and the measurements acquired. The first approach will be in static conditions and will consider a limitate number of omogeneous layers in order to verify the reliability of the results.

- 57 2nd YEAR RESULTS

*-Methodologies*

A classic mechanism of the magma climb is due to the action of the dykes. They are schematised by tensile dislocations.

The application of the theory of the dislocation to the case of tensile mechanisms has been often used and applied with success to the study of ground deformations.
But the real characteristics of the medium are different from the perfectly homogenous behaviour because, in the various layers of the subsoil, we have different values of rigidity.
Moreover the real topography is different from the flat free surface of the theory of dislocation, therefore the analysis of a real situation, with topography and stratification of the medium, is much more complex.
FEM analysis represents a valid alternative.
We have executed two-dimensional analysis in which the domain reproduces the topography of an east-west cross section of Mount Etna. In these analyses we have considered the intrusion that has characterized the recent lateral eruption of the Mount Etna in July-August 2001.
We have also considered the effects of the material and stratification of the medium order to verify their influence on the superficial ground deformations.
Two different depths of the source for every type of analysis have been considered obtaining different behaviours of the ground deformations.

*-Data acquisition.*

It is considered a perfectly elastic behaviour for the medium with condition $\lambda=\nu$.
The boundary conditions have been assumed in the bottom surface for displacements (ux=uy=0), to the symmetry surface (ux=0) and leaving free the top surface without ties in order to respect the condition of null stress.

The values of the Young's modulus of single layer have been obtained applying the theory of the P-waves propagation in linear elastic medium. In particular we have used the values of Vp from a recent tomography of Mount Etna.
From this tomography we have found the layers thickness.

*-Data processing and interpretation*
The two models without topography have been used with different reference planes: 1500 m a.s.l. and 2000 m a.s.l.

They have been used for two fundamental reasons: to obtain information about set-up of parameters for the more complex analyses with topography and to verify the correspondence with theoretical results.
We have executed also simulations for a same model varying the value of the Young's modulus, but in the condition of $\lambda=\nu$.
From the results emerges clearly that the values of vertical and horizontal deformation are equals with analytical values.

This allows to assert that the choice of the domain and of the type of FEM elements it is correct, and to have further confirmation about the theory of the tensile dislocation.
The topography instead introduces some differences with theoretical models. In particular the distribution of vertical and horizontal displacements are not symmetric.
Compared with theoretical values there is a distribution of deformations on average more elevated and a shift of the maximum peaks of displacements. The differences evidenced from the previous comparison are repeated with a trend marked in the model with top dyke to 1920 m a.s.l..
This would confirm, in agreement with other studies ( see Bonaccorso, 1998) that 1500m a.s.l. is the plane of reference that better is adapted to the studies with homogenous half-spaces.
From the previous models with topography we have introduced the stratification of medium considered homogeneous and stratified in seven layers of linear elastic material with condition $\lambda=\nu$.
The results obtained do not evidence particular differences with the values we have found in the condition of not stratified medium.

We have shown that in these conditions the effects of the case one-layer are equals to the results provoked in presence of stratification.
It has instead importance on the displacements field, the effect of the topography mostly in the near-field of the topographic variations like usually the volcanoes top surface shows.
Therefore if we considerer deformations in far-field of top area (flanks of the Etna Mount to 3-4 km of distance) the analytical method shows effects similar to those obtained considering more realistic situations with stratification and topography.

- RESEARCH PRODUCTS OF THE PROJECT

  - Presentation at national meetings: Congresso nazionale GNV Roma
  - N. 6 two-dimensional finite element models.

PUBLICATIONS LIST:

M. ELIA, R. OCCHIPINTI AMATO, G. LA ROSA - Finite element method applications in the study of deformation of volcano areas. Poster, Congresso nazionale GNV Roma
M. ELIA, R. OCCHIPINTI AMATO, A. BONNACCORSO, G. LA ROSA - Finite element analysis of ground deformation due the dike intrusion – Submitted to *Annals of geophysics.*

**RU #5 – UNICT-2 - Responsible:**
Name-Position: Prof. Stefano Gresta Associate professor of Seismology
Affiliation: Department of Geological Sciences - University of Catania

***Title of subproject: Searching for eruptive scenarios at Mount Etna volcano on the basis of a multidisciplinary integrated investigation***

# ACTIVITY REPORT–2nd YEAR

RU #5 – UNICT2 - PARTICIPANTS

| Nome-Qualifica /Name-Position | Afferenza /Affiliation | | mesi/uomo man/month |
|---|---|---|---|
| CRISTOFOLINI Renato | Full Prof. | DSG Uni CT | 2 |
| FERLITO Carmelo | Temporary Researcher | DSG UniCT | 3 |
| LA ROCCA Domenico | Laboratory technician | DSG UniCT | 1 |
| GIUFFRIDA Elisabetta | Laboratory technician | DSG UniCT | 1 |
| BARBANO Maria Serafina | Associate Prof. | DSG UniCT | 1 |
| RIGANO Rosaria | PhD Student | DSG UniCT | 1 |
| GRESTA Stefano | Associate Prof. | DSG Uni CT | 2 |
| GIAMPICCOLO Elisabetta | Contract Researcher | INGV-CT | 2 |
| TUSA Giuseppina | PhD Student | DSG UniCT | 2 |
| MUSUMECI Carla | Contract Researcher | INGV-CT | 2 |
| CAMMARATA Laura | GNV grant | INGV-CT | 3 |
| TORTORICI Luigi | Full Prof. | DSG Uni CT | 1 |
| LOMBARDO Giuseppe | Researcher | DSG UniCT | 1 |
| COSENTINO Mario | Researcher | DSG UniCT | 1 |
| SCRIBANO Vittorio | Associate Prof. | DSG Uni CT | 2 |
| BRANCATO Alfonso | SR County grant | INGV-CT | 5 |
| DI GRAZIA Giuseppe | Contract Researcher | INGV-CT | 1 |

- 2nd YEAR OBJECTIVES

Integration of data for the validation (or rejection) of the scenarios based on single databases;
dynamic scenarios (varying in time) based on relational dataset by approaching each single eruption onset;
new data acquisition;
application of the fluid filled tensile crack model to the data relating the volcanic tremor recorded during lava fauntainings;
application of a method for the precise relocation of microearthquakes, to better definine the brittle behaviour of sourrounding rock sto a magma dyke intrusion.

- 2nd YEAR RESULTS **(max 1 page)**
  - methodologies: see references

- Data acquisition: Seismotectonic and volcanological data relating the ground fractures occurred during the 2001 and 2002 eruptions; daily tremor spectra.
- Data processing and interpretation: see references

The products related to the second year are the following:

The integration of seismotectonic and instrumental seimic data for the 2001 eruption allowed to evidence that the occurrence and the behaviour of the main flank eruption at Mt. Etna are strongly controlled by the regional tectonics.

The analysis of volcanic tremor amplitude in the period 1983-1999 dynamics has evidenced that during paroxysmal eruptive stages -- lava fountains -- the daily tremor amplitude assumes an intermittent character. These time intervals were also studied by means of low-dimensional chaos analysis. Moreover, the eruptive episodes of September 1989 have been studied also to find the behaviour of their source.
The Chouet's model as source of volcanic tremor at Mount Etna has been applied to other lava fountain episodes at the Northeastern Crater (1995). The model looks better satisfying in the description of the phenomenon than that was found the previous year.
The application of high precision locations techniques to seismic swarms associated to the first stages of the 1991-1993 eruption provided very good results. The comparison between the results and the deformation source models lead to several considerations on the passive brittle response of the madium to the ongoing intrusion of the eruptive dyke.
Good rsults have been also obtained at Mt. Saint Helens volcano, evidencing that a magma recharge may have occurred during recent seismic swarms.
Finally, the collecting of data, related to the observed and documented volcanic activity, continued.

- RESEARCH PRODUCTS
  - n° of articles published on international journals: 1 published + 2 accepted + 2 submitted
  - n° of articles published on national journals, proceedings, technical reports
  - invited papers and talks
  - presentations at international meetings: 6
  - presentations at national meetings: 1
  - Data base: 1
  -
  - PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Musumeci C., Gresta S. and Malone S., 2002. Magma system recharge of Mount St. Helens (USA) from precise relative hypocenter location of microearthquakes. *J. Geophys. Res.*, 107, B10.

Privitera E., Sgroi T. and Gresta S., (in print). Statistical analysis of intermittent volcanic tremor associated with the September 1989 summit explosive eruptions at Mt. Etna, Sicily. *J. Volcanol. Geotherm. Res.*

Brancato A. and Gresta S., (in print). High precision relocation of microearthquakes at Mt. Etna (1991-93 eruption onset): a tool for better understanding the volcano seismicity. *J. Volcanol. Geotherm. Res.*

Catalano S., Cocina O., De Guidi G., Ferlito C., Gresta S., Monaco C., Musumeci C., Neri M. and Tortorici L. Tectonic control on the eruptive dynamics at Mt. Etna volcano (eastern Sicily) during the July-August 2001 eruption. *Geophys. J. Int*. (submitted September 2002)

Gresta S., Ripepe M., D'Amico S., Marchetti E., Coltelli M., Harris A.J.L. and Privitera E. A seismoacoustic experiment during the July-August 2001 eruption at Mt. Etna volcano, Italy. *J. Volcanol. Geotherm. Res.* (submitted November 2002)

Presentations at international meetings

Barbano M.S., Cosentino M., Lombardo G. , Intensity attenuation law in the eastern flank of Mt. Etna. W.G. "Seismic Phenomena Associated with Volcanic Activity", Montserrat (W.I.)

Cammarata L., Privitera E., Gresta S., Volcanic tremor spectra during a summit explosive eruption at Mount Etna, a critical application of the fluid filled crack source model European Geophysical Society, XXVII General Assembly, Nice, France, 21-26 April 2002.

Gresta S., Catalano S., Cocina O., De Guidi G., Ferlito C., Monaco C., Musumeci C., Neri M. and Tortorici L., Tectonic control on the eruptive dynamics at Mt. Etna (eastern Sicily) during the July-August 2001 eruption. AGU, San Francisco, USA, 6-10 December 2002

Leonardi S., Gresta M., Marzocchi W., Time evolution analysis of tremor amplitude at Mt. Etna: implications for magma dynamics, AGU, San Francisco, USA, 6-10 December 2002

Saccorotti G., Zuccarello L., Del Pezzo E., Ibanez J., Gresta S., Privitera E., Quantitative analysis of tremor wavefield at Etna volcano, Italy. European Geophysical Society, XXVII General Assembly, Nice, France, 21-26 April 2002.

Tusa G., Giampiccolo E., Gresta S., Malone S.D., Musumeci C., Source parameters and scaling relationships of microearthquakes at Mount St. Helens (USA), European Geophysical Society, XXVII General Assembly, Nice, France, 21-26 April 2002.

**RU #6 – UNIME - Responsible**
Name-Position: Giancarlo Neri, Associate Professor
Affiliation: Dipartimento di Scienze della Terra, Università di Messina

***Title of subproject: Seismogenic Stress And Seismic Deformation In The Etna Area***

# ACTIVITY REPORT–2nd YEAR

RU PARTICIPANTS

| Name-Position | Affiliation | man/month |
|---|---|---|
| Giancarlo Neri - Associate Prof. | Messina University | 5 |
| Domenico Caccamo - Researcher | Messina University | 2 |
| Graziella Barberi - Contract | INGV - Ct Section (Me) | 3 |
| Antonino Mostaccio - Contract | INGV - Ct Section (Me) | 2 |
| Marcello D'Agostino - Contract | INGV - Ct Section (Me) | 1 |
| Marco Aloisi - Contract | INGV - Ct Section (Me) | 1 |
| Barbara Orecchio - Fellowship | Messina University | 5 |
| Eugenio Privitera - Researcher | INGV - Ct Section | 1 |
| Ornella Cocina - Researcher | INGV - Ct Section | 2 |
| Salvatore Spampinato - Researcher | INGV - Ct Section | 2 |
| Max Wyss - Full Prof. | Wapmerr Geneve | 1 |
| Stephen Wiemer - Researcher | ETH Zurich | 2 |
| Danjiel Schorlemmer - Ph. D. | ETH Zurich | 2 |
| Debora Presti -Fellowship. | INGV - Na Section | 2 |
| Giuseppe DE Natale - Researcher | INGV - Na Section | 1 |

- 2nd YEAR OBJECTIVES

  Determination in a 3D local velocity structure of hypocenter parameters and fault-plane solutions of shear earthquakes occurring in the Etna area between 1988 and 1999, and evaluation of seismogenic stress and seismic deformation space-time patterns

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

We have performed the analysis of the space-time distribution of the seismogenic stress and seismic strain tensors in the etnean area, with the main purpose of preparing the final stage of the research, e.g. the comparison of stress and strain data with other geophysical and volcanological information available, in the framework of the Project and out of it. The analysis of stress and strain parameters has been performed by the methods of Gephart and Forsyth (1984 and 1990) and Wyss et al. (1992), respectively. The data used for this analysis came from the investigation of the focal parameters of the shear events that occurred in the study area between January 1988 and January 1999. A dataset of about 400 fault-plane solutions was collected, and this includes all the seismic

events with magnitude over 2.7, and many additional events with magnitude between 2.0 and 2.7. The analysis of hypocentral locations and fault plane solutions was performed using the tridimensional local velocity structure recently proposed by this same research unit (Aloisi et al., Phys. Earth Planet. Interiors, 2002), a velocity structure which was also proven to be a useful constraint for interpretation of the stress and strain patterns in the study region. The fault-plane solution dataset resulted more than three times larger compared to those used in the previous investigations, and the average quality of the solutions resulted also significantly improved. This allowed us to increase the space resolution of the stress and strain estimates and to extend the analysis of the dynamic processes beneath the volcano to a nearly double time period compared to the previous studies. A cooperation has also recently started with the staff of Dr. G. De Natale at INGV-Naples for the application of stress propagation modelling algorithms to data and results produced in the framework of the activity of our Research Unit.

ß RESEARCH PRODUCTS

- n° of articles published on international journals 4
- n° of articles published on national journals, proceedings, technical reports 0
- invited papers and talks 0
- presentations at international meetings 2
- presentations at national meetings; 0
- Data bases 0
- Computation codes 0
- Other 0

PUBLICATIONS LIST (inclusive of papers in prints and accepted)


- Barberi G., Cocina O., Neri G., Privitera E., Spampinato S. (2000): Volcanological inferences from seismic strain tensor computations at Mt. Etna volcano, Sicily. *Bull. of Volcanology, Vol. 62, pp. 318-330.*
- Aloisi M., Cocina O., Neri G., Orecchio B., Privitera E. (2002): Seismic tomography of the crust underneath the Etna volcano, Sicily. *Phys. Earth Planet. Int*, 134, 3-4, 139-155.
- Aloisi M., D'Agostino M., Dean K.J., Mostaccio A., Neri G. (2002): Satellite analysis and physical modelling of the eruptive cloud generated by the Mount Etna big paroxysm of 22 July 1998. *Jour. Geophys. Res.*, accepted, in press.
- Neri G., Barberi G., Orecchio B., Aloisi M. (2002): Seismotomography of the crust in the transition zone between the Southern Tyrrhenian and Sicilian tectonic domains. *Geophys. Res. Letters.*, accepted, in press.

**RU #7 – INGV-CT3 - Responsible:**
Name-Position: Eugenio Privitera - First researcher (2nd level)
Affiliation: Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Catania.

# ACTIVITY REPORT–2nd YEAR

RU #7 – INGV CT3 - PARTICIPANTS

| Name-Position | Affiliation | man/month |
|---|---|---|
| Eugenio Privitera - Researcher (resp. R.U.) | INGV-CT | 7/11 |
| Salvatore Alparone - Researcher | INGV-CT | 2/11 |
| Graziella Barberi - Researcher | INGV-CT | 3/11 |
| Laura Cammarata - Fellowship | INGV-CT | 8/11 |
| Ornella Cocina - Researcher | INGV-CT | 5/11 |
| Salvatore D'Amico - Researcher | INGV-CT | 2/11 |
| Vincenza Maiolino - Researcher | INGV-CT | 4/11 |
| Salvatore Spampinato - Researcher | INGV-CT | 1/11 |
| Orazio Torrisi - Technician | INGV-CT | 1/11 |

- 2nd YEAR OBJECTIVES

4) Integration of Mt. Etna Fault Plane Solution (FPS) databases in the period 1994 –2002.
5) Relevance of Volumetric (V) and CLVD seismic sources and their role in the dynamics of eruptive processes.
6) Mt. Etna Stress and Strain fields characterization in time and space domains.

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

- The delayed start of a fellowship influenced the operation linked to the integration of Mt. Etna FPS database available in the period 1994 – 2002, nevertheless a relevant amount of integrate FPSs are still available and only quality control checks are need. The occurrence of 2001 and 2002 Mt. Etna eruptions induced us to modify our original programs in order to devote a great attention to the relevant scientific problems raised from these eruptive activities. A relevant amount of data was collected and processed in order to obtain FPSs able to determine the evolution of the stress and strain fields at Mt. Etna before and during the two eruptions.
- The entire database collected (1994 – 2002) is underneath to a relocation process using a 3D velocity model, in order to evaluate affordable ray paths in a representative media. Consequently, spurious effects due to unrealistic refraction do not affect evaluated FPSs. Obtained result will be used for inversion of stress (Gephart & Forsyth, JGR, 1984) and strain (Kostrov, IAS,1974) fields, in order to study their evolution in space and in time domains.
- Analyses on seismic activity that have preceded Mt. Etna 2001 eruption were completed and a paper is in preparation. Main result (obtained on the basis of seismicity time-space distribution, FPSs analyses and stress tensor inversion) evidenced a magma intrusion along the NNW-SSE structural trend. The local stress field induced by magma overpressure in the plumbing complex, induced a fragile response of ENE-WSW fault system in the western flank of the volcano at a depth of 5-10 km range. On the contrary, in the eastern flank fragile response occurred at shallower depth (0-5 km) and involved several structural systems.

- After the end of the 2001 eruption, seismicity remained at low level until the beginning of the October 2002 Mt. Etna eruption. The beginning of the eruption was heralded and followed by a powerful seismic swarm. Seismicity spread progressively on the whole eastern flank, involving several structures. Preliminary analyses on seismicity time-space distribution and FPSs, suggest a possible mechanism of the volcano east flank movement in eastward direction, triggered by magma injection in a c.a. N-S eruptive system.
- Data analyses related to moment tensor inversion encountered problems due to the delayed start of a fellowship. At this stage of the project, we were able only to select a data set related to the 2001 Mt. Etna eruption and perform preliminary analyses propaedeutic to data inversion.

- RESEARCH PRODUCTS
  - n° 1 of articles published on international journals
  - presentations at international meetings;
    EGS 2002 – Nice - France
  - presentations at national meetings;
    GNV 2001 - Roma
  - FPS Data bases (1988 –2002)

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Aloisi M., Cocina O., Neri G., Orecchio B, Privitera E. (2002). Seismic tomography of the crust underneath the Etna volcano, Sicily. *Physics of the Earth and Planetary Interiors.* 134, 139-155.

Patané D., Cocina O., Falsaperla S., Privitera E., Spampinato S. (2002). Mt. Etna volcano: A seismological framework. Monograph of American Geophysical Union, “Etna Volcano Laboratory”. In print.

**RU #8 – INGV-CNT - Responsible**
CLAUDIO CHIARABBA, DIRIGENTE DI RICERCA
INGV-CNT

ACTIVITY REPORT–2nd YEAR

RU #8 INGV CNT - PARTICIPANTS

| Name-Position | Affiliation | man/month |
|---|---|---|
| Claudio Chiarabba Dir. Ric. | INGV | 3/12 |
| Milena Moretti Borsista | INGV | 1/12 |
| Pasquale De Gori Ric. A contratto | INGV | 6/12 |
| Piergiorgio Scarlato Ric. | INGV | 4/12 |
| Carmela Freda Ass. Ricerca | INGV | 3/12 |
| Brent Poe Ass. Ricerca | INGV | 3/12 |

- 2nd YEAR OBJECTIVE

Definition of the magmatic feeding system of Mt. Etna employing seismological and petrological data, relationships between seismic deformation and stress field at regional and volcanic scale.
A) Deep strucure: Vp, Vp/Vs, Qp models
B) Seismic deformation: Focal mechanisms for the 1994-2000 seismicity
C) Geophysical parameters of rocks: predict the resistivity of etnean rocks as a function of temperature and degree (and composition) of partial melting

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

- Seismology: The new data recorded during the present day activity have been analyised to refineof P-wave and Vp/Vs velocity models, focused on the upper 5 km. A complete set of high quality focal mechanisms have been computed using the 3D velocity model to study the seismic deformation of the recent years. The very interesting results have been compared with geodetic data and the mechanism of deformation at the volcano has been recognised. A general radial compression around the main high Vp body has been recognized and related to s trong re-pressurization of the volcano since 1994.

The study of attenuation tomography is in progress. Tstar estimates from the velocity spectrum of selected earthquakes have been computed to define a Qp model of the volcano. The technique of analysis have been developed and has been applied to a percentage of the available data.

- Laboratory measurements of electric parameters: We investigated the physical properties of Etnean rocks performing experiments using a multi-anvil apparatus. We measured and compared the electrical conductivity of a primitive basalt and of an ultramafic nodule. The electrical conductivity of the two samples were measured *in situ* at pressures of 900 and 1500 MPa, temperatures ranging from 400 to 1100 °C and frequencies ranging from 0.1 to $10^5$ Hz. In order to investigate the electrical properties of the Etnean products as a function of partial melting, a few experiments were performed in the piston cylinder apparatus prior to the electrical measurements (in the multianvil). The amount and the composition of the glasses in the experimental products were determined by using a scanning electron microscope and an electron microprobe, respectively. Interpretation of impedance spectra indicates that the conductivity of basalt behaves Arrheniusly over the entire temperature range investigated with an activation energy of 0.75 eV. We confirmed that the conductivity is pressure independent. On the contrary, experiments performed using a

partially molten sample indicate that conductivity significantly depends on the quantity of glass and is less dependent on the glass composition. However, when the amount of partial melt increases, the conductivity of the sample increases too. In particular, at the same temperature, the conductivity of sample having 80% of glass is a factor of four higher than the conductivity of a sample with 8% of glass.

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

PUBLICATIONS LIST (inclusive of papers in prints and accepted)

Patane' D., Chiarabba C., Cocina O., De Gori P., Moretti M., and Boschi E., Tomographic images and 3D earthquake location of the seismic swarm preceding the 2001 Mt. Etna eruption: Evidence for dike intrusion, G.R.L., 29, 10,1029-10,1032, 2002.

Taddeucci J., Pompilio M., Scarlato P., Monitoring the esplosive activity of the July-August 2001 eruption of Mt. Etna (Italy) by ash characterization. Geophysical Research Letters., 29, (8), 10.1029/2001GL014372, 2002.

Chiarabba C., De Gori P., and Patane' D., The Mt. Etna plumbing system, The contribution of seismic tomography, AGU monograph "Etna Volcano Laboratory", in press.

Patanè D., De Gori P., Chiarabba C., and Bonaccorso A. (2002), *Uprising mechanisms and magma re-pressurization at Mt. Etna volcano* (2002). Science, accepted.

- presentations at international meetings:

Scarlato P., Poe B., Freda C., Gaeta M.. *HP-HT measurements of electrical conductivity in basaltic rocks from Mt. Etna (Sicily, Italy)* Geophysical Research Abs. 4. 27th General Assembly of the European Geophysical Society. Nizza, 21-26 aprile 2002