GRUPPO NAZIONALE PER LA VULCANOLOGIA

2000-2002 Frame Program - Second Year Report, December 2002

TITLE OF PROJECT: Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

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RESEARCH LINE: Phlegrean Fields

LENGTH OF PROJECT: 3 years

RESEARCH UNITS:

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2. Mauro Rosi, Dipartimento di Scienze della Terra, Università di Pisa
3. Claudia Romano, Dipartimento di Scienze Geologiche, Università Roma Tre
4. Augusto Neri, Istituto di Geoscienze e Georisorse, CNR Pisa
5. Malcolm J. Rutherford, Department of Geological Sciences, Brown University, RI, USA
6. Donald B. Dingwell, Department of Earth and Environmental Sciences, University of Munich, Germany

Other key participants (task responsibles):

Don Baker, McGill University, Montreal
Antonella Bertagnini, INGV Pisa
Carmela Freda, INGV Roma
Patrizia Landi, INGV Pisa
Margherita Polacci, INGV Pisa

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Summary

Project activities

The project activities during the second year of project have continued in substantial agreement with the executive plan approved by the GNV Evaluation Committee. At the end of second year, all tasks (with the exception of one) have been accomplished well above the 50% threshold which has been indicated by the GNV as the necessary one for successful projects, and some of them have fully accomplished their 2nd year objectives. This in spite of severe delay in project funding, that in some cases caused troubles that we were able to face thanks to close cooperation between Research Units in performing the project research and sharing the related costs.

Close coordination between Research Units has been maintained during the second year of project, as during the first year. Relevant results from different RU's and different tasks have been shared between all the potentially interested project participants, allowing significant advancement in the overall project research. A one-day project meeting was held in Pisa on September 26, 2002, in order to share results between all the participants, outline possible project difficulties, discuss their solution, and plan the next research. A summary of the main outcomes of the meeting is included below.

Differently from the first year, we were not able to organise inter-project meetings, although this was recommended by the Evaluation Committee. This was due to the attitude of many coordinators of other GNV projects who expressed strong concerns about the delays in project funding, and decided not to participate to such meetings unless the time schedule for funding was respected by the GNV and by the Civil Protection. Most of the e-mails between coordinators concerning this point were sent to the GNV director, Prof. Paolo Gasparini, for his knowledge. Together with him, we have decided to make new efforts to organise inter-project meetings during the third year of project. We still outline the necessity that a single synthetic final document be produced for Civil Protection purposes, including the main results and recommendations from all the projects dedicated to Phlegrean Fields, but we also stress the necessity that project funding be kept at deadlines useful for performing the research within the indicated schedule.

Project results

A summary of main project results is included in the Report on the 2nd Year Project Meeting attached below, as well as in the Project Activity Report also included.

Project outcomes

Apart from one exception, none of the participants to the present project had never published or even worked on Phlegrean Fields eruptions. Therefore, most of the scientific papers produced in the frame of this project are still submitted or under preparation. To-date the project has produced or contributed to 13 papers published or in press in international journals, and to additional 6 papers which are at present under review for publication in international journals. During the year 2002, 28 presentations at international scientific meetings have originated from this project. We have also produced one general technical report (1st year GNV report), one database of scientific publications on Phlegrean Fields published in the GNV web site, and one new computer code for the determination of multicomponent volatile saturation in silicate liquids. We foresee that most publications will be produced during the third and following years from the beginning of project.

New project developments

A few months ago, a new project for measuring magma viscosities with innovative techniques involving high pressure experiments and in situ visualization through synchrotron radiation has been submitted to the GNV by the HP-HT laboratory group at the INGV in Rome. This new technique would allow obtaining hydrous viscosities at close-to-eruptive temperature, which are to-date not routinely measured due to the impossibility of taking the water dissolved in the liquid for the time required by the experimental measurement. The project was focused on the analysis of trachytic magmas from Phlegrean Fields, due to the great interest for Civil Protection purposes as outlined in the present GNV Frame Project. The GNV decided not to consider the project for immediate funding, as all the projects should be funded in correspondence of the official annual project deadlines. However, due to the great interest of the proposal, and considering its great relevance for the present project and the perfect matching with some of its research tasks, in particular task 2.2 which is devoted to viscosity determinations with standard techniques and at complementary P-T-H_2O conditions, the GNV Director Paolo Gasparini suggested that the proposal be incorporated among the third year objectives of the present project. We accept his suggestion, and remark the importance of this new research for the present project objectives. The new research from the HP-HT laboratory group at the INGV in Rome is therefore added to the third year objectives of the present project reported in the included Executive Project for the Third Year. Accordingly, we also propose to expand further the number of Research Units in the project, by adding a new one constituted by the HP-HT laboratory group of INGV-Rome, and to include a new task (2.7) devoted to viscosity determinations on natural magma compositions from Phlegrean Fields with the synchrotron technique. The new task 2.7 is detailed in the Executive Project below, and includes the related financial request which is added to the general financial request of the project for the third year.

Project funding

During the first year of project we outlined the difficulties encountered due to too severe initial financial cut-off (50%), and asked an increase of budget for the second and third year of project. In detail, we proposed an increase from 150 ML (millions of lira) to 300 ML for the second year, and from 150 ML to 250 ML for the third year. Our request was partly granted by the EC, and we received 235 ML for the second year research. This allowed most of the foreseen research activities to be performed, although with limited resources requiring again the availability of many of us to partly fund the research with other resources. In general, the project is still left with a very severe cut-off as compared with the proposed research which was instead accepted *in toto*. For the third year of research, and according to our request of last year, we ask that the project budget be increased to 250 ML (about 130 keuros), plus 30 keuros corresponding to the request for the new proposed research at task 2.7 (see above, the Request of addition of a new RU and new research task, and the Executive Plan and Financial Request for third year, included below).

Report on the 2nd – year project meeting
(also a summary of the main project results)

The second year project meeting was held on September 26, 2002, at the INGV building in Pisa. The meeting lasted one day, and saw the participation of the project coordinator P. Papale, the RU responsibles A. Neri, M. Rosi, M.J. Rutherford, and D.B. Dingwell, the task responsibles P. Landi, A. Bertagnini, C. Freda, M. Polacci, and D. Baker, the project participants P. Scarlato, A. Longo, D. Giordano, A. Di Muro, the PhD students L. Pioli, T. Esposti Ongaro, D. Del Seppia, and S. Arrighi, the grant student G. Chirico, the undergraduate students C. D'Oriano, E. Poggianti, and G. Luciani, and R. Cioni.

The aim of the meeting was that of sharing results, discussing difficulties, and planning the next research. The meeting was organized in a series of talks reflecting the tasks in the project, with the addition of a presentation by R. Cioni who showed the results of a recent study at the Rabaul caldera, New Guinea, which shares many similarities with the Phlegrean Fields caldera, and which represents one of the very few cases in the world of recent and witnessed caldera eruption.

P.Papale introduced the meeting, up-dated the funding situation and main next GNV appointments, and gave a brief summary of the main research results obtained during the first year of project.

M. Rosi, A. Bertagnini, P. Landi, C. D'Oriano, and E. Poggianti (Tasks 1.1 and 2.1) presented the results of further field investigation of the Agnano Monte Spina eruption, and of field, sedimentological, and mineralogical investigation on the Monte Nuovo eruption. Lower and upper members of the Agnano Monte Spina eruption, that had been interpreted in the literature as being the result of phreatomagmatic and pyroclastic surge currents, have been studied in detail in the field, for their implications in the hazard. These deposits present characteristics which are more consistent with a fallout rather than flow origin. Therefore, the strong implications that were called upon in the literature for the long-distance hazard from phreatomagmatic pyroclastic surges do not seem to be justified. The deposits of the Monte Nuovo eruption were divided into a Lower and an Upper member. The characteristics of the former suggest pulsating hydromagmatic activity at their origin, while the latter appears to be related to prevalent magmatic activity. Major and trace analysis, and mineral and glass chemistry, of the Lower and Upper Member products were performed. Although through the entire sequence the bulk chemistry varies only moderately, and the mineral chemistry is substantially homogeneous, the glass composition varies significantly as a result of different microlite content at different stratigraphic layers. The variations in the content and composition of microlites in the groundmass of the products of LM and UM, associated with textural variations, suggest syneruptive processes of crystallization mainly due to different degassing modes, related to changes in the eruptive dynamics.

M.J. Rutherford (Task 2.3) presented the results from his recent investigation of the pre-eruptive

conditions for the Agnano Monte Spina eruption of Phlegrean Fields, this one being the eruption on which most of the studies within the project are focused, as from the Project Executive Plan. One of the major point of discussion was represented by the great difficulties in obtaining an estimate of the total amount of volatile species present in the magma chamber before the eruption. There is no standard way to get to these numbers at present in the international literature, especially for ancient eruptions for which no data on the gas plume are available. On the other hand, the numerical simulations demonstrate that the total volatile content (including dissolved and possibly exsolved volatiles) exerts a strong control on the eruption dynamics. We have therefore started working on the definition of a new integrated technique involving numerical simulations of the thermodynamic multicomponent equilibrium between liquid magma and gas and ad hoc experimental petrology runs to get to a best estimate of total volatile contents. We plan to make this investigation during the third year of project. M.J. Rutherford also reported on the new experimental runs he did, which allow a better estimate of P-T-fO2 conditions in the magma chamber prior to the eruption, and that will constitute the input for next numerical simulations of magma ascent and dispersal dynamics. Carbon dioxide and minor volatile species like F, Cl and S appear to have been present in the Agnano Monte Spina magma in significant quantities. *Ad hoc* experimental determinations of the solubility of volatiles in trachytic magmas, which are being planned by M.J. Rutherford and by D. Baker (see below), will allow the inclusion of these volatile species in future numerical simulations of magma ascent and fragmenation planned for the third year of project.

D.B. Dingwell and D. Giordano (Tasks 2.2 and 2.4) presented the results of recent experimental investigation on the viscosity and fragmentation conditions of trachytic magmas from the selected eruptions of Phlegrean Fields. His group completed the low-to-high T, dry and hydrous liquid viscosity determinations included in the executive project, but they couldn't perform the investigations for the crystal-bearing magmas, since the acquisition of the new instrumentation for this aim took more time than foreseen. However, they have now received the new instrumentation and begun to install it, and they have guaranteed that they will make all their efforts to develop that part of the research during the third year, together with the investigation initially planned for third year of project. D.B. Dingwell showed a new modelling of the anhydrous viscosity of natural magmas as a function of temperature and composition, that he developed together with D. Giordano in the frame of the present project. Such a new modelling is very promising and absolutely needed, since at present there is no general model in the literature for liquid magma viscosity, this being a crucial quantity in determining the dynamics of volcanic eruptions. P. Scarlato and P. Papale introduced an additional proposal by the HP-HT laboratory group in Rome, and which consists in measuring in-situ HT hydrous viscosities with synchrotron techniques. D.B. Dingwell found this proposal of great relevance, and declared his availability to help the proponents in developing that within the frame of the present project. D.B. Dingwell also showed the results of fragmentation experiments for the trachytic magmas of Phlegrean Fields, and compared them with similar results on a variety of different natural compositions. The trachytic magmas from Phlegrean Fields show a relatively large pressure treshold required for fragmentation, a result which was not expected. We are now planning new appositely designed numerical simulations to investigate the possible importance of this result for the fragmentation and eruption dynamics at Phlegrean Fields. Finally, D.B. Dingwell told us of additional experimental determinations, not initially included in the executive plan of the project, of the dry and hydrous constant pressure specific heat of trachytes from Phlegrean Fields. This quantity is of crucial importance for a next extension of the magma ascent modelling to include non-isothermal flow conditions along volcanic conduits. The hydrous Cp data obtained are among the very few data of this kind which are to-date available in the literature for natural magmas of any composition.

C. Freda and D. Baker (Task 2.5) reported on their recent experimental determinations of the water and carbon dioxide diffusion coefficients in the trachytic magma from the Agnano Monte Spina eruption. Water diffusion at eruptive temperatures turns out to be comparable to that in rhyolitic magmas at the same temperature, but with a larger activation energy resulting in more pronounced increase with increasing temperature, up to values at high temperature comparable to water diffusion in basaltic magmas at the same temperature. The experiments pertaining to carbon dioxide diffusion are being now analysed in order to get numbers. They also reported of some experiments with carbon dioxide which revealed the formation of a front of gas bubbles at a given distance from the CO_2 source in the experiments, constituted by a crystal of calcite. These experiments should contribute to understand the relationships between CO_2 solubility in trachytic magmas and CaO content, the latter being known as the component of silicate liquids which mostly affects CO_2 solubility. New ad hoc experiments on the water and carbon dioxide solubility in trachytic magmas from Phlegrean Fields, which were not initially included in the executive project, are being planned for the third year of project. These experiments, together with others similar which are planned by M.J. Rutherford, will allow more confident simulations of magma ascent to be done during the third year of project.

M. Polacci (Tasks 2.6 and 3.1) reported on recent determinations of the textural characteristics of pumice from trachytic eruptions at Phlegrean Fields, as compared to the same characteristics in more widespread rhyolitic and dacitic pumice. The results show similar classes of pumice in the two compositional groups. These classes are distinct on the basis of macroscopic and microscopic features of pumice. Three main types of pumice are found in both trachytic and rhyolitic/dacitic pumice, namely, microvesicular, tube, and expanded pumice. The different pumice types are interpreted to originate as a consequence of horizontal distribution of flow conditions in volcanic conduits, with the most abundant microvesicular pumice reflecting conditions in the central part of the conduit, and the expanded pumice being generated by processes related with viscous dissipation at the conduit walls. Tube pumice would be generated at intermediate regions where the velocity gradient becomes predominant over the temperature gradient due to viscous dissipation close to the walls. The characteristics of the expanded pumice can be very different in rhyolitic and trachytic magmas, possibly due to the very different viscosity vs. dissolved water patterns at low dissolved water contents less than 1 wt%. The importance of viscous dissipation in the dynamics of magma ascent can be extremely large, deeply modifying the mass flow-rate of an eruption, and extending the range of conditions where steady eruptive phases can occur. M. Polacci also compared the vesicularity of microvesicular pumice from rhyolitic and trachytic eruptions, and found that although similar, the vesicularity in trachytic pumice tends to be slightly larger, a result which is in full agreement with the results of numerical simulations of magma ascent and fragmentation. To show this, M. Polacci also presented the results of numerical simulations, made in cooperation with P. Papale and D. Del Seppia, and with D. Giordano and C. Romano who defined appropriate constitutive equations for magma viscosity for the two different compositions. In these simulations, the conditions along volcanic conduits pertaining to rhyolitic and trachytic magma flow have been systematically compared. Any other condition being equal over an investigated range covering conduit diameters from 30 to 90 m, and total water contents from 2 to 6 wt%, fragmentation of rhyolitic magma was found at magma vesicularities in the range 0.65-0.75, and that of trachytic magma in the range 0.80-0.85. The complex, non-linear relationships between mass flow-rate and magma composition were also investigated, and the unexpected (but subsequently well understood) result that low-viscosity trachytes can be associated with lower mass flow-rates has been described.

P. Papale (Task 3.1) reported on the results of numerical simulations of magma ascent dynamics performed during last year of project. Three groups of simulations were performed, in addition to those performed during the first year. The first group of eighteen new simulations was aimed at completing the systematic comparison between the dynamics of rhyolitic and trachytic eruptions that was started during the first year of project. The results of this part of the study have been presented by M. Polacci (see above). The second group of six simulations was aimed at investigating the possible roles of carbon dioxide in the dynamics of the Agnano Monte Spina eruption. Carbon dioxide is found to have been an important volatile component in this eruption (see presentation above by M.J. Rutherford). These simulations were coupled with those of gas-particle dispersion dynamics in the atmosphere presented by A. Neri (see below), in order to get a picture of the whole eruption dynamics involving water plus carbon dioxide bearing magma. These are the first coupled numerical simulations of conduit flow and atmospheric dispersal for CO_2-bearing magmas ever done. The conduit flow simulations show that due to very low CO_2 solubility in the AMS magma at magma chamber P-T conditions, even large amounts of this volatile species in the AMS magma could not be seen in glass inclusions formed in the magma chamber.

Conversely, even small amounts of CO_2 result in the separation of a gas phase in the magma chamber, and in important changes in the distribution of the flow variables along the volcanic conduit. These changes are due to the large effect that the presence of a relatively insoluble volatile species like CO_2 has on the water content at saturation. In particular, the magma fragmentation level largely deepens with the addition of small amount of CO_2 to the erupted magma, whereas the magma vesicularity at fragmentation is substantially unaffected by the presence of CO_2. In spite of such big changes in the deep conduit flow, the upper conduit and vent conditions, as well as the conduit diameter consistent with the mass flow-rate of the eruption, are only slightly affected by the presence of CO_2. The third group of twelve simulations was aimed at investigating the conduit dynamics for conditions pertaining to the Plinian phase of the Campanian Ignimbrite eruption. Magma discharged during this eruption was hotter and less viscous than the AMS magma, as reported in the literature and according to the viscosity measurements and parameterisations done within the present project, and the conduit length was probably no more than 3-4 km. The results of the simulations show that these differences are sufficient to explain the one order of magnitude increase of the mass flow-rate from the AMS to the CI eruption, without the necessity to invoke the presence of a much wider magma chamber as from the literature. Since mass flow-rate is a crucial parameter for the definition of the volcanic hazard from explosive eruptions, with one order of magnitude changes associated with enormous differences in the areas affected by highly hazardous phenomena, it follows that knowledge of the kind of magma within the present magma chamber, and of its depth, is strictly needed for a proper assessment of the volcanic hazard. Numerical simulations pertaining to the CI eruption also revealed the possibility of a totally unexpected and previously never described phenomenon in the dynamics of conduit flow during explosive eruptions. This phenomenon is related to the short conduit for such an eruption involving relatively low-viscosity magma, and consists in an inverse relationship between the total water content of magma and the mass flow-rate of the eruption. A positive relationship between water content and mass flow-rate has been always found in all the to-date published numerical simulations of magma ascent, including those from this group. Now, we can demonstrate that in some particular conditions that can be attained during eruptions at Phlegrean Fields, an opposite relationship can hold. We have therefore planned for the third year of project a more systematic and more thorough investigation of the relationships between mass flow-rate, conduit size, and water content in trachytic, rhyolitic, and basaltic eruptions, in order to get to a general picture of the possible importance of this phenomenon in the dynamics of volcanic eruptions.

A. Neri and T. Esposti Ongaro (Task 3.2) reported on the simulations of gas-particle dispersal that have been performed during the second year of project. These simulations can be divided into three groups. The first group was aimed at investigating relevant aspects of the dynamics of transitional style explosive eruptions, like the Agnano Monte Spina eruption at Phlegrean Fields. These eruptions are characterized by the contemporaneous presence of a buoyant gas-particle plume above the vent and of pyroclastic flows produced by volcanic column collapse, and produce deposits with typical intermingling of fallout and flow layers. These deposits have been described in the sequence of the Agnano Monte Spina eruption in the course of the research performed during the first year of project. In particular, the simulations were aimed at defining the factors that produce different distribution of mass of particles between the different regions of a transitional style volcanic column. Such simulations allowed to better understand the dynamics of columns at the transition between the buoyant and collapsing regimes. Such a transitional regime is characterized by greater collapse height, generation of dilute density currents, shorter flow runout, less steady behavior of the column, and intermittent feeding of the flows. The second group of simulations was aimed at advancing the study of the coupled dynamics of conduit flow and atmospheric gas-particle dispersion for the Agnano Monte Spina eruption. Such an investigation had started during the first year of project, and involves simulating the eruptive conditions for two distinct phases of the eruption, each characterized by two end-member values of mass flow-rate and by three possible water contents from 2 to 6 wt%. Simulations results obtained with water content between 4 and 6 wt% substantially agree with the indication of transitional eruptive style inferred from independent volcanological studies. Water content values lower than 4 wt% produce substantially fully collapsing columns whereas values of 6 wt% produce a buoyant column. These results appear to be relatively independent on the value of mass flow-rate within the range considered for each eruptive phase. The third group of simulations was aimed at investigating the coupled conduit flow and gas-particle dispersion dynamics still for the Agnano Monte Spina eruption, but by considering the presence of carbon dioxide besides water in the magmatic volatiles. Surprisingly, it was found that the addition of even 2 wt% carbon dioxide does not appear to modify significantly the style of the eruption (collapsing, transitional, or buoyant), although it produces large changes in the dynamics of magma flow in the deep conduit region far from the volcanic conduit exit.

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

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ACTIVITY REPORT –2nd YEAR

PROJECT PARTICIPANTS

RU# 1	Istituto Nazionale di Geofisica e Vulcanologia, sez. Roma1, sede di Pisa	Responsible: Paolo Papale
RU# 2	Dipartimento di Scienze della Terra, Università di Pisa	Responsible: Mauro Rosi
RU# 3	Dipartimento di Scienze Geologiche, Università Roma Tre	Responsible: Claudia Romano
RU# 4	Istituto di Geoscienze e Georisorse, CNR Pisa	Responsible: Augusto Neri
RU# 5	Department of Geological Sciences, Brown University, RI, USA	Responsible: Malcolm J. Ruherford
RU# 6	Department of Earth and Environmental Sciences, University of Munich	Responsible: Donald B. Dingwell

GENERAL OBJECTIVES

The objective of the present research is the quantitative definition of volcanic scenarios at Phlegrean Fields caldera (Italy). Reference volcanic eruptions are selected in the past history of the volcano, and are represented by Campanian Ignimbrite (36 ka), Agnano Monte Spina (4400 BP), Astroni (3700 BP), and Monte Nuovo (1538 AD). These eruptions cover ranges of magnitude and intensity that encompass the entire activity of Phlegrean Fields. The Agnano Monte Spina eruption represents the Maximum Expected Event (GNV website, March 1999), and it is therefore selected for deep investigation in the project. The Campanian Ignimbrite eruption, and the two more recent Astroni and Monte Nuovo eruptions, represent cases with larger and lower intensity, respectively.

The project objective will be achieved through the realization of the following groups of tasks:

1. Field Studies.

   Field studies are directed to the selection of stratigraphic layers of major interest in the project, reconstruction of their stratigraphy and dispersal, sampling for laboratory studies, and comparison with the results of numerical simulations. Layers that will be selected include deposits produced during pyroclastic fallout and flow phases of the eruptions.

Task 1.1 Selection of stratigraphic layers of major interest for the project, reconstruction of their stratigraphy and dispersal, and sampling

Responsibles: Mauro Rosi, Antonella Bertagnini
Collaborators: Patrizia Landi, Margherita Polacci, Andrea Di Muro, Paolo Papale

2. Laboratory Studies.

Laboratory studies are directed to the determination of physical, chemical, rheological and petrological properties and behavior of samples from the selected stratigraphic layers, reconstruction of conditions prior and during the eruptions, and definition of constitutive equations for use in numerical simulations.

TASK 2.1: Petrochemical study of volcanic products

Responsibles: Patrizia Landi, Mauro Rosi
Collaborators: Antonella Bertagnini, Margherita Polacci

TASK 2.2: Determination of magma viscosity

Responsibles: Claudia Romano, Donald B. Dingwell
Collaborators: Daniele Giordano, Brent Poe, Lucio Costa

TASK 2.3: Experimental Petrology Studies

Responsible: Malcolm J. Rutherford
Collaborators: Angela Roach

TASK 2.4: Experimental determination of magma strength and fragmentation behavior

Responsible: Donald B. Dingwell
Collaborators: Oliver Spieler, Margherita Polacci

TASK 2.5: Determination of volatile diffusivity

Responsibles: Carmela Freda, Claudia Romano
Collaborators: Don Baker, Piergiorgio Scarlato, Paolo Papale

TASK 2.6: Textural characterization of pyroclasts

Responsibles: Margherita Polacci, Mauro Rosi, Paolo Papale
Collaborators: Patrizia Landi, Laura Pioli

3. Numerical Studies.

Numerical studies are directed to the simulation of the multiphase dynamics of magma ascent, degassing, fragmentation, acceleration, and dispersion in the atmosphere and along pyroclastic flows.

TASK 3.1: Numerical simulations of magma ascent dynamics

Responsible: Paolo Papale
Collaborators: Margherita Polacci, Augusto Neri, Antonella Longo, Dario Del Seppia, Daniele Giordano

TASK 3.2: Numerical simulation of gas/pyroclast dispersion processes and pyroclastic flow dynamics

Responsible: Augusto Neri
Collaborators: Paolo Papale, Tomaso Esposti Ongaro, Andrea Di Muro, Dimitri Gidaspow, Mauro Rosi

The final product of the proposed research is represented by the quantitative definition of eruptive scenarios at Phlegrean Fields, with particular emphasis on the description of the Agnano Monte Spina eruption which represents the maximum expected event at Phlegrean Fields. This will provide a basis for a quantitative definition of the volcanic hazard at Phlegrean Fields, and a reference for the forecasting of volcanic risk.

TASK 1.1 - SELECTION OF STRATIGRAPHIC LAYERS OF MAJOR INTEREST FOR THE PROJECT, RECONSTRUCTION OF THEIR STRATIGRAPHY AND DISPERSAL, AND SAMPLING

Responsibles: Mauro Rosi, Antonella Bertagnini
Collaborators: Patrizia Landi, Margherita Polacci, Andrea Di Muro, Paolo Papale

- RU PARTICIPANTS: RU2

- II YEAR OBJECTIVES

Stratigraphy, grain-size, componentry and sampling of the deposits of Monte Nuovo eruption; stratigraphy and sampling of the deposits of the Astroni eruption.

- II YEAR RESULTS

Agnano Monte Spina. Additional information has been acquired on the tephra succession of AMS. Previous researches have allowed grouping the AMS pyroclastic deposits in three members (Lower, Middle, Upper). Particular emphasis has been laid on ash beds of the Lower Member (layer A1 of De Vita et al., 1999) and of the Upper Member (layers E1, E2, E3 of De Vita et al., 1999), because of the significant hazard implications arising from their interpretation. In fact, according to De Vita et al. (1999), ash layer A1 has been interpreted as the deposit of an initial phreatomagmatic base surge with a NE dispersion reaching the city of Naples. Layers E are dispersed towards N-NE and have been interpreted as a sequence of fall and pyroclastic surge deposits able to reach the town of Aversa (De Vita et al., 1999). This interpretation had been questioned during the first year report. Therefore, key stratigraphic sections have been identified in the NE and NNE areas to analyse in detail the sedimentologic features of these deposits. Outcrops are located between 2 and 4 km at NE and at distances >4 km at N-NE respect to the centre of the caldera of Agnano.

The fine-ash layer A1 is sandwiched between a thin swarm of < 1 cm angular pumices at the base and a thicker lapilli fallout bed at the top (A1 fall). The A1 lapilli fall bed has been interpreted as the deposit of a very low (5 km) convective column by De Vita et al. (1999). The thickness of the A1 ash bed regularly decreases with distance from the vent area and does not increase in small- or large-scale topographic lows. The main features of the ash layer remain constant in all the observed outcrops. The layer contains <1cm large accretionary lapilli, vesiculae and uncharred leaves, which lay subparallel to the ground. A few angular pumice lapilli can also be observed dispersed in the fine-ash matrix.

The E succession is built up by a sequence of 1) dm- to cm-thick fine to coarse ash beds characterised by a plane parallel lamination and 2) cm-thick fine lapilli layers. The thickness of the E sequence does not increase in topographic lows and decreases with distance from the vent. Low-angle and small-amplitude cross-bedding, lensoid beds of angular to subrounded pumices in ashy matrix can locally be observed. These beds are laterally discontinuous and their sedimentological features (wavelength, waveheight, grain-size) do not show a clear negative relationship with increasing distance from the source.

On the whole, the studied layers do not show clear evidence of having been deposited by laterally moving currents. In particular, areal dispersion, thickness variation with distance and sedimentologic feature indicate that the described ash and fine lapilli layers can have been deposited by fallout activity from low intensity convective columns. Furthermore, the presence of uncharred vegetation and accretionary lapilli point out to a low temperature (<100°C) of the depositing medium.

Monte Nuovo. The cone of Monte Nuovo was built during the last eruption of Phlegrean Fields in 1538. This year, three field trips, grain-size and componentry analyses and analytical scrutiny of contemporary accounts were performed in order to reconstruct stratigraphy of deposits, eruptive dynamics and timing of the eruption.

Monte Nuovo is a tuff cone, 119 m high, slightly asymmetrical. The main feature is a horseshoe structure on the southern slope, 450 m large. The dispersal of the eruptive products is rather limited, the most distal recognized outcrops being about 1 km from the crater.

A lower (LM) and upper member (UM) have been recognized. Mud-flow deposits and an erosion surface with gullies mark the boundary between the deposits of the LM and UM.

The LM is mainly made up of massive to cross bedded ash and pumice deposits emplaced by pyroclastic density currents, alternating with accretionary-lapilli-rich ash fall layers. Medium sorted, rather continuous, clast supported pumice fall layers are present at different levels. Ballistic blocks and pumiceous bombs up to tens of decimetres are common and increase in the upper part of the sequence. Non juvenile material is scarce and surficial, being mainly constituted of fragments of yellow tuffs and pumice of the Averno eruption. On the whole the characteristics of deposits and some textural features such as presence of accretionary and armored lapilli, vesiculated tuffs suggest that the first phase of the eruption was dominated by pulsating, hydromagmatic, low-energy explosions originated by interaction with sea water and/or shallow aquifers.

The UM consists of two main units which form the uppermost part of the Monte Nuovo cone and show a fairly radial dispersal. They are coarse, dark grey deposits with variable matrix content, mostly made up of juvenile clasts with variable density and vesicularity (see task 2.6). The characteristics of deposits suggest that they were emplaced through prevalent pyroclastic flow dynamics, and were originated by violent explosions of a magma plug, driven by exsolution and expansion of magmatic volatiles.

Research Products

Two degree theses at Dipartimento di Scienze della Terra, University of Pisa:

- The Monte Nuovo eruption (Phlegrean Fields,1538 A.D.): reconstruction of the first eruptive phase by means of textural and compositional studies of the emitted products (C. D’Oriano)
- The Monte Nuovo eruption (Phlegrean Fields,1538 A.D.): reconstruction of the second eruptive phase by means of textural and compositional studies of the emitted products (E. Poggianti)

TASK 2.1 - PETROCHEMICAL STUDY OF VOLCANIC PRODUCTS

Responsibles: Patrizia Landi, Mauro Rosi
Collaborators: Antonella Bertagnini, Margherita Polacci

- RU PARTICIPANTS: RU2
- II YEAR OBJECTIVES

  Analyses on samples from Monte Nuovo eruption, to an advanced stage; MI studies on samples from Campanian Ignimbrite and Agnano Monte Spina eruptions.

- II YEAR RESULTS

Monte Nuovo eruption**.** Whole rock chemical analyses of major elements, by XRF, were performed on 21 samples collected from base to top of the eruptive sequence. Fifteen of them were selected for trace elements analyses (by ICP-MS). Mineral chemistry and compositions of microlites and glasses of the groundmass were performed on two samples of the Lower Member (LM) and three of the Upper Member (UM) (see task 2.1).

All the products are trachytes/phonolites ($SiO2$=60.8-62.2 wt%; $Na2O+K2O$=12.3-14.3) with slight peralkaline chemistry, and show subaphyric texture with rare phenoceysts (<4-5 vol%) of K-feldspar and subordinate amphibole, clinopyroxene, oxide and sphene. Plagioclase is found as crystals with large rims of K-feldspar, and in aggregates of crystals together with K-feldspar, oxide and sphene. Such aggregates, even if rare, are mainly found in the pumice of the LM. The groundmass ranges from glassy with scarce microlites of K-feldspar in vesiculated pumice, to nearly holocrystalline with abundant microlites of feldspars, up to 300-400 µm, and grains of oxides in scoriae of the final activity. The cristallinity of the groundmass appears related to the vesicularity of the products (see task 2.6).

As a whole, the erupted products cover a narrow compositional range (for ex. CaO=1.50-1.82 wt%; MgO=0.16-0.51 wt%; Zr=890-980 ppm; La=169-185 ppm; Sr=3.8-17.8 ppm;).

Mineral chemistry appear homogeneous through the entire sequence and consists of: K-feldspar Or 62-70, ferropargasitic amphibole, oxide Usp 32-33, clinopyroxene Fs 20.5-23.5, sphene with TiO2=35-36 wt% and plagioclase both as crystal with antirapakivi texture An27-35. Crystals in aggregates have the same composition than the single crystals.

Preliminary analyses of the groundmass highlight a wide compositional range of the matrix glasses, as a result of different crystallinity. Average compositions range from SiO2=59.3, Na2O+K2O=14.7 in the pumice of the Lower Member, to SiO2=57, Na2O+K2O=15.4 in the scoriae of the Upper member (Fig. 1). Feldspar microlites range in composition from Or20-25, An18-22 to Or55-60, An4-5 and, compared with those of the scoriae of the UM, mirolites of the pumice of the LM show higher content of CaO (Fig. 2).

The variations in the content and composition of microlites in the groundmass of the products of LM and UM, associated with textural variations (see task 2.6), suggest syneruptive processes of crystallization mainly due to different degassing mode, related to changes in eruptive dynamics.

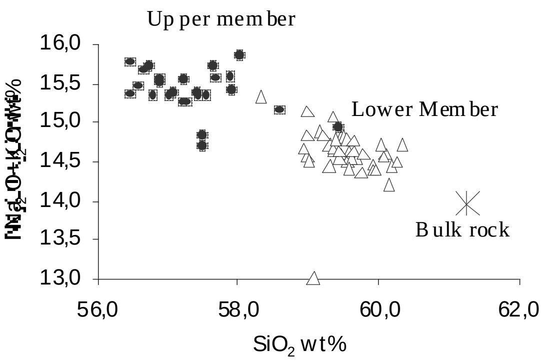


Fig. 1: chemical compositions of the matrix glasses

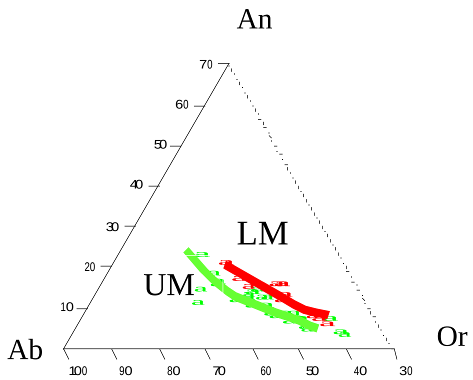


Fig.2: Compositions of groundmass microlites in pumice of the Lower Member and scoriae of the Upper Member.

Research products

Two degree theses at Dipartimento di Scienze della terra – Univ. Pisa

- The Monte Nuovo eruption (Plegrean Fields 1538): reconstruction of the first eruptive phase by means of compositional and textulal studies of the emitted products (Claudia D'Oriano)
- The Monte Nuovo eruption (Plegrean Fields 1538): reconstruction of the second eruptive phase by means of compositional and textulal studies of the emitted products (Elisa Poggianti)

TASK 2.2 - DETERMINATION OF MAGMA VISCOSITY

Responsibles: Claudia Romano, Donald B. Dingwell
Collaborators: Daniele Giordano, Brent Poe, Lucio Costa, Valeria Misiti

- RU PARTICIPANTS: RU3, RU1

- II YEAR OBJECTIVES

Parameterization of rheology of crystal-bearing magmas.

- II YEAR RESULTS

Introduction. In the second year of activity, Newtonian viscosities of dry and hydrous natural liquids representative of the glassy matrices of products from Monte Nuovo (MNV) and Astroni eruptions were measured. Results of this task (2.2) were also used to simulate ascent of magma along conduit (TASK 3.1) providing new interesting insight to the fluid dynamic behaviour of different magmatic suites.
As the milestones of this year project could not be fully accomplished because of delay due to the setup of the new uniaxial press necessary to investigate the multi-phase rheology, new additional elements were investigated. In this new study, we determined the isobaric heat capacities of dry and hydrous liquids for products of Monte Nuovo, and Ignimbrite campana. The isobaric heat capacity of silicate melts (Cpl) is in fact a very important property of interest for thermal modelling of magmatic processes, phase equilibria calculations, or theoretical investigations of physical properties of liquids (Courtial and Richet, 1993; Yoder 1976; Carmichael et al. 1977). The new uniaxial press will be operative starting from March 2003, and at the time the multi phase rheology will be investigated for the products from Monte Nuovo Astroni and Campanian Ignimbrite and Agnano Monte Spina.

Methodologies, Data acquisition, Data processing and interpretation. Pumice samples were collected by hand-picking from the fallout deposits. The general reasons and the localities of this sampling may be found in TASK 1.1. The samples selected were processed and analysed separately as it follows.

Glasses were separated from the coarsely crashed samples of the selected total rocks with the aid of a binocular microscope. The melts used in this study were then generated by fusion and homogenisation by stirring of the thus separated trachitic glass matrices at 1 atm and 1400-1650 °C. The high temperature anhydrous viscosities were determined, for the different samples, in a temperature range between 1500 and 1150 °C and for a log viscosity range (Pa s) from 2.45 to 4.55 using methods described by Dingwell and Virgo (1988).

The anhydrous glass compositions were analysed by electron microprobe. After the concentric-cylinder experiments, the glasses were retrieved by drilling and used for the hydration experiments. For each composition, three to five glasses with different water contents (H_2O = 0.73 to 3.86 wt%) were synthesised at T = 1600 °C and P = 10 kbar in a piston cylinder apparatus for several hours, in order to ensure dissolution and homogenisation of water into the melt. The quenched hydrous glasses (quench rate from dwell T to Tg of order 100 °C/sec) were then recovered and prepared for micropenetration viscometry, infrared spectroscopy and Karl-Fisher Titration (KFT). Dissolved water contents ranged from dry to 3.86 wt%.

The low temperature viscosities were measured using a micropenetration technique. The high viscosity measurements were performed in the viscosity range between $10^{8.76}$ to $10^{11.6}$ Pa s, and in a temperature range between 385 and about 831 °C. The viscosities are reproduced within an error of $\pm$ 0.06 log units (see Hess et al., 1995). The total water content, homogeneity and stability of the samples were also measured by KFT and FTIR spectroscopy. Samples were analysed before and after each viscosity measurement to check for water loss during viscometry. The absolute H_2O content was measured by using the Karl-Fisher titration (KFT) methods, whereas the homogeneity was controlled by measuring absorbances pertaining the 4500 cm^{-1} and 5200 cm^{-1} bands. In order to calculate the water content from the measured absorbances, thickness and density of each samples were also measured. The thickness of each glass plate was measured with a digital Mitutoyo micrometer (precision ± 3.10^{-4}). Densities of the anhydrous glasses and for some of the hydrous glasses were determined by weighing in air and in ethanol using a Mettler Toledo AG 204 balance. Uncertainties are estimated to be ± 0.05 g/l. A polynomial expression for densities has been obtained by a least-squares regression method. Results of the measurements showed that, within the uncertainty of the infrared determination, all samples, measured before and after viscometry, appeared homogeneous and no evidence of water concentration gradients was observable.

Results and comparison with previous studies. The viscosities of the dry and hydrous melts Phlegrean Fields samples are presented as a function of reciprocal temperature respectively in Figure 1. For comparison, selected samples from the literature (Whittington et al., 2001; Romano et al., submitted; Giordano et al., 2000; Hess and Dingwell, 1996) have been incorporated in the present analysis (Figs. 1 and 2).

The addition of water to the melts results in a large shift of the viscosity-temperature relationship to lower temperatures, in good agreement with the trend observed for a wide range of natural as well as synthetic melts (Dingwell, 1987; Persikov, 1991; Schulze et al., 1996; Dingwell et al., 1996; Hess et al., 1996; Holtz et al., 1999; Romano et al., 2000; Giordano et al., 2000; Whittington et al., 2001). The viscosity drops dramatically when the first 1 wt% H_2O is added to the melt, then tends to level off at higher water content. The viscosity of dry and hydrous products was once more successfully parameterised by using the modified Tammann-Vogel-Fulcher (TVF) equation from Giordano et al. 2000, that allows viscosity to be calculated as a function of temperature and water content.

The general form of the equation is the following:

$$\log_{10} \eta = [a_1+a_2\ln(W)]+[b_1+b_2(w)]/\{T-[c_1+c_2\ln(W)]\} \qquad (1)$$

where a_1, a_2, b_1, b_2, c_1 and c_2 are the fit parameters, η is the viscosity in Pa s, W is the concentration of water in weight percent, and T is the temperature in K.

Figure 2 shows the calculated viscosity as a function of water content for the liquid compositions analysed in this work and for others used for comparison. All viscosity curves in the figure refer to a constant temperature of 830 ºC. The liquids analysed in this work show viscosities similar to those analysed in previous works or by different authors, and pertaining to the same compositional type (Fig. 2). The viscosity of natural trachitic liquids falls between that of natural phonolitic and rhyolitic liquids, consistent with the dominantly explosive eruptive style of Phlegrean Fields volcano as compared with the similar style of rhyolitic volcanoes, the mixed explosive-effusive style of phonolitic volcanoes like Vesuvius, and the dominantly effusive style of basaltic volcanoes which are associated with the lowest viscosities among those considered in this work. Compositional variations between the different considered trachytes translate into liquid viscosity differences of nearly two orders of magnitude at dry conditions, and less than one order of magnitude at hydrous conditions.

In Fig.3 the isobaric heat capacities of dry and hydrous liquids for products of Monte Nuovo are presented.

The results of this study will be used to define constitutive equations for the energy balance equation in fluid dynamic modelling from researchers in TASK 3.1

Research products

Publications in international journals

1. Modelling the non-Arrhenian rheology of silicate melts: numerical considerations (2002). J.K. Russell, D. Giordano, K.U, Hess and D.B. Dingwell (Eur. J. Mineral. 14, 417-427).
2. Predicting shear viscosity during volcanic processes at the glass transition: a calorimetric calibration (2002). J. Gottsmann, D. Giordano and D.B. Dingwell. Earth Planet. Sci. Lett. 198, 417-427.
3. Viscosity of Etna Basalt: implications for Plinian-style basaltic eruptions (in press). D. Giordano and D.B. Dingwell (Bull. Volcanol. *In press* – DOI format-published online);
4. The “kinetic” fragility of natural silicate melts: constraints using Vogel–Fulcher-Tammann equation. D. Giordano and D.B.Dingwell (*In press* Jour. Phys.: Non-Cond. Matter).
5. Non-Arrhenian Multicomponent Melt Viscosity: A Model. D. Giordano and D.B. Dingwell (*In press* Earth Planet. Sci. Lett.).
6. Viscosity of trachytes from Phlegrean Fields, and comparison with basaltic, phonolitic, and rhyolitic melts. D. Giordano, C. Romano, P. Papale, and D.B. Dingwell. (*Submitted* to Jour. Volcanol. Geoth. Res.)
7. The dry and hydrous viscosities of alkaline melts from Vesuvius and Phlegrean Fields. C. Romano, D. Giordano, P. Papale, V. Mincione, D. B. Dingwell, M. Rosi. (*In press* Chemical Geology)
8. High-temperature limits of non-Arrhenian silicate melts: Implications for modelling compositional dependencies. J. K.Russell, D. Giordano and D.B.Dingwell (*Submitted* to Science);

Presentations at international meetings

1. Modeling the viscosity of anhydrous silicate melts. D. Giordano, D.B. Dingwell. EGS 2001;
2. Further progress in phlegrean fields magma rheology. D. Giordano, D.B. Dingwell, C. Romano, M. Rosi. EGS 2001;
3. Rheological measurements and modeling of phlegrean fields eruptive events. C. Romano, D. Giordano, P. Papale, V. Mincione, D.B. Dingwell, M. Rosi. EGS 2001;
4. A Model for NonArrhenian Newtonian Viscosities for Multicomponent Melts. D. Giordano, D.B. Dingwell. EGS 2002;
5. Dynamics of conduit flow and fragmentation of trachytic versus rhyolitic eruptions. P. Papale, D. Giordano, D. Del Seppia, C. Romano, and D.B. Dingwell. EGS 2002;
6. Prediction of Non-Arrhenian viscosity of Multicomponent silicate melts. D. Giordano, D.B. Dingwell. EMPG 2002;
7. High-temperature limits of non-Arrhenian silicate melts.J. K. Russell, D. Giordano and D. B. Dingwell. III Workshop on Non equilibria phenomena in supercooled fluids, glasses and amorphous materials 2002.

Fig. 1. Measured vs calculated (eqn. **2**) viscosity values for the Agnano Monte Spina (AMS), Campanian Ignimbrite (IGC), Monte Nuovo (MNV) and Astroni (ATN) Phlegrean Fields selected eruptions. Several syntheses at different water content were performed and are following listed:

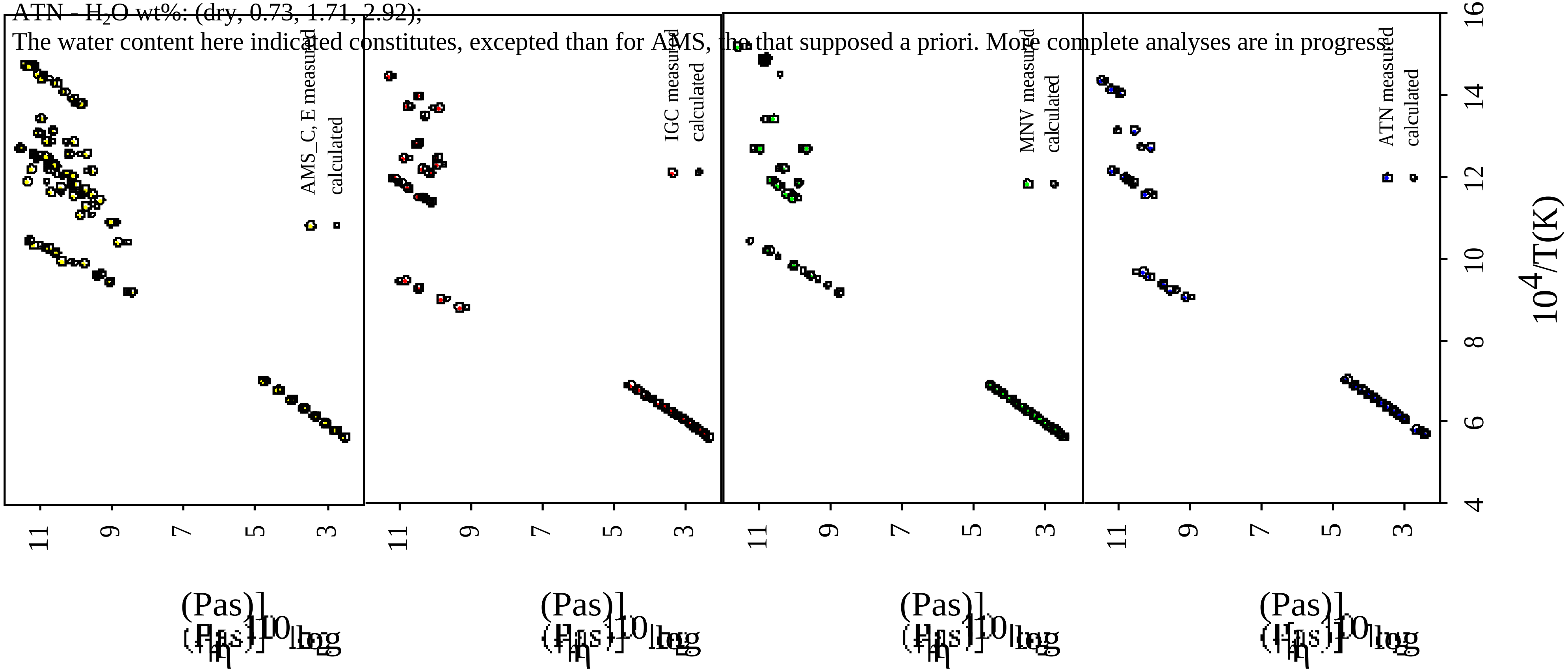
AMS - H_2O wt%: level E (dry, 1.15, 2.04, 2.38, 3.75); *level C* (dry, 0.79, 1.19, 1.26, 3.78);

IGC - H_2O wt%: (dry, 0.81, 1.52, 2.01, 2.96, 3.41);

MNV - H_2O wt%: (dry, 1.00, 1.39, 2.41, 3.86);

ATN - H_2O wt%: (dry, 0.73, 1.71, 2.92);

The water content here indicated constitutes, excepted than for AMS, the that supposed a priori. More complete analyses are in progress.



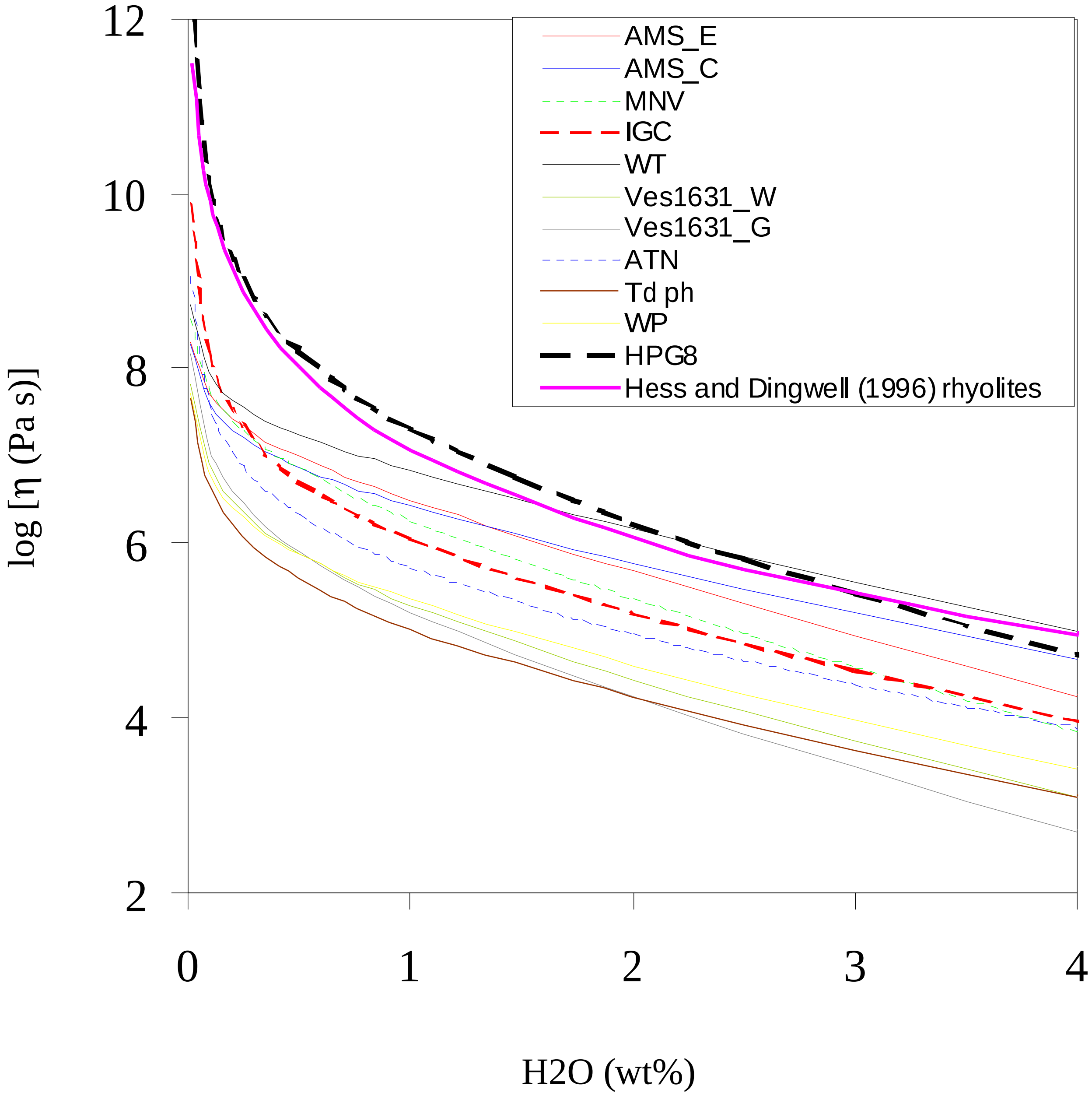


Fig 2. Viscosity as a function of water content for AMS samples (level E and C), IGC, MNV, ATN and from trachytic, phonolitic and rhiolitic compositions from literature (Hess and Dingwell, 1996, Whittington et al., 2000; Giordano et al., 2000), all at T = 1100 K. We can distinguish the three groups of the rhyolites (upper curves) from those of the trachytes (intermediate curves) and phonolites (lower curves).

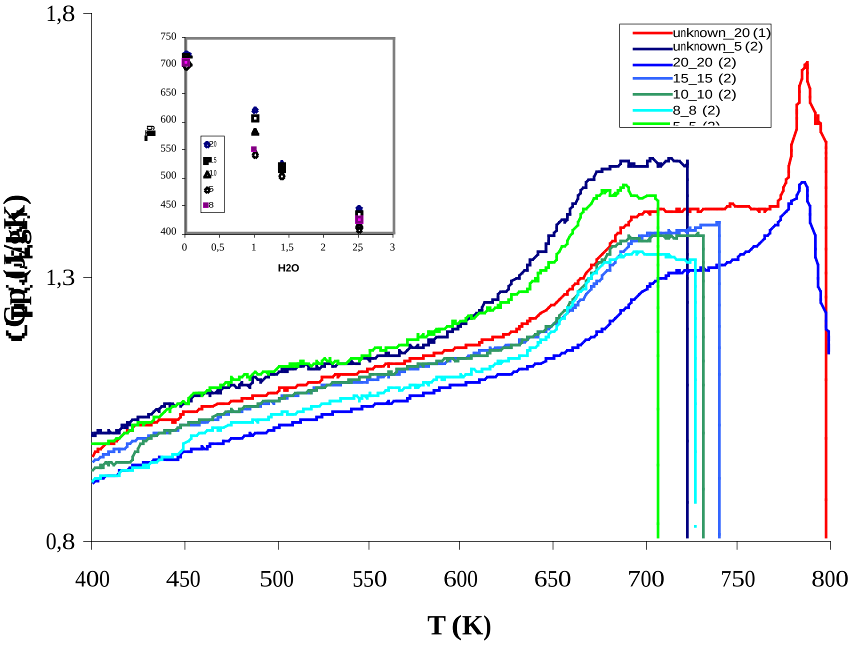


Fig. 3. Measured Cp as a function of temperature.

TASK 2.3 - EXPERIMENTAL PETROLOGY STUDIES

Responsible: Malcolm J. Rutherford
Collaborators: Angela Roach

- RU PARTICIPANTS: RU1

- II YEAR OBJECTIVES

  Analyses of phenocrysts and melt inclusions in the Campanian Ignimbrite samples, and equilibrium experiments for these samples; determination of the depth, temperature and volatile content in the pre-eruption magma storage zone; possibly, similar analyses on younger eruptions.

- II YEAR RESULTS

Methodologies. Experimental and natural samples from the different eruptive units were analyzed by Electron Microprobe for S,Cl, F, and total volatiles, and by FTIR for H_2O and CO_2. Experimental samples were prepared from the natural pumice at temperatures in the range indicated by mineral geothermometry with volatile H_2O and CO_2 volatile pressures to mimic the natural melt and phenocryst compositons.

Data. Electron microprobe analyses of glassy melt inclusions trapped in pyroxene and sanidine phenocrysts indicate that inclusions contain 200-650 ppm S, 1400-3200 ppm F, and 5800-10950 ppm Cl. FTIR results indicate that melt inclusions contain between 1-3 % H_2O and 0-2000 ppm CO_2 as carbonate. Generally, the Cl content of melt inclusions decreases with H_2O content suggesting that samples with low water content and low CO_2 are the result of syn- or post-eruptive degassing ("leaking").

Initial results from experimental charges prepared with Agnano Monte Spina glass and $NaCO_3$ confirm that carbon is complexed in the trachyte glass as CO_3. Although this result was unanticipated, recent studies on haplo-phonolite also confirm it (Morizet et al., 2002). A better experimental calibration of CO_3 solubility as a function of pressure in the Agnano Monte Spina trachyte is nearly complete, but the results will not change the original interpretation of the CO_2 pressure required to explain the carbonate observed in the FTIR spectra.

Interpretation. The volatile content of Agnano Monte Spina melt inclusions suggests a pre-eruption magma storage zone at ~80 MPa (Fig. 1). Our interpretation of the analytical data is that early-formed phenocrysts grew with both CO_3 and H_2O dissolved in the melt at a pressure of 80-100 MPa. A few melt inclusions in pyroxene were trapped in this environment. With continued crystallization, CO_2 was preferentially partitioned into an exsolved volatile phase and the volatiles remaining in the melt evolved to an increasingly water-rich and Cl-enriched composition (e.g. Wallace et al., 1995).

Initially, we suggested that the magma storage region would be located at pressures >1kb due to the likelihood of leucite crystallizing at lower pressures. However, we have not produced leucite in experiments as low as 500 bar. Further, to obtain stable sanidine phenocrysts at temperatures as high as 890°C (as determined by P. Landi), the pressure must be less than ~90 MPa. This information, combined with the melt inclusion data, suggests that the magma storage region was located at ~80 MPa and that the melt was water-saturated at these conditions. We interpret the CO_2-rich melt to have been present at an earlier stage (time) of magma evolution, based on the lower Cl in the CO_3-bearing melt (glass) compared to the H_2O-rich melt, but a similar magma may have existed below the H_2O-enriched magma.

Research products

Roach, A. and Rutherford, M., 2001, Experimental Petrology of the Trachytes of Agnano Monte Spina, Campi Flegrei: Programma Quadro per L'Attivita di Sorveglianza e Ricerca sui Vulcani Italiani, p. 196-197.

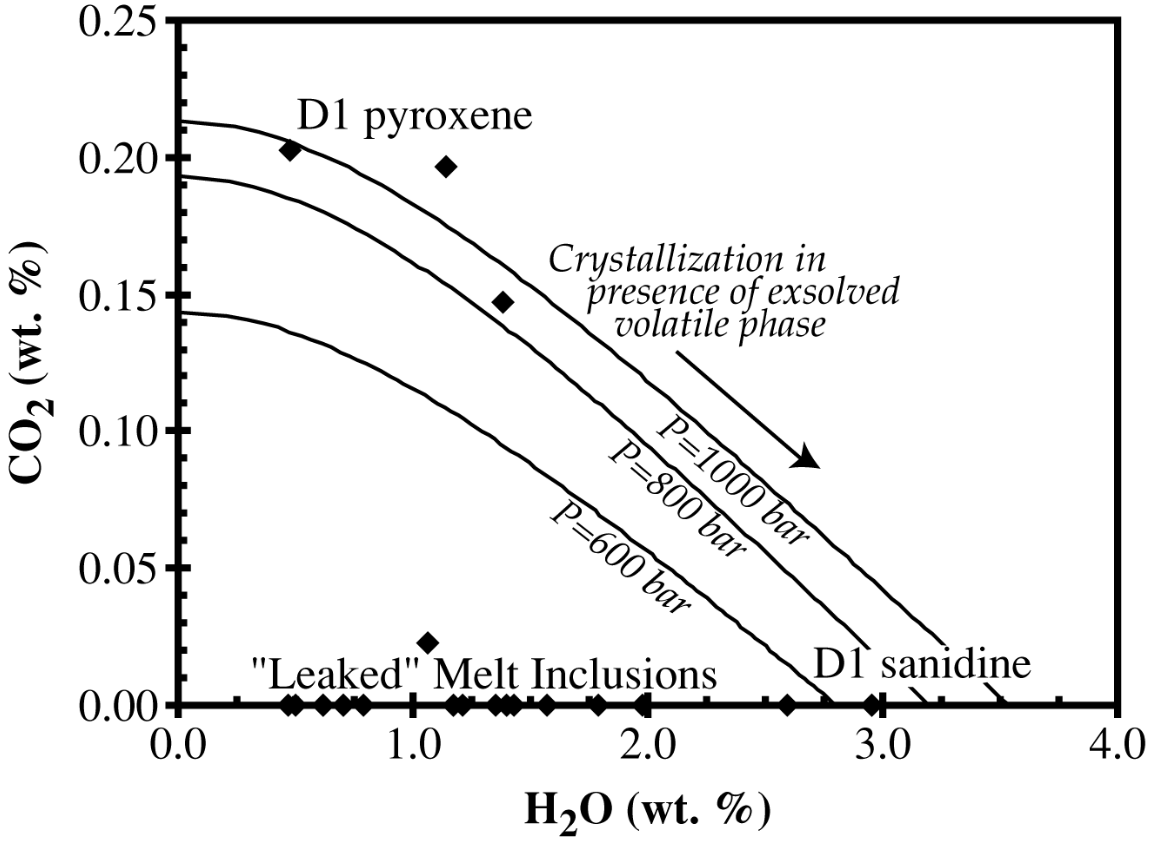


Figure 1. Volatile contents of melt inclusions from Agnano Monte Spina phenocrysts.

TASK 2.4 - EXPERIMENTAL DETERMINATION OF MAGMA STRENGTH AND FRAGMENTATION BEHAVIOR

Responsible: Donald B. Dingwell
Collaborators: Oliver Spieler, Sebastian Mueller, Bettina Scheu

- RU PARTICIPANTS: RU3

- II YEAR OBJECTIVES

  Parameterization of grain-size distribution-determining factors as a function of pressure, temperature, and rate of pressure decrease.

- II YEAR RESULTS

Introdction

During the experimental analysis of the fragmentation behaviour, and threshold values for pumices from Agnano Monte Spina eruption, we were surprised by the higher than expected fragmentation threshold (ΔP_{fr}) values of the most porous (>80 vol%) samples (fig.1). This was lead to a change in target of the second year investigation. Since the threshold is usually controlled by the porosity, the deviation had to be explained by the permeability. A new technique was designed and installed to measure the permeable gas flow as a result of the rapid decompression. The results show the influence of a high permeability on ΔP_{fr} of high porous samples.

Methodologies

The measurements were performed under non steady gas flow conditions in a cold sealed pressure vessel. A cylindrical sample is glued gastight into a ceramic sample holder using a high temperature cement. The autoclave is pressurised by argon with a known volume below the sample cylinder. Above the sample a set of rupture discs closes the device and allows pressurisation. The over pressurization and followed opening of the rupture discs starts the decompression. The pressure path below the sample is used to calculate the pressure dependent gas flow rate. The "Klinkenberg correction" is applied to calculate K (permeability) from the low pressure segment of the recorded pressure path. The high permeability of Agnano Monte Spina Pumice (CFS-06), Fig.2, might explain the relatively high fragmentation threshold [ΔP_{fr}]. We hope to explain the high permeability by the size distribution and shape of vesicles. The textural investigation is the main aspect of the ongoing collaboration with Margherita Polacci.

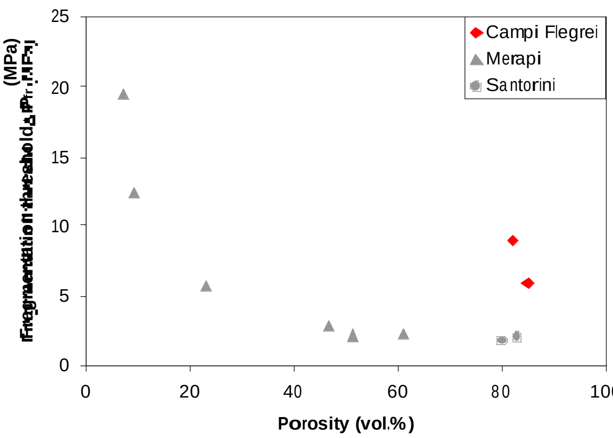


Fig. 1 : The fragmentation threshold of Agnano Monte

Data acquisition

The data are acquired using two pressure transducers one above the sample and a second attached to the lower end of the pressure vessel. The pressure data are recorded using a program written in labview. Time and pressure are used to calculate the flow rate using the known gas volume below the sample. Darcy's law, limited to laminar flow, can not be applied in the turbulent gas flow regime. Therefore, the pressure dependent gas flow rate recorded in the experiments is transferred in permeability values using the "Klinkenberg correction" (Eq.1).

$$K = \frac{2 ?\eta ?L ?Q_{atm} ?p_{atm}}{A ?\left(p^2_{in} - p^2_{out}\right)}$$

Eq.1.: Klinkenberg correction

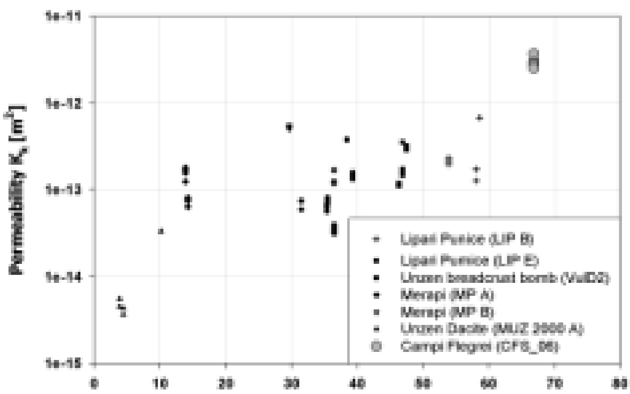


Fig.2: The diagram demonstrates the dependence of porosity and permeability. Volcanic samples between 5 vol.% and 70 vol.% porosity were measured. The samples CFS_06 shows a high permeability and thus provides evidence for a textural origin of an elevated threshold value.

The data include:
Density measurements, fracture toughness data, fragmentation speed measurements, preliminary grain size data.

Data processing and interpretation
Data from Agnano Monte Spina samples were plotted with a broad variety of samples in a threshold vs. porosity graph (Fig.1). This data follow an exponential distribution with a deviation that can be explained due crystal content and pore textures (permeability) (Fig.2). The experimental data need comparison to textural and density information from field investigations. We found that the grain size of the experimentally produced fragments were larger than expected. Our interpretation takes the extreme high gas flow rate and the shape of the decompression front into account. The internal ΔP_{fr} is not exceeded in the expected geometry, since the decompression front will easily enter large pores. Since the gas can easily escape less mechanical energy of the expanding gas phase is applied to the glass matrix. The dependency of pore size and resulting fragment size needs closer examination.
All collected materials have a high number of cooling cracks.

Research products

Presentations at international meetings:

1. Spieler, O., Grain size characteristics experimental pyroclasts. 2002 ERI Tokyo.
2. Spieler, O., and Dingwell, D.B., Fragmentation Speed, Sound Speed and Fracture Velocity. Shock Wave Research Meeting 2002, Sendai.
3. Scheu, B., Spieler, O., Dingwell, D.B., Fragmentation speed, elastic wave velocity and fracture velocity in dome magma. EGS 2002, Nice, April 2002.
4. Spieler, O., and Dingwell, D.B., The speed of pumice fragmentation. EGS 2002, Nice, April 2002.
5. Mueller, S., Spieler, O., Scheu, B., Dingwell, D.B., Fragmentation Speed and permeability of hot volcanic rocks. EGS 2002, Nice, April 2002.
6. Scheu, B., Mueller, S., Spieler, O., Dingwell, D.B., The speed of pumice fragmentation. AGU 2002, S. Francisco, December 2002.
7. Spieler, O., and Dingwell, D.B., The speed of pumice fragmentation. DMG 2002.
8. Mueller, S., Spieler, O., Scheu, B., Dingwell, D.B., Permeability measurements on hot rock samples. DMG 2002.
9. Spieler, O., and Dingwell, D.B., Fragmentation speed in explosive volcanism. ESC 2002.

TASK 2.5 - DETERMINATION OF VOLATILE DIFFUSIVITY

Responsibles: Carmela Freda, Claudia Romano
Collaborators: Don Baker, Piergiorgio Scarlato, Paolo Papale

- RU PARTICIPANTS: RU3

- II YEAR OBJECTIVES

Carbon dioxide diffusion experiments at constant pressure and different temperatures; analysis of the experimental products; determination of carbon dioxide diffusion coefficients.

- II YEAR RESULTS

We successfully completed 90% of our milestone for the second year, which is to measure CO_2 diffusion in the trachytic melt for which we have already measured the diffusion of H_2O. We have performed all of the necessary experiments on CO_2 diffusion, but have not yet successfully analyzed the run products by ion microprobe. We are sending out the run products for analysis by another technique, FTIR, and expect the results before the end of February 2003. In addition to our experiments on CO_2 diffusion, we used our water diffusion data collected in the first year of the research project in order to achieve part of the third year milestone which is to determine diffusion as a function of water concentration at constant pressure in the trachytic melt.

During the second year we synthesized a series of glasses having the same composition as D1, but with variable concentrations of CO_2 (0.2, 0.5, and saturated). These glasses are used as CO_2 reservoirs for diffusion couple experiments and as standards for the analysis of the experimental products. The synthesis experiments were performed in a piston cylinder apparatus at 0.9 GPa and 1350 °C. Preliminary analyses of the synthesised glasses were performed at Canmet (Ottawa, Canada) using a Cameca IMS-4F ion microprobe. These analyses demonstrate that CO_2 is homogeneously distributed in the sample and that the saturation value of CO_2 in the system studied at 0.9 GPa, 1350 °C is slightly above 0.5 wt%. Diffusion couple experiments were performed in a piston cylinder apparatus at 1.2 GPa and variable temperature (1100, 1150, 1200, 1300, and 1400 °C) and time (ranging from 540 to 1080 s). We planned to analyze these experiments by electron microprobe, ion microprobe, and Fourier-Transform Infra-red spectroscopy (FTIR). Preliminary analyses of the experimental products performed using the electron microprobe demonstrated that at 1200 °C the CO_2 diffusion coefficient in this composition is approximately $2x10^{12}$ m^2 s^{-1}. The electron microprobe data is very scattered and the precision and accuracy of this value is poor. Our attempts to measure diffusion profiles with the ion microprobe have, so far, been fruitless due to technical difficulties with the instrument. We will again attempt to measure diffusion profiles with the ion microprobe in January 2003. We are sending all of the experiments to the Department of Earth Sciences at the University of Bristol (UK) where aliquots of the standard glasses will be analysed with a LECO carbon analysis system and the diffusion experiments will be analyzed by FTIR. We are confident that the FTIR will provide us with the diffusion profiles necessary for the determination of CO_2 diffusion in the melt.

In addition to our work on CO_2 diffusion during the second year, we reduced our water diffusion data for the D1 composition in order to obtain a general equation for the prediction of water diffusion in the trachytic composition at all conditions studied. Our results indicate that water diffusion coefficients for a trachytic composition vary from the minimum value of $5.99x10^{-12}$ m^2 s^{-1} at 1100 °C and 0.25 wt% of H_2O to the maximum value of $2.77x10^{-10}$ m^2 s^{-1} at 1400 °C and 2.0 wt% water (Table 1). In the range of temperatures and water content we investigated, water diffusion is described by Arrhenius equations that can be combined (Figure 1) to yield a general equation for the prediction of water diffusion in the trachytic composition at concentrations up to 2 wt%:

$$D_{water} = \exp\left(-11.924 - 1.003\ln C_{H_2O}\right)\exp\left(\frac{-\left(\exp\left(11.836 - 0.139\ln C_{H_2O}\right)\right)}{RT}\right)$$

where C is the water concentration in the melt in wt%, R is 8.314 J mol^{-1} K^{-1}, and T is given in K . Additionally, Experiments at 1300 and 1100 °C provide preliminary data on water diffusion at concentrations up to 6 wt%.

Water diffusivities in trachytic melt were compared to water diffusivities in rhyolitic and basaltic melts. The activation energies for water diffusion in trachytic (this study) and basaltic (Zhang & Stolper 1991) melts at a water concentration of 0.25 wt% are comparable: 172±57 and 126±32 kJ mol^{-1}, respectively. The activation energy for water diffusion in the trachytic melt with 0.5 wt% water, 164±10 kJ mol^{-1}, is slightly higher than the activation energy of water diffusion in a haplogranitic melt with 0.5 wt% water, 147±42 kJ mol^{-1} (Novak & Behrens (1997). This behaviour results in the convergence of diffusion coefficients at lower (magmatic) temperatures and divergence at higher temperatures. The difference between water diffusivities in trachytic and haplogranitic melts becomes significant when 2 wt% water is added to the melts.

Reseach products

Presentations at international meetings

1. C. Freda, D.R. Baker, C. Romano, P. Scarlato (2002) *Water diffusion in a trachytic melt.* J. Conf. Abs. 7, p 35. (EMPG IX, Zurigo, 24-27 marzo 2002)

Publications in international books/journals

1. C. Freda, D.R. Baker, C. Romano, P. Scarlato. *Water diffusion in natural potassic melt.* In Volcanic Degassing: experiments, models, observations and impacts (eds. Oppenheimer C., Pyle D.M., Barclay J.). Geological Society of London. In press

Table 1. *Diffusivities of water at P=1 GPa*

H_2O (wt%)	T_{exp} (°C)	T_{avg} (°C)	D (m^2s^{-1})
0.25	1100	1079	$5.99x10^{-12}$
	1200	1167	$4.04x10^{-11}$
	1300	1253	$5.48x10^{-11}$
	1400	1328	$7.02x10^{-11}$
0.5	1100	1070	$1.19x10^{-11}$
	1200	1155	$5.50x10^{-11}$

	1300	1238	5.04×10^{-11}
	1400	1308	1.09×10^{-10}
1.0	1100	1065	2.35×10^{-11}
	1200	1148	8.91×10^{-11}
	1300	1230	8.59×10^{-11}
	1400	1297	1.77×10^{-10}
2.0	1100	1061	4.46×10^{-11}
	1300	1223	1.05×10^{-10}
	1400	1288	2.77×10^{-10}

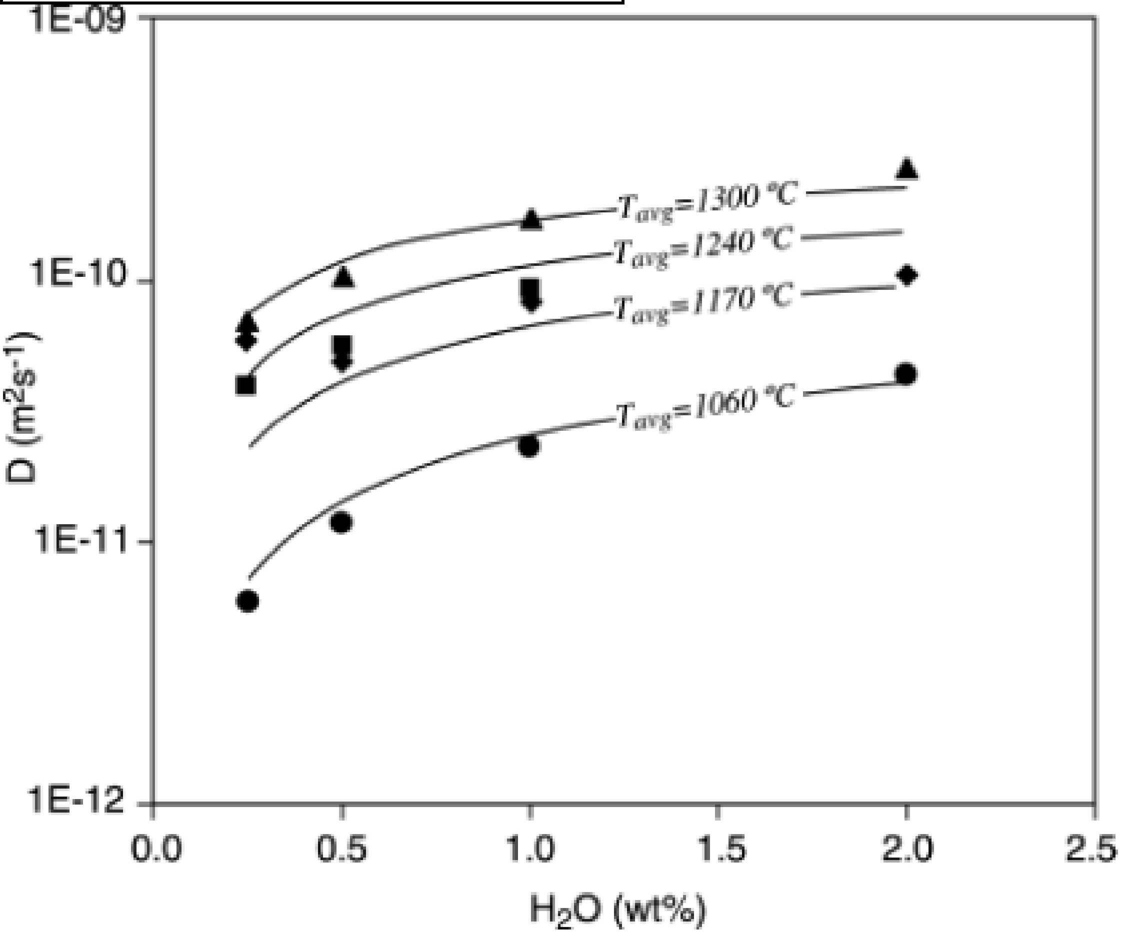


Fig. 1.Diffusivity of water as a function of water content at different temperatures.

TASK 2.6 - **TEXTURAL CHARACTERIZATION OF PYROCLASTS**

Responsibles: Margherita Polacci, Mauro Rosi, Paolo Papale
Collaborators: Patrizia Landi, Laura Pioli

- RU PARTICIPANTS: RU1, RU2

- II YEAR OBJECTIVES

Completion of the study on Agnano Monte Spina samples, and to an intermediate/advanced stage on Monte Nuovo samples.

- II YEAR RESULTS

Characterization of volcanic products from Phlegrean Fields selected eruptions. We have characterized the juvenile fraction of the Campanian Ignimbrite (CI) and Agnano Monte Spina (AMS) eruptions. Investigations on pumice samples were performed at both macroscopic and microscopic scales, and details of the procedure can be found in Polacci et al. (2002a) and were summarized in the I year report. According to clast color and morphologies, pumice clasts have been subdivided into three end member types, namely microvesicular, tube and expanded. Equidimensional to angular microvesicular pumice clasts are from moderately to rather vesicular and contain heterogeneous vesicle populations in terms of vesicle sizes, shapes and distributions. Typical elongated tube pumice clasts vary from dense to vesicular and are characterized by highly stretched/deformed vesicles at various steps of fragmentation. Finally, expanded pumice clasts encompass products marked by a great variety of vesicle growth and expansion, as silicic reticulites, with vesicularity >90% vol., and more common inflated pumices, characterized by a vesicularity gradient moving from clast center to the margins. Boundaries among different pumice types are not sharp and pumice products presenting transitional textures are commonly found.

Qualitative observations of microscopic pumice textures have been performed on 35 polished thin sections. Optical and scanning electron microscopy accomplished on different pumice types have revealed that macroscopic textural heterogeneities are also repeated at the sub-millimeter scale. This extreme textural variability is present not only among the different pumice types but also within each single pumice fragment, where areas of sub-rounded, poorly deformed vesicles coexist with areas of elongated, deformed vesicles at distances of tens/hundreds of microns (Polacci et al. 2002a). Quantification of textural parameters performed on selected clasts belonging to all three different pumice types includes measurements of bulk and groundmass vesicularities and vesicle number densities, vesicle sizes, shapes, spatial distributions and degree of interconnectivity. Table 1 reports all the textural parameters measured. Both eruptions overall exhibit very high bulk vesicularities, with typical values ranging 0.80-0.90, and bulk vesicle number densities from 10^5 to 10^6 cm^{-2}. Interestingly, the degree of vesicle interconnectivity is rather high in all pumice types, with coalesced vesicles generally representing 80-90% of the bulk vesicle population. In comparison to microvesicular and expanded pumice products, tube pumice clasts present the largest and most deformed vesicles, a likely effect of combined efficient shear stress and coalescence.

The occurrence of textural heterogeneities at different scales has been ascribed to an heterogeneous distribution of magma properties and flow variables within the conduit. Such distribution is likely to promote the onset of processes as viscous heating at the conduit walls that may have an important role in the dynamics of high intensity explosive eruptions (Polacci et al. 2002a, Rosi et al. 2002).

The study of the juvenile fraction of the Monte Nuovo (MTN) eruption so far has regarded macroscopic characterization of pumice clasts, including measurements of the density distribution of the whole deposit. Preliminary investigation of groundmass textures is in course and will be completed in the first half of 2003 in collaboration with Task 2.1. Details on the stratigraphy, componentry, grain size characteristics and compositions of the deposit can be found in Task 1 and 2.1.

Pumice products from the lower unit has revealed close similarities with the classification proposed for the other Phlegrean Fields eruptions. Interesting to note, banded pumices constitute half of the juvenile products, followed, in order of abundance, by the expanded and tube pumice types. Moving from the bottom to the top of the deposit, banded pumice clasts exhibit a wide range of textures, typically given by alternating layers characterized by different colors (from yellow to gray/dark gray up to black), vesicle content (from vesicular to microvesicular to non-vesicular), size (from cm- to submm-sized) and shape (from rounded/subrounded to very irregular and deformed). Vesicular up to dense dark gray to black blocks and bombs up to several tens of dm represent the typical pyroclastic material of the upper unit. The transition between the two units is not sharp, and a whole spectrum of volcanic products with transitional macroscopic and microscopic features is present throughout the erupted sequence.

Densities vary from 1.9 to 0.4 g/cm^3 (corresponding vesicularities 27-85 vol.%) in the lower unit, with a mode shifting from 1.1 to 0.8 g/cm^3 from the bottom to the top of the unit, and range 2.4 -1.1 g/cm^3 (vesicularities 8-58 vol.%) in the upper unit, with a peak at 1.5 g/cm^3.

Scanning electron microscopic investigations has revealed complex textures in both eruptive units. The transition from the bottom to the top of the lower unit is accompanied by an overall crystallinity increase and vesicularity decrease, with changing proportions of crystals and vesicles well evidenced in different pyroclast types, and particularly defined in banded pumice clasts. Heterogeneities are present also in the textures of the products of the upper unit, but they do not appear to be correlated with a clear vertical crystal and/or vesicle content zonation. Crystallinities reach the highest values in dense clasts, where groundmass is constituted by a network of intersecting microlites below 100 µm and vesicles of extremely irregular shapes.

Comparison between pumice textures in the deposits from trachytic and rhyolitic eruptions. The compositional and textural data set accomplished in the last three years on the products of calc-alkaline (Pinatubo 1991, Quilotoa 800 BP) and alkaline (CI, AMS, MTN-in course) eruptions has provided a natural comparison between the juvenile fractions of these two compositions. Results point out that close similarities do exist in the crystal and vesicle textures of pumice products from both magma types and suggest that these textures represent markers of common conduit processes. These observations, along with results coming from numerical modelling of trachytic and rhyolitic conduit magma ascent in collaboration with task 3.1, offer a detailed frame of the specific characteristics of calc-alkaline and alkaline magmas, focusing on the important role that the different rheological properties of the two magma types has on the related eruption dynamics (Polacci et al. 2002b).

Research products

Publications in international books/journals

1. M. Polacci, M. Pioli, M. Rosi (2002a) The Plinian Phase of the Campanian Ignimbrite eruption (Phlegrean Fields, Italy): evidence from density measurements and textural characterization of pumice. Bull. Volcanol., in press.
2. M. Polacci, P. Papale, D. del Seppia, D. Giordano (2002b) Dynamics of magma ascent and fragmentation in trachytic vs rhyolitic eruptions. J. Volcanol. Geotherm. Res., submitted.
3. M. Rosi, P. Landi, M. Polacci, A. Di Muro, D. Zandomeneghi (2002) Role of conduit shear for the crystal-rich magma feeling the 800 yr BP eruption of Quilotoa Volcano (Ecuador). E. Planet. Sci. Lett., submitted.

Presentations at international meetings

1. P. Papale, M. Polacci. CONDUIT4 – a computer code for the simulation of magma ascent through volcanic conduits and fissures. Volcanic Eruption Mechanism Modeling Workshop, University Of New Hampshire, USA, November 14-16 2002
2. M. Polacci, L. Pioli, P. Papale e M. Rosi Pumice textures reflecting degassing, vesiculation and conduit flow conditions in Phlegrean Fields eruptions. Montagne Pelee 1902-2002 meeting, Martinique, 12-16 May 2002.
3. M. Rosi, D. Zandomeneghi, P. Landi, M. Polacci, A. Di Muro Influence of conduit-wall shear on ascent of the crystal-rich magma feeding the 800 yr BP, plinian eruption of Quilotoa volcano (Ecuador). Montagne Pelee 1902-2002 meeting, Martinique, 12-16 May 2002.
4. P. Papale, R. Moretti, G. Ottonello, M. Polacci Role of volatiles H2O, CO2, and S in magma degassing and eruption dynamics. Montagne Pelee 1902-2002 meeting, Martinique, 12-16 May 2002.

TASK 3.1 - NUMERICAL SIMULATIONS OF MAGMA ASCENT DYNAMICS

Responsible: Paolo Papale
Collaborators: Margherita Polacci, Augusto Neri, Dario Del Seppia, Daniele Giordano, Roberto Moretti, Giulio Ottonello

- RU PARTICIPANTS: RU1, RU4

- II YEAR OBJECTIVES

Completion of simulations for the Campanian Ignimbrite eruption; accurate analysis of the ascent dynamics for the Agnano Monte Spina eruption (maximum expected event); evaluation of consistency between numerical modeling results, experiments, and textural analysis; preliminary simulations of Monte Nuovo eruption.

- II YEAR RESULTS

Three groups of simulations were performed, in addition to those performed during the first year.

Dynamics of trachytic vs. rhyolitic eruptions. The first group of eighteen simulations was aimed at completing the systematic comparison between the dynamics of rhyolitic and trachytic eruptions that was started during the first year of project. We investigated a range of conditions spanning from a conduit diameter from 20 to 90 m, and water contents from 2 to 6 wt%. Any other condition being equal, fragmentation of rhyolitic magma was found to occur much deeper in the conduit, and at magma vesicularities in the range 0.65-0.75, while that of trachytic magma was found to occur at vesicularities in the range 0.80-0.85. The much shallower fragmentation of trachytes with respect to rhyolites might be the cause of the high frequency of phreatomagmatic events involving trachytic magma at Phlegrean Fields, since shallow aquifers can easily enter the volcanic conduit close to the fragmentation level where the magmatic pressure is commonly tens of MPa less than lithostatic.

The complex, non-linear relationships between mass flow-rate and magma composition were also investigated. An unexpected result is that low-viscosity trachytes can be associated with lower mass flow-rates with respect of rhyolitic magma. This is due to the combined effect of viscosity (which is lower for trachytic magma) and water solubility (higher for trachyites) in determining the distribution of flow variables along the volcanic conduit, and the occurrence of fragmentation conditions. While magma viscosity is lower for trachytes, delayed magma fragmentation for this type of magma with respect to rhyolites implies a longer region characterized by bubbly flow regime, where viscous forces play an important role. Therefore, the total dissipation due to viscous forces can be higher for the less viscous trachytic magma, reflecting in a low mass flow-rate. In spite of large differences in the distribution of flow variables occurring in the deep conduit region, the flow dynamics in the upper conduit region close to conduit exit, and the calculated vent conditions, are very similar for the two rhyolitic and trachytic magmas with same conduit size and total water content. This is consistent with the observation that the phenomenological characteristics of eruptions associated with the two types of magma, and the kind of deposits produced, are the same.

Role of carbon dioxide in trachytic eruptions at Phlegrean Fields. The second group of six simulations was aimed at investigating the possible roles of carbon dioxide in the dynamics of the Agnano Monte Spina (AMS) eruption. Carbon dioxide is found to have been an important volatile component in this eruption (see task 2.3 above). These simulations were coupled with those of gas-particle dispersion dynamics in the atmosphere presented by A. Neri (see below), in order to get a picture of the whole eruption dynamics involving water plus carbon dioxide bearing magma. These are the first coupled numerical simulations of conduit flow and atmospheric dispersal for CO_2-bearing magmas ever done. The conduit flow simulations show that due to very low CO_2 solubility in the AMS magma at magma chamber P-T conditions, even large amounts of this volatile species in the AMS magma could not be seen in glass inclusions formed in the magma chamber. Conversely, even small amounts of CO_2 result in the separation of a gas phase in the magma chamber, and in important changes in the distribution of the flow variables along the volcanic conduit. These changes are due to the large effect that the presence of a relatively insoluble volatile species like CO_2 has on the water content at saturation. In particular, the magma fragmentation level largely deepens with the addition of small amounts of CO_2 to the erupted magma, whereas the magma vesicularity at fragmentation is substantially unaffected by the presence of CO_2. In spite of large changes occurring in the deep conduit flow when CO_2 is added to magma, the upper conduit and vent conditions, as well as the conduit diameter consistent with the mass flow-rate of the eruption, are only slightly affected by the presence of CO_2. The role of CO2 on the large scale eruption dynamics, as it emerges from the coupled simulations of conduit and atmospheric dispersion dynamics, is discussed at task 3.2 below.

Simulations of magma ascent for the Campanian Ignimbrite eruption. The third group of twelve simulations was aimed at investigating the conduit dynamics for conditions pertaining to the Plinian phase of the Campanian Ignimbrite (CI) eruption. Magma discharged during this eruption was hotter and less viscous than the AMS magma, as reported in the literature and according to the viscosity measurements and parameterisations done within the present project, and the conduit length was probably no more than 3-4 km. The results of the simulations show that these differences are sufficient to explain the one order of magnitude increase of the mass flow-rate from the AMS to the CI eruption, without the necessity to invoke the presence of a much wider magma chamber as can be found in the literature. Since mass flow-rate is a crucial parameter for the definition of the volcanic hazard from explosive eruptions, with one order of magnitude changes associated with enormous differences in the areas affected by highly hazardous phenomena, it follows that knowledge of the composition and temperature of magma within the present magma chamber, and of its depth, is strictly needed for a proper assessment of the volcanic hazard. Numerical simulations pertaining to the CI eruption also reveal a totally unexpected and previously never described phenomenon in the dynamics of conduit flow during explosive eruptions. This phenomenon is related to the short conduit for such an eruption involving relatively low-viscosity magma, and consists in an inverse relationship between the total water content of magma and the mass flow-rate of the eruption. A positive relationship between water content and mass flow-rate has been always found in all the to-date published numerical simulations of magma ascent, including those from this group. Now, we can demonstrate that in some particular conditions that can be attained during eruptions at Phlegrean Fields, an opposite relationship can hold. We have therefore planned for the third year of project a more systematic and more thorough investigation of the relationships between mass flow-rate, conduit size, and water content in trachytic, rhyolitic, and basaltic eruptions, in order to get to a general picture of the possible importance of this phenomenon in the dynamics of volcanic eruptions.

Modeling of multicomponent volatile saturation. In addition to numerical simulations of magma ascent dynamics, we have developed a new model (in collaboration with R. Moretti and G. Ottonello) for the saturation of multicomponent volatiles in silicate liquids, by adding sulfur species (oxydized and reduced) to water and carbon dioxide. The new model allows the location in P-T-f_{O2}-composition space of the saturation surface of a magma containing the three above volatile components, the determination of the amount of each dissolved and exsolved volatile, and the composition of the coexisting gas phase. First applications have been made to rhyolitic and basaltic magmas, since these are the compositions for which the experimental data are more abundant and an evaluation of the capabilities of the modelling is possible. We know however, from the results of the research performed at task 2.3, that sulfur is an abundant volatile component in the trachytic magma from the Agnano Monte Spina eruption, and possibly from other eruptions at Phlegrean Fields. After the first phase of model development, we plan for the third year of project applications to Phlegrean Fields magmas. Also planned is the inclusion of sulfur as a third volatile component in the magma ascent modelling, on which we have just started working. We will be therefore able during the third year of project to include this important additional volatile component in the simulations of the dynamics of magma ascent and fragmentation at Phlegrean Fields.

Research products

Publications in international books/journals:

1. Moretti R., P. Papale, G. Ottonello (2003) A model for the saturation of C-O-H-S fluids in silicate melts. In: *Volcanic Degassing: experiments, models, observations and impacts* (Eds. Oppenheimer C., Pyle D.M., Barclay J.). Geological Society of London. In press
2. Romano C., D. Giordano, P. Papale, V. Mincione, D.B. Dingwell, M. Rosi (2003) The dry and hydrous viscosities of alcaline melts from Vesuvius and Phlegrean Fields. Chemical Geology, in press.
3. Polacci M., P. Papale, D. del Seppia, D. Giordano (2003) Dynamics of magma ascent and fragmentation in trachytic vs rhyolitic eruptions. Journal of Volcanology and Geothermal Research, sub judice.
4. Giordano D., C. Romano, P. Papale, D.B. Dingwell (2003) Viscosity of trachytes from Phlegrean Fields, and comparison with basaltic, phonolitic, and rhyolitic melts. Journal of Volcanology and Geothermal Research, sub judice.

Technical reports:

1. *Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard*. P. Papale (project coordinator). First-year report del progetto GNV 2000-02/17, in: Gruppo Nazionale per la Vulcanologia, Programma quadro per l'attività di sorveglianza e ricerca sui vulcani attivi italiani 2000-2002 – Rapporti dei coordinatori di progetto: 153-174.

Invited talks:

1. Conduit4 - a computer code for the simulation of magma ascent through volcanic conduits and fissures. P. Papale and M. Polacci. 1st International Model Intercomparison Workshop, University of New Hampshire, November 15-16, 2002.

Presentations at international meetings:

1. A model for multicomponent fluid saturation in C-O-H-S silicate melt systems. R. Moretti, P. Papale, G. Ottonello. European Geophysical Society 2002, Nizza, aprile 2002.
2. Dynamics of conduit flow and fragmentation of trachitic versus rhyolitic eruptions. P. Papale, D. Giordano, D. Del Seppia, C. Romano, D.B. Dingwell. European Geophysical Society 2002, Nizza, aprile 2002.
3. Numerical simulation of the coupled conduit and atmospheric dispersal dynamics for the 4400 BP Agnano Monte Spina trachitic eruption. P. Papale, A. Neri, D. Del Seppia, T. Esposti Ongaro. European Geophysical Society 2002, Nizza, aprile 2002.
4. The achievement of fragmentation conditions in sustained explosive eruptions. P. Papale. Montagne Pelee 1902 – 2002. Explosive volcanism in subduction zones. Saint-Pierre, Martinique, 12-16 maggio 2002.

5. Pumice textures reflecting degassing, vesiculation and conduit flow conditions in Phlegrean Fields eruptions. M. Polacci, L. Pioli, P. Papale e M. Rosi. Montagne Pelee 1902 – 2002. Explosive volcanism in subduction zones. Saint-Pierre, Martinique, 12-16 maggio 2002.
6. Role of volatiles H2O, CO2, and S in magma degassing and eruption dynamics. P. Papale, R. Moretti, G. Ottonello, M. Polacci. Montagne Pelee 1902 – 2002. Explosive volcanism in subduction zones. Saint-Pierre, Martinique, 12-16 maggio 2002.

Database:

1. Database of scientific publications on Phlegrean Fields. Paolo Papale. GNV web site (http://gnv.ingv.it).

Computation codes:

1. COSH – a computer code for the determination of the saturation surface of multcomponent H2O+CO2+S volatiles in natural and synthetic silicate liquids. P. Papale and R. Moretti (manual in preparation).

Degree thesis :

1. Numerical simulations of the eruptive dynamics during the 4400 BP Agnano Monte Spina eruption, Phlegrean Fields, with multiparticle spectrum from grainsize and component distribution analyses of the deposits. Giacomo Luciani (tutor: Paolo Papale), Dipartimento di Scienze della Terra, Università di Pisa (in preparation).

TASK 3.2 - NUMERICAL SIMULATION OF GAS/PYROCLAST DISPERSION PROCESSES AND PYROCLASTIC FLOW DYNAMICS

Responsible: Augusto Neri
Collaborators: Paolo Papale, Tomaso Esposti Ongaro, Andrea Di Muro, Dimitri Gidaspow, Mauro Rosi

- RU PARTICIPANTS: RU4, RU1

- II YEAR OBJECTIVES

Simulations of the Agnano Monte Spina eruption with vent conditions from the magma ascent modeling.

- II YEAR RESULTS

The research work carried out in the second year of the project was aimed at the completion and publication of pyroclastic dispersal modeling studies of great relevance for the study of Campi Flegrei's hazard, as well as at the carrying out of coupled conduit plus dispersal simulations of the most important phases of the Agnano-Monte Spina eruption. As a consequence, the research work was organised along the following lines.

Application of the PDAC-2D dispersal multiphase flow code to the quantification of pyroclastic mass partition and pyroclastic flow hazard assessment. The multiphase flow model PDAC-2D, developed in the ambience of the GNV project n. 9 coordinated by Prof. R.Trigila (Neri et al., in press), has been applied in the present project to investigate the pyroclast partitioning during sustained explosive eruptions as well as the hazard posed by the collapse of the eruptive column and the formation of pyroclast flows. Pyroclastic mass partitioning represents one of the most important data that allows to link stratigraphic data with the dynamics of the eruptive column. As a consequence, the spatial and temporal dispersal of pyroclasts during collapsing and transitional columns was investigated by using a three-phase formulation of the multiphase flow model (one gas phase and two solid phases representative of pyroclasts of varying size and density) (Neri et al, 2002). Simulation results allowed us to quantify the mass of pyroclasts of different sizes forming the pyroclastic density current, the phoenix column and the convective plumes rising from the proximal area of the flow and above the fountain. In particular the simulations allowed to better understand the dynamics of columns at the transition between the buoyant and collapsing regimes. Such a regime is characterized by greater collapse height, generation of dilute density currents, shorter flow runout, less steady behavior of the column, and intermittent feeding of the flows. Similarly, the analysis of simulation outputs carried out at Vesuvius in a previous European project has been completed and published in order to get a better estimation of the hazard associated with pyroclastic flows (Todesco et al., 2002; Esposti Ongaro et al., 2002). The estimation of critical flow variables such as the flow velocity, density, temperature, and dynamic pressure as well as the flow runout is indeed crucial for the assessment of building damages and casualties due to similar phenomena at Campi Flegrei.

Coupled conduit plus column simulation of the Agnano Monte Spina eruption**.** In the second year of the project we further extended the number of simulations of the coupled conduit plus column dynamics of the Agnano Monte Spina eruption in close cooperation with the research unit coordinate by P.Papale. According to this approach the input data of the dispersal model consist of vent conditions as computed by the magma ascent model. A total of 15 coupled simulations were performed to investigate the column dynamics leading to layers B1 and D1, i.e. two of the main layers of the Agnano Monte Spina deposit. Furthermore, we performed preliminary simulations considering the simultaneous presence of water and carbon dioxide as volatiles in both conduit and dispersal models. In details, we investigated the column dynamics of the two eruptive phases for two different mass flow-rates (considered as lower and upper limits on the basis of stratigraphic data), three different water contents of the mixture (2, 4, and 6 wt%) and three different carbon dioxide contents (0.5, 1, and 2 wt%). Simulations results obtained with water content between 4 and 6 wt% and no carbon dioxide substantially agree with the indication of transitional eruptive style inferred from independent volcanological studies. Water content values lower than 4 wt% produce substantially fully collapsing columns whereas values greater than 6 wt% produce a buoyant column. These results appear to be relatively independent on the value of mass flow-rate assumed within the range specified. Finally, from the preliminary simulations performed using the input data of phase B1, the addition of carbon dioxide to a given content of water does not appear to significantly change the eruptive style of the dispersal process. In the next year of the project the best estimates of the input magmatic data of the Agnano Monte Spina eruption will be provided by the other research units and therefore consistencies between simulation outputs and field evidences will be finally evaluated.

Research products

Publications in international books/journals:

1. Esposti Ongaro T., A.Neri, M.Todesco, G.Macedonio, Pyroclastic flow hazard at Vesuvius by using numerical simulations. II. Analysis of local flow variables. *Bull. Volcanol*. 64:178-191, 2002.
2. Neri A., T.Esposti Ongaro, G.Macedonio, D.Gidaspow, Multiparticle simulation of collapsing volcanic columns and pyroclastic flows. *J. Geophys. Res, in press.*
3. Neri A., A. Di Muro, M. Rosi, Mass partition during collapsing and transitional columns by using numerical simulations. *J. Volcanol. Geotherm. Res.*, 115:1-18, 2002.
4. Todesco M., A.Neri, T.Esposti Ongaro, P.Papale, G.Macedonio, R.Santacroce, A.Longo, Pyroclastic flow hazard at Vesuvius by using numerical simulations. I. Large-scale dynamics. *Bull. Volcanol.* 64:155-177, 2002.

Presentations at international meetings:

1. Papale P., A.Neri, D.Del Seppia, T.Esposti Ongaro, Numerical simulation of the coupled conduit and atmospheric dispersal dynamics of the 4400 BPO Agnano Monte Spina trachitic eruption, Phlegrean Fields, *XXVII European Geophysical Society General Assembly*, Nice, 26-30 April, 2002.
2. Rosi M., A.Neri, A.Di Muro, The transitional regime of sustained magmatic explosive eruptions, *IAVCEI International Conference Montagne Pelèe*, Martinique, 12-16 May 2002.

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 1, Responsible: Paolo Papale, Researcher, Istituto Nazionale di Geofisica e Vulcanologia, Pisa

ACTIVITY REPORT –2nd YEAR

UR PARTICIPANTS:

Name-Position	Affiliation	Man/month
Paolo Papale, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	4
Patrizia Landi, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	0.5
Antonella Bertagnini, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	0.5
Margherita Polacci, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	7
Augusto Neri, Head Researcher	CNR – Istituto di Geoscienze e Georisorse	0.5
Mauro Rosi, Full Professor	Dipartimento di Scienze della Terra, Univ. Pisa	0.5
Carmela Freda, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Roma	0.5
Daniele Giordano, post PhD	DEES, University of Munich	1
Piergiorgio Scarlato, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Roma	0.5
Dario Del Seppia, Contract Researcher	CNR – Istituto di Geoscienze e Georisorse, and DST – Università di Pisa	4

- II YEAR OBJECTIVES

Within TASK 2.6 – Textural characterization of pyroclasts: Completion of the study on Agnano Monte Spina samples, and to an intermediate/advanced stage on Monte Nuovo samples.

Within TASK 3.1 - Numerical simulations of magma ascent dynamics: Completion of simulations for the Campanian Ignimbrite eruption; accurate analysis of the ascent dynamics for the Agnano Monte Spina eruption (maximum expected event); evaluation of consistency between numerical modeling results, experiments, and textural analysis; preliminary simulations of Monte Nuovo eruption.

- II YEAR RESULTS

TASK 2.6: The task objectives have been fully accomplished. The textural characterization of pumice clasts from the Campanian Ignimbrite and Agnano Monte Spina eruption has been completed, and the analysis of the Monte Nuovo eruption has been carried out at an intermediate/advanced stage. Main results are constituted by the recognition of different types of pumice clasts based on their macroscopic and microscopic features, and their classification into three main classes interpreted to reflect horizontal distribution of flow conditions within the volcanic conduit. In detail, magma flowing from central conduit regions gives origin to the most abundant microvesicular pumice type, magma flowing close to the conduit walls gives origin to the expanded pumice type (>0 – 5 vol% of the deposits), and magma flowing in intermediate regions gives origin to tube pumice (>0 – 5 vol%). The process responsible for the generation of expanded pumice is recognised to be viscous heating due to large velocity gradients close to conduit walls, which originated a localised temperature increase and associated viscosity decrease which allows gas expansion up to large or very large (> 90) volume percentage. Tube pumice reflects a larger extension toward the inner conduit region of the velocity with respect to the thermal boundary layer. Comparison with rhyolitic pumice reveals that the subdivision into three main classes appears to be a generalised feature of explosive volcanic eruptions, and shows that vesicularity of trachytic pumice overlaps with that of rhyolitic pumice, but tends to be slightly larger than that (75-85 vol% for the former, and 65-80% for the latter).

TASK 3.1: The task objectives have been accomplished to a >90% level. Conditions pertaining to the Agnano Monte Spina eruption have been deeply investigated by employing the information from all the field and laboratory tasks, and the numerical simulations of magma ascent and fragmentation have been coupled to those of gas-pyroclast dispersion in the atmosphere and along pyroclastic flows at task 3.2. For a subset of simulations, the possible roles of the presence of carbon dioxide in the magma, which is revealed by the laboratory task 2.3, have been also investigated, still by coupling conduit and atmospheric dispersal dynamic simulations (see also task 3.2). A deep comparative investigation of the dynamics of trachytic and rhyolitic eruptions, started during the first year of project, has been accomplished, revealing strong non-linear relationships between magma viscosity (as determined at the laboratory task 2.2), compositional-dependent water solubility, and mass flow-rate of the eruption. Numerical simulations of magma ascent for conditions pertaining to the Campanian Ignimbrite, the eruption with highest intensity in the volcanic history of Phlegrean Fields, has revealed that the ultra-Plinian character of this eruption is totally accounted for by the lower viscosity (still determined at the laboratory task 2.2), higher temperature of magma, and shallower magma chamber with respect to the Agnano Monte Spina eruption. No need to invoke a role of much wider magma chamber is therefore necessary to explain the much higher mass flow-rate of the Campanian Ignimbrite eruption with respect to other explosive eruptions at Phlegrean Fields, implying that the depth of magma chamber and the kind of magma contained in it can be more crucial than the size of the chamber itself in determining a high or very high volcanic hazard.
Additional research in collaboration with R. Moretti (OV-INGV) and G. Ottonello (DIPTERIS Univ. Genova), which will be applied to Phlegrean Fields eruptions during the third year of project, has led to a new modelling and computer code for calculating the saturation surface of multicomponent H2O+CO2+S volatiles in natural magma as a function of magma composition. At present, this new model is being included within the magma ascent code, what will allow to get to a more reliable representation of the eruption dynamics for S-rich eruptions at Phlegrean Fields.

Research products

N. 2 publications in press in international journals
N. 2 publications submitted in international journals
N. 1 invited presentations at international meetings
N. 8 presentations at international meetings
N. 1 technical report
N. 1 published database of scientific publications on Phlegrean Fields (http://gnv.ingv.it)
N. 1 new computer code
N. 1 degree thesis (in preparation)

Publication list (papers sub-judice not included)

M. Polacci, M. Pioli, M. Rosi (2002a) The Plinian Phase of the Campanian Ignimbrite eruption (Phlegrean Fields, Italy): evidence from density measurements and textural characterization of pumice. Bull. Volcanol., in press.

Moretti R., P. Papale, G. Ottonello (2003) A model for the saturation of C-O-H-S fluids in silicate melts. In: *Volcanic Degassing: experiments, models, observations and impacts* (Eds. Oppenheimer C., Pyle D.M., Barclay J.). Geological Society of London. In press

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 2, Responsible: Mauro Rosi, Full Professor, Dipartimento di Scienze della Terra, University of Pisa

ACTIVITY REPORT –2nd YEAR

UR PARTICIPANTS:

Name-Position	Affiliation	Man/month
Mauro Rosi, Full Professor	Dipartimento di Scienze della Terra, Università di Pisa	3
Patrizia Landi, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	3
Antonella Bertagnini, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	3
Paolo Papale, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	0.5
Margherita Polacci, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	4
Augusto Neri, Head Researcher	CNR – Istituto di Geoscienze e Georisorse, Pisa	0.3
Daniele Giordano, post PhD	IMPG Univ. Munich	1
Andrea Di Muro, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	1
Laura Pioli, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	1

- II YEAR OBJECTIVES

Within TASK 1.1 - Selection of stratigraphic layers of major interest for the project, reconstruction of their stratigraphy and dispersal, and sampling: Stratigraphy, grain-size, componentry and sampling of the deposits of Monte Nuovo eruption; stratigraphy and sampling of the deposits of the Astroni eruption.

Within TASK 2.1 - Petrochemical study of volcanic products: Analyses on samples from Monte Nuovo eruption, to an advanced stage; MI studies on samples from Campanian Ignimbrite and Agnano Monte Spina eruptions.

- II YEAR RESULTS

TASK 1.1: The task objectives have been accomplished to an 80% level. Namely, the stratigraphy, componentry, grain-size, and sampling of the Monte Nuovo eruption, and the sampling of the Astroni eruption for laboratory tasks 2.1-6, have been accomplished. Additionally, further investigation of the Agnano Monte Spina eruption has been carried out, in order to investigate stratigraphic layers the origin of which was previously interpreted as from pyroclastic flows. Our new field investigation suggests instead a prevalent fallout origin, implying less strong implications for the volcanic hazard. The investigation of the Monte Nuovo eruption led us to define a lower (LM) and upper member (UM) in the stratigraphic succession. Mud-flow deposits and an erosion surface with gullies mark the boundary between the deposits of the LM and UM. The LM is mainly made up of massive to cross bedded ash and pumice deposits emplaced by pyroclastic density currents, alternating with accretionary-lapilli-rich ash fall layers. Medium sorted, rather continuous, clast supported pumice fall layers are present at different levels. Ballistic blocks and pumiceous bombs up to tens of decimetres are common and increase in the upper part of the sequence. Non juvenile material is scarce and surficial, being mainly constituted of fragments of yellow tuffs and pumice of the Averno eruption. On the whole the characteristics of deposits and some textural features such as presence of accretionary and armored lapilli, vesiculated tuffs suggest that the first phase of the eruption was dominated by pulsating, hydromagmatic, low-energy explosions originated by interaction with sea water and/or shallow aquifers. The UM consists of two main units which form the uppermost part of the Monte Nuovo cone and show a fairly radial dispersal. They are coarse, dark grey deposits with variable matrix content, mostly made up of juvenile clasts with variable density and vesicularity (see task 2.6). The characteristics of deposits suggest that they were emplaced through prevalent pyroclastic flow dynamics, and were originated by violent explosions of a magma plug, driven by exsolution and expansion of magmatic volatiles.

TASK 2.1: The task objectives have been accomplished to a 60% level. Namely, the petrochemical analysis of samples from the Monte Nuovo eruption has been conducted to an advanced stage. Whole rock major and trace element analyses, mineral chemistry, and compositions of microlites and glass of the groundmass were performed. All the products are trachytes/phonolites with slight peralkaline chemistry, and show subaphyric texture with rare phenoceysts of K-feldspar and subordinate amphibole, clinopyroxene, oxide and sphene. Plagioclase is found as crystals with large rims of K-feldspar, and in aggregates of crystals together with K-feldspar, oxide and sphene. Such aggregates, even if rare, are mainly found in the pumice of the LM. The groundmass ranges from glassy with scarce microlites of K-feldspar in vesiculated pumice, to nearly holocrystalline with abundant microlites, up to 300-400 μm, and grains of oxides in scoriae of the final activity. The cristallinity of the groundmass appears related to the vesicularity of the products (see task 2.6). As a whole, the erupted products cover a narrow compositional range. Mineral chemistry appears homogeneous throughout the entire sequence and consists of: K-feldspar Or 62-70, ferropargasitic amphibole, oxide Usp 32-33, clinopyroxene Fs 20.5-23.5, sphene with TiO_2=35-36 wt% and plagioclase with antirapakivi texture An27-35. Crystals in aggregates have the same composition than the single crystals. Analyses of the groundmass highlight a wide compositional range of the matrix glasses, as a result of different crystallinity. Average compositions range from SiO_2=59.3, Na_2O+K_2O=14.7 in the pumice of the Lower Member, to SiO_2=57, Na_2O+K_2O=15.4 in the scoriae of the Upper member. Feldspars microlites range in composition from Or20-25, AN18-22 to Or55-60, An4-5 and, compared with those of the scoriae of the UM, mirolites of the pumice of the LM show higher content of CaO (Fig. 2). The variations in the content and composition of microlites in the groundmass of the products of LM and UM, associated with textural variations (see task 2.6), suggests sin-eruptive crystallization mainly due to different degassing modes, possibly related to changes in eruptive dynamics.

Research products

N. 2 degree thesis
Set of selected samples from Phlegrean Fields eruptions for laboratory investigations

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 3, Responsible: Claudia Romano, Researcher, Dipartimento di Scienze Geologiche, Università Roma Tre

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Claudia Romano, Researcher	Dipartimento di Scienze Geologiche, Univ. Roma Tre	2
Donald B. Dingwell, Professor	DEES, University of Munich	0.5
Carmela Freda, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Roma	3
Don Baker, Associate Professor	McGill University, Montreal	1
Daniele Giordano, Post PhD	DEES, University of Munich	3
Brent Poe, Associate Professor	Dipartimento di Scienze Geologiche, Università di Chieti	1
Valeria Misiti, PhD Student	Dipartimento di Scienze Geologiche, Univ. Roma Tre	0.5
Lucio Costa, PhD Student	Dipartimento di Scienze Geologiche, Univ. Roma Tre	0.5

- II YEAR OBJECTIVES

Within TASK 2.2 - Determination of magma viscosity: Parameterization of rheology of crystal-bearing magmas (in collaboration with RU 6).

Within TASK 2.5 - Determination of volatile diffusivity: Carbon dioxide diffusion experiments at constant pressure and different temperatures; analysis of the experimental products; determination of carbon dioxide diffusion coefficients.

- II YEAR RESULTS

TASK 2.2: The task objective has not been accomplished, due to much longer time than expected required to have the instrumentation available at the DEES of Munich University (RU 6). However, the research responsible and participants, together with research responsible of RU 6 collaborating to the research, do not feel the need for a re-modulation of the three-years research objectives. The instrumentation will be available in a short time since now (2 months), and more resources will be dedicated to the accomplishment of the second and third year objectives during the third year of project. The responsible of this RU and of RU 6 feel confident that the three years objectives will be fully accomplished.

During the second year of project the determination and parameterization of the viscosity-temperature-H_2O relationships for liquid magmas from Phlegrean Fields has been completed, by adding the Monte Nuovo and Astroni determinations to those of Agnano Monte Spina and Campanian Ignimbrite performed during the first year of project. Therefore, the first year objectives are now fully accomplished. The results show that although the viscosity of all analysed trachytes from Phlegrean Fields fall in a well defined region of viscosity-temperature-water content space, significant variations up to more than one order of magnitude in viscosity are possible depending on the specific composition (or eruption) considered. Since viscosity has a controlling role in the eruption dynamics (see task 3.1), it follows that knowledge of the specific composition of magma in the present Phlegrean Fields magma chamber is required to properly address future volcanic scenarios and forecast the volcanic hazard. Due to the above delay in setting up a procedure for the accomplishment of the 2nd year objectives, additional aspects of the physical properties of magmas from Phlegrean Fields were investigated. Namely, we determined the isobaric heat capacities of dry and hydrous liquids for products of Monte Nuovo and Campanian Ignimbrite eruptions. The isobaric heat capacity of silicate melts (Cpl) is a crucial property for modelling the thermal evolution of magma during volcanic processes, for phase equilibrium calculations, and for the theoretical investigation of the physical properties and structure of silicate liquids (Courtial and Richet, 1993; Yoder 1976; Carmichael et al. 1977). Our determinations of the hydrous heat capacities for natural magmas are among the first data of this kind in the international literature, and the first for trachytic compositions. The data are now being analysed in order to derive constitutive equations that can be used in energy balance calculations within the thermo-fluid dynamic modelling of volcanic eruptions at tasks 3.1 and 3.2.

TASK 2.3: The task objectives have been accomplished at a 90% level. We have performed all of the necessary experiments on CO_2 diffusion, but have not yet successfully analyzed the run products by ion microprobe. We are sending out the run products for analysis by another technique, FTIR, and expect the results before the end of February 2003. In addition to our experiments on CO_2 diffusion, we used our water diffusion data collected in the first year of the research project in order to achieve part of the third year milestone which is to determine diffusion as a function of water concentration at constant pressure in the trachytic melt. In addition to our work on CO_2 diffusion during the second year, we reduced our water diffusion data for the D1 composition from the Agnano Monte Spina eruption in order to obtain a general equation for the prediction of water diffusion in the trachytic composition at all conditions studied. Our results indicate that water diffusion coefficients for a trachytic composition vary from the minimum value of 5.99×10^{-12} m^2 s^{-1} at 1100 °C and 0.25 wt% of H_2O to the maximum value of 2.77×10^{-10} m^2 s^{-1} at 1400 °C and 2.0 wt% water. In the range of temperatures and water content we investigated, water diffusion is described by Arrhenius equations that has been combined to yield a general equation for the prediction of water diffusion in the trachytic composition at concentrations up to 2 wt%. Water diffusivities in trachytic melt were compared to water diffusivities in rhyolitic and basaltic melts. The activation energies for water diffusion in trachytic (this study) and basaltic (Zhang & Stolper 1991) melts at a water concentration of 0.25 wt% are comparable: 172±57 and 126±32 kJ mol^{-1}, respectively. The activation energy for water diffusion in the trachytic melt with 0.5 wt% water, 164±10 kJ mol^{-1}, is slightly higher than the activation energy of water diffusion in a haplogranitic melt with 0.5 wt% water, 147±42 kJ mol^{-1} (Novak & Behrens (1997). This behaviour results in the convergence of diffusion coefficients at lower (magmatic) temperatures and divergence at higher temperatures. The difference between water diffusivities in trachytic and haplogranitic melts becomes significant when 2 wt% water is added to the melts.

Research Products

N. 7 publications printed or in press in international books/journals
N. 4 publication submitted for international journals
N. 9 presentations at international meetings

Publication list (papers sub-judice not included)

1. C. Freda, D.R. Baker, C. Romano, P. Scarlato (2003). *Water diffusion in natural potassic melt*. In Volcanic Degassing: experiments, models, observations and impacts (eds. Oppenheimer C., Pyle D.M., Barclay J.). Geological Society of London. In press.
2. J.K. Russell, D. Giordano, K.U, Hess and D.B. Dingwell (2002) Modelling the non-Arrhenian rheology of silicate melts: numerical considerations. Eur. J. Mineral. 14, 417-427.
3. J. Gottsmann, D. Giordano and D.B. Dingwell (2002) Predicting shear viscosity during volcanic processes at the glass transition: a calorimetric calibration. Earth Planet. Sci. Lett. 198, 417-427.
4. D. Giordano and D.B. Dingwell (2003) Viscosity of Etna Basalt: implications for Plinian-style basaltic eruptions. Bull. Volcanol., in press – DOI format-published online.
5. D. Giordano and D.B.Dingwell (2003) The “kinetic” fragility of natural silicate melts: constraints using Vogel–Fulcher-Tammann equation. Jour. Phys.: Non-Cond. Matter, in press.
6. D. Giordano and D.B. Dingwell (2003) Non-Arrhenian Multicomponent Melt Viscosity: A Model. Earth Planet. Sci. Lett., in press.
7. C. Romano, D. Giordano, P. Papale, V. Mincione, D. B. Dingwell, M. Rosi (2003) The dry and hydrous viscosities of alkaline melts from Vesuvius and Phlegrean Fields. Chemical Geology, in press.

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 4, Responsible: Augusto Neri, Centro di Studio per la Geologia Strutturale e Dinamica dell'Appennino, CNR Pisa

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Augusto Neri, 1st Researcher	CNR – Istituto di Geoscienze e Georisorse, Pisa	4
Tomaso Esposti Ongaro, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	4
Andrea Di Muro, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	4
Paolo Papale, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	1
Mauro Rosi, Full Professor	Dipartimento di Scienze della Terra, Univ. Pisa	1
Micol Todesco, Contract Researcher	Dip. Scienze Geologiche, Univ. Bologna	1
Dimitri Gidaspow, Full Professor	Illinois Institute of Technology, Chicago	1
Dario Del Seppia, PhD student	Dipartimento di Scienze della Terra, Univ. Pisa	2

- II YEAR OBJECTIVES

Within TASK 3.2 - Numerical simulation of gas/pyroclast dispersion processes and pyroclastic flow dynamics:
Simulations of the Agnano Monte Spina eruption with vent conditions from the magma ascent modeling.

- II YEAR RESULTS

TASK 3.2: The task objectives were fully accomplished. A total of 15 numerical simulations of gas-pyroclast dispersion dynamics in the atmosphere and along pyroclastic flows have been performed in order to investigate conditions pertaining to the Agnano Monte Spina eruption at Phlegrean Fields. Fortheen of them were performed by employing vent conditions as determined by numerical simulations of magma ascent dynamics at task 3.1. Main results include the followings: for both the B1 and D1 eruptive phases investigated, a water content between 4 and 6 wt% is required to reproduce the transitional eruptive style reconstructed from the field investigation at task 1.1; the uncertainty on mass flow-rate for each considered eruptive phase does not affect the above conclusion, but it significantly modifies the runout of pyroclastic flows and the details of the gas-pyroclast disperion dynamics; addition of carbon dioxide up to 2 wt%, although deeply changing the flow conditions in the deep conduit region (see task 3.1), does not significantly modify the sub-aerial eruption dynamics. In addition to the above simulations, several others were performed in order to investigate the partition of the mass of pyroclasts between the different regions of the sub-aerial gas-pyroclast dispersion. Simulation results allowed us to quantify the mass of pyroclasts of different sizes forming the pyroclastic density current, the phoenix column and the convective plumes rising from the proximal area of the flow and above the fountain. In particular the simulations allowed to better understand the dynamics of columns at the transition between the buoyant and collapsing regimes. Such a regime is characterized by greater collapse height, generation of dilute density currents, shorter flow runout, less steady behavior of the column, and intermittent feeding of the flows.

Research products

N. 4 papers printed or in press in international journals
N. 2 presentations at international meetings

Publication list (papers sub-judice not included)

1. Esposti Ongaro T., A.Neri, M.Todesco, G.Macedonio, Pyroclastic flow hazard at Vesuvius by using numerical simulations. II. Analysis of local flow variables. *Bull. Volcanol*. 64:178-191, 2002.
2. Neri A., T.Esposti Ongaro, G.Macedonio, D.Gidaspow, Multiparticle simulation of collapsing volcanic columns and pyroclastic flows. *J. Geophys. Res, in press.*
3. Neri A., A. Di Muro, M. Rosi, Mass partition during collapsing and transitional columns by using numerical simulations. *J. Volcanol. Geotherm. Res.,* 115:1-18, 2002.
4. Todesco M., A.Neri, T.Esposti Ongaro, P.Papale, G.Macedonio, R.Santacroce, A.Longo, Pyroclastic flow hazard at Vesuvius by using numerical simulations. I. Large-scale dynamics. *Bull. Volcanol.* 64:155-177, 2002.

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 5, Responsible: Malcolm J. Rutherford, Department of Geological Sciences, Brown University, RI - USA

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Malcolm J. Rutherford, Full Professor	Department of Geological Sciences, Brown University, RI	2
Angela Roach, PhD student	Department of Geological Sciences, Brown University, RI	8

- II YEAR OBJECTIVES

Within TASK 2.3 - Experimental Petrology Studies: Determination of the depth, temperature and volatile content in the pre-eruption magma storage zone; analyses of phenocrysts and melt inclusions in the Campanian Ignimbrite samples, and equilibrium experiments for these samples; possibly, similar analyses on younger eruptions.

- II YEAR RESULTS

TASK 2.3: The task objectives were accomplished at a 60% level. Volatile content analyses in glass inclusions from the Agnano Monte Spina eruption reveal the presence of abundant “minor” volatile components like F, Cl, and S, the roles of which in the magma and eruption dynamics should be evaluated. Water contents range from 1 to 3 wt%, and carbon dioxide contents up to 2000 ppm are found. Carbon dioxide turns out to be totally dissolved in the form of CO_3^{2-}. The volatile content of Agnano Monte Spina melt inclusions suggests a pre-eruption magma storage zone at ~80 MPa (Fig. 1). Our interpretation of the analytical data is that early-formed phenocrysts grew with both CO_3 and H_2O dissolved in the melt at a pressure of 80-100 MPa. A few melt inclusions in pyroxene were trapped in this environment. With continued crystallization, CO_2 was preferentially partitioned into an exsolved volatile phase and the volatiles remaining in the melt evolved to an increasingly water-rich and Cl-enriched composition (e.g. Wallace et al., 1995). Initially, we suggested that the magma storage region would be located at pressures >1kb due to the likelihood of leucite crystallizing at lower pressures. However, we have not produced leucite in experiments as low as 500 bar. Further, to obtain stable sanidine phenocrysts at temperatures as high as 890°C (as determined by P. Landi), the pressure must be less than ~90 MPa. This information, combined with the melt inclusion data, suggests that the magma storage region was located at ~80 MPa and that the melt was water-saturated at these conditions. We interpret the CO_2-rich melt to have been present at an earlier stage (time) of magma evolution, based on the lower Cl in the CO_3-bearing melt (glass) compared to the H_2O-rich melt, but a similar magma may have existed below the H_2O-enriched magma.

Research results

N. 1 technical report

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 6, Responsible: Donald B. Dingwell, Department of Earth and Environmental Sciences, Munich University

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Donald B. Dingwell, Full Professor	Department of Earth and Environmental Sciences, Munich University	2
Oliver Spieler, Researcher	Department of Earth and Environmental Sciences, Munich University	3
Sebastian Mueller, PhD student	Department of Earth and Environmental Sciences, Munich University	2
Bettina Schau, PhD student	Department of Earth and Environmental Sciences, Munich University	2

- II YEAR OBJECTIVES

Within TASK 2.2 - Determination of magma viscosity: Parameterization of rheology of crystal-bearing magmas (in collaboration with RU 3).

Within TASK 2.4 - Experimental determination of magma strength and fragmentation behavior: Parameterization of grain-size distribution-determining factors as a function of pressure, temperature, and rate of pressure decrease.

- II YEAR RESULTS

TASK 2.2: the results pertaining to this task are described in the Activity Report by the RU 3.

TASK 2.4: the task objectives have been accomplished at a 60% level, taking into account that results from the first year of investigation suggested a re-direction of task objectives for the second year, in order to understand them. Investigation to be performed during the third year of project will take into account, besides the objectives specific for that year, also the original objective for second year.

Fragmentation thresholds in terms of pressure differential determined for trachytic samples from Phlegrean Fields eruptions reveal too high values when compared to the general trend shown by several other natural samples of different composition. Due to this particular result, and to the great relevance that the modalities of magma fragmentation have on the eruptive dynamics, detailed investigation of the relationships between sample porosity and permeability were performed. Trachytic samples are indeed characterized by very large porosity, the highest among natural samples we have ever investigated for fragmentation in the lab. We have found that such a large porosity corresponds to comparative high values of permeability, possibly also enhanced by the presence of several cooling fractures in the analysed samples. The experimental data need comparison to textural and density information from field investigations. We found that the grain size of the experimentally produced fragments were larger than expected. Our interpretation takes the extreme high gas flow rate and the shape of the decompression front into account. The internal ΔP_{fr} is not exceeded in the expected geometry, since the decompression front will easily enter large pores. Since the gas can easily escape less mechanical energy of the expanding gas phase is applied to the glass matrix. The dependency of pore size and resulting fragment size needs closer examination.

Research products

N. 9 presentations at international meetings

Request of addition of a new Reseach Unit (N. 7) and new Research Task (2.7) for the third year of project

A few months ago, a new project for measuring magma viscosities with innovative techniques involving high pressure experiments and in situ visualization through synchrotron radiation has been submitted to the GNV by the HP-HT laboratory group at the INGV in Rome. This new technique would allow obtaining hydrous viscosities at close-to-eruptive temperature, which are to-date not routinely measured due to the impossibility of keeping water dissolved in the liquid at such conditions and atmospheric pressure for the time required by the experimental measurement. The proposed project is focused on the analysis of trachytic magmas from Phlegrean Fields, due to the great interest for Civil Protection purposes as outlined in the present GNV Frame Project. The GNV decided not to consider the project for immediate funding, as all the projects should be funded in correspondence of the official annual project deadlines. However, due to the great interest of the proposal, and considering its great relevance for the present project objectives and the perfect matching with some of our research tasks, in particular task 2.2 which is devoted to viscosity determinations with standard techniques and at complementary P-T-H_2O conditions, the GNV Director Paolo Gasparini suggested that the new proposal be submitted for being incorporated in the third year objectives of the present project.

We accept such a suggestion, and make it an official request for the third year of activity. We remark the importance of the new proposed research for the present project objectives. Magma viscosity, and its dependency on temperature and on the dissolved water content, is among the most crucial controlling factors in determining the large-scale dynamics of volcanic eruptions. Most of our conduit flow simulation results within the present project and prior to it are interpreted in terms of magma viscosity and its variations with local conditions along the volcanic conduit.

In spite of such a great relevance, magma viscosity is not routinely measured at eruptive temperature conditions, or at large water contents comparable with those at deep conduit regions. By performing experiments under high pressure conditions allows to circumvent the difficulties of measuring high-T, high H_2O viscosities, resulting in the production of data which are of great relevance for understanding and modelling magma properties and eruption dynamics.

The proposing group includes highly qualified researchers of international level and long-standing experience in experimental volcanology and magma viscosity determinations. The HP-HT laboratory at the INGV in Rome is relatively young, although possibly a fast-growing one, but the scientific level of the proponents guarantees the achievement of results at the required international standard. The proposed use of modern and technically advanced synchrotron radiation technique for in situ visualization of the experiments guarantees a control on the experimental runs which is a further warranty of the quality of the research results. The addition of this new Research Unit and Research Task has been discussed at the 2nd Year Project Meeting, and received an enthusiastic support by all the RU responsibles and project participants.

The new research proposed by the HP-HT laboratory group at the INGV in Rome is therefore submitted for addition to the third year objectives of the present project reported in the included Executive Project for the Third Year. Accordingly, we propose to expand the number of Research Units in the project, by adding a new one constituted by the HP-HT laboratory group of INGV-Rome (RU #7), and to include a new task (2.7) devoted to viscosity determinations on natural magma compositions from Phlegrean Fields with the new proposed technique. The new task 2.7 is detailed in the attached original proposal by the HP-HT research group below. In case of acceptance by the Evaluation Committee and by the GNV, such a proposal will form part of the Executive

Project for the third year. The associate financial request is added to the financial request for the third year of project, also included below.

Original Proposal

High pressure viscosity measurements of hydrous silicate liquids using the falling sphere viscometry in a piston cylinder apparatus

Don R. Baker***, Carmela Freda*, Brent Poe*, Claudia Romano**, Piergiorgio Scarlato*

*Istituto Nazionale Di Geofisica e Vulcanologia, Roma; **Dipartimento di Scienze Geologiche, Università Roma Tre, Roma; ***Dept of Earth and Planetary Sciences, McGill University, Montreal, Canada

Introduction

Magma properties play major roles in determining the dynamics of volcanic eruptions; among magma properties, viscosity is probably the most relevant one (Webb, 1997; Dingwell, 1998; Papale et al., 1998; Neri et al., 1998). Without an appropriate knowledge of the viscosity of magma, and particularly of its dependency on the amount of dissolved volatiles, no confident modeling of magma chamber, magma ascent, and therefore magma dispersion dynamics is possible. On the other hand, the modeling of such processes is required in order to predict possible volcanic scenarios and forecast the volcanic hazard.

The viscosity of phonolitic and trachytic magmas erupted at the two potentially most dangerous Italian volcanoes, Vesuvius and Phlegrean Fields, is still unknown, as no data have been published to-date. Recent experimental work performed in the frame of an on-going GNV project (N. 17) has determined the dry viscosities of a number of trachytic liquids from samples collected at Phlegrean Fields, and the hydrous viscosities at temperatures close to the glass transition (some hundreds degrees below eruptive temperatures). On the other hand, the effects of dissolved water, even in trace amounts, on the physical properties of silicate melts can be profound (e.g. Dingwell, 1998), and the conventional methods for measuring the viscosity of silicate liquids at ambient pressure, such as concentric cylinder viscometry and parallel plate viscometry, are incapable of investigating hydrous silicate liquids at eruptive temperatures. This is because with these open-system techniques, the sample will degas as the temperature becomes moderately high. For example, only very high viscosities (10^9 – 10^{12} Pa s) at temperatures near the glass transition temperature can be measured using the parallel plate method (Schulze et al, 1999).

Proposed Research and Research Results

We propose to perform a 1 year research finalized at determining the hydrous viscosities of selected samples with trachytic composition from relevant eruptions at Phlegrean Fields, and at temperatures approaching those estimated during eruptions. Samples will come from selected eruptions, including the 36,000 BP Campanian Ignimbrite, 4500 BP Agnano Monte Spina, and 1538 AD Monte Nuovo eruptions which also constitute the object of deep investigation from other GNV projects. The new data will complement those at dry conditions, or at hydrous conditions but very low temperature (much less than the eruptive one), which are being obtained within such projects. The data will be used to constrain a model for the viscosity of trachytic magmas from Phlegrean Fields as a function of temperature and dissolved water content. The results will be made available to interested researchers working within other GNV projects on Phlegrean Fields, in order to allow such researchers to use our new results for the purposes of their projects. The proposed research will represent a fundamental advancement in the knowledge of magma properties at a potentially very dangerous Italian volcano, allowing therefore a more confident simulation and prediction of volcanic scenarios, and an advancement in the general knowledge of hydrous magma rheology, which is relatively poorly known at an international level.

Methods

To circumvent the problem of degassing during measurements on hydrous samples at high T, we will measure viscosity at elevated pressures, in which degassing and foaming is hindered. Although adapting viscometric techniques to high-pressure apparatus inherently places added experimental uncertainties in the measurements, two methods have been developed with some success. One method is simply an adaptation of the micropenetration technique to the inside of an internally heated autoclave. However, like the micropenetration method at ambient pressure, such measurements are limited to the high viscosity range at temperatures near the glass transition. A second technique, called "falling sphere viscometry" is able to measure lower viscosities, as it is based on the Stokes equation, in which the terminal velocity of a sphere (υ) accelerating under the force of gravity (g) in a liquid is a function of difference in density between sphere and liquid ($\Delta\rho$) and the sphere's radius (r_s):

$$\eta = \frac{2r_s^2 \Delta\rho g W}{9\upsilon E} \qquad 1)$$

where g is the constant of acceleration due to gravity and W and E are wall and end corrections (Faxen, 1925), respectively, which become important for capsules with diameter and length of limited dimensions due to the volume limitations of a high-pressure apparatus.

The falling sphere method has been used successfully for measurement of silicate liquid viscosities at high pressure over the past 25 years (Kushiro, 1976; Kushiro, 1978; Scarfe et al, 1987; Kanzaki et al, 1987), and we will adopt such a method for our measurements within the present research. The method consists of placing a small, perfectly spherical ball of metal at the top of the sample capsule in a standard piston cylinder assembly. When the apparatus is at the specific applied load to generate pressure, the system is heated. As the sample melts at the temperature of interest, the metallic sphere will begin to fall towards the bottom of the capsule because its density is greater than that of the liquid. It is important to quench the temperature, thereby freezing the sphere in place before it reaches the bottom of the capsule. In this way, one can determine the velocity of the sphere based on the distance that it travelled during the time it was at temperature. Because the sphere is initially at rest at the beginning of the experiment, it does not reach its terminal velocity (required by Stokes Law) immediately. Thus, a number of experiments of different duration are necessary in order to more precisely determine the velocity at various points of descent. If addtional time becomes available, a second set of experiments can be performed in order to determine the density of hydrous silicate liquids. Using essentially the same experimental design, a second sphere of different composition, thus having a different density, may be inserted in the capsule. By simultaneous solution of the Stoke's equation for two different spheres in the same liquid, the density of the liquid can be more accurately determined (e.g. rather than using inappropriate equation of state data).

Using this method for hydrous (and CO_2-bearing) silicate liquids, it is possible to weld the capsule (typically made of platinum tubing) in order to prevent loss of any volatile component during the experiment. For a standard _ inch piston cylinder assembly with capsule diameter of 5 mm and length of 10 mm, viscosities in the range 1 Pa s up to 10^4 Pa s can be measured, which correspond to experiment durations ranging from about 10 seconds (low viscosity liquids) to 30 hours (higher viscosity liquids).

The falling-sphere method relies on an accurate determination of the sphere's position as a function of time. Without the aid of an in-situ detection method, we must rely on quench experiments. In order to verify that our quench technique is suitable for the expected viscosities that we intend to measure in this project, we have already carried out a series of in-situ viscometry experiments at the Spring-8 synchrotron radiation facility in Japan. These experiments take advantage of very intense xray radiation to visually observe the sphere's path by density contrast imaging (see Figure 1 below). We have measured the viscosity of an albite composition liquid containing various amounts of dissolved water (up to 2.7 wt%). The experiments were carried out at 2.5 GPa and 1500ºC. We will carry out falling sphere experiments using our quench technique on the same samples at the same conditions to evaluate the accuracy of our technique. We also expect the possibility of carrying out future in-situ viscometry measurements at Spring-8 in the event that our quench technique is less reliable in the very low viscosity regime.

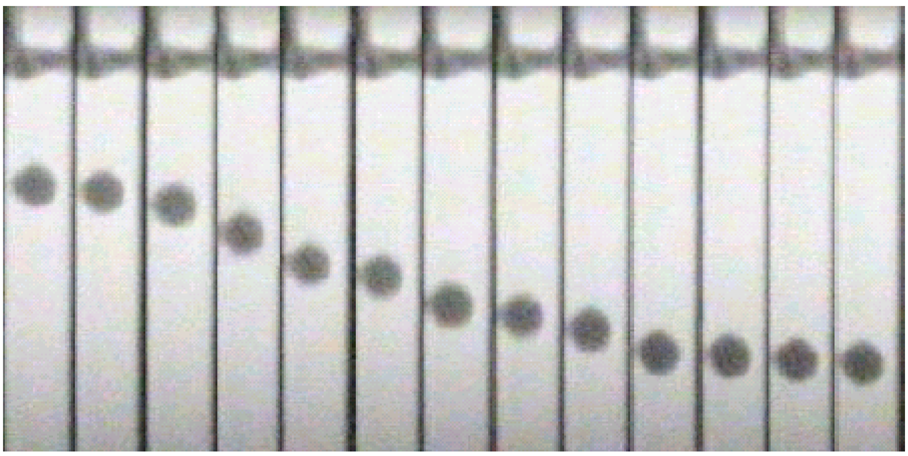


Figure 1. A series of 13 density contrast images acquired over an interval of approximately one second as a platinum sphere (radius 250 μ) falls due to the force of gravity in a silicate liquid at high-pressure and high-temperature. The terminal velocity (sphere's fastest decent, evident in the central images) is used in the Stoke's equation to determine the viscosity of the liquid. The dark object near the top of each

image is the thermocouple and is used as a point of reference for determining the sphere's position, as well as determining the temperature.

The High Pressure High Temperature Laboratory of experimental Volcanology and Geophysics of Istituto Nazionale di Geofisica e Vulcanologia – Rome

The proposed research will be developed at the HP-HT Laboratory of the INGV in Rome.

The laboratory is equipped with a 750 tons press that can be used either as a multianvil press or as a piston cylinder press.

The press, indeed, is supplied with a high-pressure "Walker type pressing-tool" for a maximum pressing force up to 800 tons which allows to perform experiments at pressure up to 25 GPa and temperature up to 3000 K. Alternatively, in the press can be inserted a second "hydraulic cylinder", with a maximum pressing force of 200 tons which allows to perform experiments up to 4 GPa of pressure and 2000 K of temperature.

Thus, for this project purpose the press will be equipped with the "hydraulic cylinder" in order to be used in its piston cylinder configuration. Moreover, in the press equipped with the "hydraulic cylinder" it is possible to perform experiments by using two different size autoclaves (_ inch and 1 inch). This will allow to use sample capsules larger than usually used (larger than 5 mm in diameter and 10 mm long) and this will probably help in determine the wall and end capsule correction in equation (1) easier.

The laboratory is of course equipped also with all the tools and the instruments (i.e. high temperature oven, high precision balance, microscopes, high precision saw, etc.) necessary for making the experiments described above.

Financial request (in kilo euro)

Consumables platinum capsules and spheres; items for making the assemblies (i.e. graphite furnaces, crushable alumina, salt, Pyrex); thermocouple wire, etc.	10
Personnel 1 year research contract full time dedicated	15
Travel **1 person 10 days at the Spring 8 Synchrotron laboratory (Hyogo, Japan)**	3
Other general costs i.e. Publications	2
Total	**30**

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GRUPPO NAZIONALE PER LA VULCANOLOGIA

2000-2002 Frame Program
Executive Plan for Second Year of Activity, July 2001

TITLE OF PROJECT: Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

COORDINATOR: Paolo Papale, Istituto Nazionale di Geofisica, at Dip.to Scienze della Terra, via S. Maria 53, 56126 Pisa, tel. 050 847 273, fax 050 500 675, papale@dst.unipi.it

RESEARCH LINE: Phlegrean Fields

LENGTH OF PROJECT: 3 years

The research activity for the second year of project is outlined in the Executive Plan sent to the Gruppo Nazionale per la Vulcanologia at the beginning of project. We will follow that Plan, and will accomplish the third year milestones indicated there and reported below, provided that we will have the necessary financial support to do that, as specified in the first page of the original approved Executive Plan, and according to the letter sent to the GNV on March 5th, 2001, where we outlined the necessity of a reduction of the initial too severe cut-off, and to the financial request included below.

Please, also note that according to the request above, we propose to add a new Research Unit (# 7) to the project structure, and a corresponding new Research Task (2.7), detailed in the proposal from the HP-HT laboratory group of the INGV Rome included above. Accordingly, we include the corresponding financial request in the project request below.

The new project structure is the following:

Research Unit 1.

Scientific Responsible: Paolo Papale – Istituto Nazionale di Geofisica e Vulcanologia, Pisa

Collaborators:
Patrizia Landi – Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Antonella Bertagnini – Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Carmela Freda – Istituto Nazionale di Geofisica e Vulcanologia, Roma
Augusto Neri – CNR-IGG, Pisa
Mauro Rosi - Dipartimento Scienze della Terra – Pisa
Margherita Polacci – Dipartimento Scienze della Terra – Pisa
Daniele Giordano – DEES Univ. Munich

Piergiorgio Scarlato – Istituto Nazionale di Geofisica e Vulcanologia, Roma
Malcolm J. Rutherford – Brown Univ. RI
Angela Roach – Brown Univ. RI

Research Unit 2.

Scientific Responsible: Mauro Rosi - Dipartimento Scienze della Terra – Pisa

Collaborators:
Antonella Bertagnini - Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Patrizia Landi - Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Paolo Papale – Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Augusto Neri – CNR-IGG, Pisa
Margherita Polacci – Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Andrea Di Muro – Dipartimento di Scienze della Terra – Pisa
Laura Pioli – Dipartimento di Scienze della Terra – Pisa
Daniele Giordano – DEES Univ. Munich

Research Unit 3.

Scientific Responsible: Claudia Romano – Dipartimento di Scienze Geologiche, Roma Tre, Rome

Collaborators:
Don B. Dingwell – DEES Univ. Munich
Carmela Freda – Istituto Nazionale di Geofisica e Vulcanologia, Roma
Brent Poe – Univ. Of Chieti and INGV Rome
Oliver Spieler – DEES, Univ. Munich
Daniele Giordano – DEES Univ. Munich
Lucio Costa - Dipartimento di Scienze Geologiche, Roma
Tre, Rome
Valeria Misiti - Dipartimento di Scienze Geologiche, Roma
Tre, Rome
Don Baker – McGill Univ. Montreal

Research Unit 4.

Scientific Responsible: Augusto Neri – CNR-IGG – Pisa

Collaborators:
Paolo Papale - - Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Mauro Rosi - Dipartimento di Scienze della Terra, Pisa

Dimitri Gidaspow – Illinois Institute of Technology, Chicago
Tomaso Esposti Ongaro - Dipartimento di Scienze della Terra – Pisa
Andrea Di Muro – Dipartimento di Scienze della Terra – Pisa
Micol Todesco – Istituto Nazionale di Geofisica e Vulcanologia, Bologna

Research Unit 5

Scientific Responsible: Malcolm J. Rutherford – Brown Univ. RI

Collaborators:
Angela Roach – Brown Univ. RI
Patrizia Landi - Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Paolo Papale – Istituto Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Margherita Polacci – Istituto Istituto Nazionale di Geofisica e Vulcanologia, Pisa

Research Unit 6

Scientific Responsible: Donald B. Dingwell – DEES Univ. Munich

Collaborators:
Oliver Spieler – DEES Univ. Munich
Daniele Giordano – DEES Univ. Munich
Claudia Romano – Dipartimento di Scienze Geologiche, Roma Tre, Rome
Patrizia Landi - Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Paolo Papale – Istituto Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Margherita Polacci – Istituto Istituto Nazionale di Geofisica e Vulcanologia, Pisa
Carmela Freda – Istituto Nazionale di Geofisica e Vulcanologia, Roma
Piergiorgio Scarlato – Istituto Nazionale di Geofisica e Vulcanologia, Roma

Research Unit 7

Scientific Responsible: Piergiorgio Scarlato – INGV sez. Roma1, HP-HT laboratori group, Rome

Collaborators:
Brent Poe – University of Chieti and INGV Rome
Carmela Freda – INGV sez. Roma1, HP-HT laboratori group, Rome
Daniele Giordano – DEES Univ. Munich
Claudia Romano – Dipartimento di Scienze Geologiche, Roma Tre, Rome

Paolo Papale – Istituto Istituto Nazionale di Geofisica e Vulcanologia, Pisa

MILESTONES FOR THIRD YEAR OF ACTIVITY

TASK 1.1: Selection of stratigraphic layers of major interest for the project, reconstruction of their stratigraphy and dispersal, and sampling

Grain-size and componentry of the Astroni eruption.

TASK 2.1: Petrochemical study of volcanic products

Further analysis of samples from Monte Nuovo eruption, and analysis of samples from Astroni eruption.

TASK 2.2: Determination of magma viscosity

Parameterization of rheology of crystal- and bubble-bearing magmas.

TASK 2.3: Experimental Petrology Studies

Synthesis of results; additional experiments on kinetics of magma ascent or mixing.

TASK 2.4: Experimental determination of magma strength and fragmentation behavior

Parameterization of textural controls on strength and fragmentation efficiency.

TASK 2.5: Determination of volatile diffusivity

Water and carbon dioxide diffusion experiments to evaluate the role of different water contents; dependence of diffusion coefficients on pressure.

TASK 2.6: Textural characterization of pyroclasts

Completion of the study on Monte Nuovo and Astroni samples.

TASK 2.7: High pressure viscosity measurements of hydrous silicate liquids using the falling sphere viscometry in a piston cylinder apparatus

Determination of the hydrous viscosities of selected samples with trachytic composition from the 36,000 BP Campanian Ignimbrite, 4500 BP Agnano Monte Spina, and 1538 AD Monte Nuovo eruptions, at temperatures approaching those estimated during eruptions.

TASK 3.1: Numerical simulations of magma ascent dynamics

Additional simulations of the Agnano Monte Spina eruption; simulations of the Astroni eruption; investigation of the dependence of magma ascent dynamics on different magma compositions corresponding to different reference eruption; other simulations to include further results from other tasks.

TASK 3.2: Numerical simulation of gas/pyroclast dispersion processes and pyroclastic flow dynamics

Completion of the Agnano Monte Spina simulations; comparison of numerical results with field evidence; evaluation of hazard implications; possibly, simulation of eruptive scenarios pertaining to other reference eruptions.

NEXT PROJECT MEETING: a next and final project meeting is planned for September 2003, 3 months before the end of project (December 2003).

COSTS FOR THIRD YEAR OF ACTIVITY

(Amounts in keuros)

	RU 1		**RU 2**		**RU 3**		**RU 4**		**RU 5**		**RU 6**		**RU 7**		**Total**
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	
DM	5				2		2.2								**9.2**
C,GC		2.8		6.5		1.5		6.5		6		3		9.8	**36.1**
TS		2		4.3		1		1.3		1.5					**10.1**
CP		15.2		13		13								15.2	**56.4**
MC		5		5.6		1.5		4.3		5		2		3	**26.4**
P		5		1.7		1		2.2		3		1.5		2	**16.4**
O		2		3.4											**5.4**
Total	**5**	**32**		**34.5**	**2**	**18**	**2.2**	**14.3**		**15.5**		**6.5**		**30**	**160**

Legenda:

DM: Durable Material
C,GC: Consumables and other General Costs
TS: Travel and Subsistence
CP: Contracts for temporarily employed personnel
MC: Meetings and Congresses
P: Publications
O: Other costs (mainly analytical costs)

GRUPPO NAZIONALE PER LA VULCANOLOGIA

2000-2002 Frame Program - Second Year Report, December 2002

TITLE OF PROJECT: Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

COORDINATOR: Paolo Papale, Istituto Nazionale di Geofisica e Vulcanologia, sede di Pisa, via della Faggiola 32, 56126 Pisa, tel. 050 8311931, fax 050 8311942, e-mail papale@pi.ingv.it

RESEARCH LINE: Phlegrean Fields

LENGTH OF PROJECT: 3 years

RESEARCH UNITS:

1. Paolo Papale, Istituto Nazionale di Geofisica e Vulcanologia, Pisa
2. Mauro Rosi, Dipartimento di Scienze della Terra, Università di Pisa
3. Claudia Romano, Dipartimento di Scienze Geologiche, Università Roma Tre
4. Augusto Neri, Istituto di Geoscienze e Georisorse, CNR Pisa
5. Malcolm J. Rutherford, Department of Geological Sciences, Brown University, RI, USA
6. Donald B. Dingwell, Department of Earth and Environmental Sciences, University of Munich, Germany

Other key participants (task responsibles):

Don Baker, McGill University, Montreal
Antonella Bertagnini, INGV Pisa
Carmela Freda, INGV Roma
Patrizia Landi, INGV Pisa
Margherita Polacci, INGV Pisa

Including: UR activity report

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 1, Responsible: Paolo Papale, Researcher, Istituto Nazionale di Geofisica e Vulcanologia, Pisa

ACTIVITY REPORT –2nd YEAR

UR PARTICIPANTS:

Name-Position	Affiliation	Man/month
Paolo Papale, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	4
Patrizia Landi, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	0.5
Antonella Bertagnini, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	0.5
Margherita Polacci, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	7
Augusto Neri, Head Researcher	CNR – Istituto di Geoscienze e Georisorse	0.5
Mauro Rosi, Full Professor	Dipartimento di Scienze della Terra, Univ. Pisa	0.5
Carmela Freda, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Roma	0.5
Daniele Giordano, post PhD	DEES, University of Munich	1
Piergiorgio Scarlato, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Roma	0.5
Dario Del Seppia, Contract Researcher	CNR – Istituto di Geoscienze e Georisorse, and DST – Università di Pisa	4

- II YEAR OBJECTIVES

Within TASK 2.6 – Textural characterization of pyroclasts: Completion of the study on Agnano Monte Spina samples, and to an intermediate/advanced stage on Monte Nuovo samples.

Within TASK 3.1 - Numerical simulations of magma ascent dynamics: Completion of simulations for the Campanian Ignimbrite eruption; accurate analysis of the ascent dynamics for the Agnano Monte Spina eruption (maximum expected event); evaluation of consistency between numerical modeling results, experiments, and textural analysis; preliminary simulations of Monte Nuovo eruption.

- II YEAR RESULTS

TASK 2.6: The task objectives have been fully accomplished. The textural characterization of pumice clasts from the Campanian Ignimbrite and Agnano Monte Spina eruption has been completed, and the analysis of the Monte Nuovo eruption has been carried out at an intermediate/advanced stage. Main results are constituted by the recognition of different types of pumice clasts based on their macroscopic and microscopic features, and their classification into three main classes interpreted to reflect horizontal distribution of flow conditions within the volcanic conduit. In detail, magma flowing from central conduit regions gives origin to the most abundant microvesicular pumice type, magma flowing close to the conduit walls gives origin to the expanded pumice type (>0 – 5 vol% of the deposits), and magma flowing in intermediate regions gives origin to tube pumice (>0 – 5 vol%). The process responsible for the generation of expanded pumice is recognised to be viscous heating due to large velocity gradients close to conduit walls, which originated a localised temperature increase and associated viscosity decrease which allows gas expansion up to large or very large (> 90) volume percentage. Tube pumice reflects a larger extension toward the inner conduit region of the velocity with respect to the thermal boundary layer. Comparison with rhyolitic pumice reveals that the subdivision into three main classes appears to be a generalised feature of explosive volcanic eruptions, and shows that vesicularity of trachytic pumice overlaps with that of rhyolitic pumice, but tends to be slightly larger than that (75-85 vol% for the former, and 65-80% for the latter).

TASK 3.1: The task objectives have been accomplished to a >90% level. Conditions pertaining to the Agnano Monte Spina eruption have been deeply investigated by employing the information from all the field and laboratory tasks, and the numerical simulations of magma ascent and fragmentation have been coupled to those of gas-pyroclast dispersion in the atmosphere and along pyroclastic flows at task 3.2. For a subset of simulations, the possible roles of the presence of carbon dioxide in the magma, which is revealed by the laboratory task 2.3, have been also investigated, still by coupling conduit and atmospheric dispersal dynamic simulations (see also task 3.2). A deep comparative investigation of the dynamics of trachytic and rhyolitic eruptions, started during the first year of project, has been accomplished, revealing strong non-linear relationships between magma viscosity (as determined at the laboratory task 2.2), compositional-dependent water solubility, and mass flow-rate of the eruption. Numerical simulations of magma ascent for conditions pertaining to the Campanian Ignimbrite, the eruption with highest intensity in the volcanic history of Phlegrean Fields, has revealed that the ultra-Plinian character of this eruption is totally accounted for by the lower viscosity (still determined at the laboratory task 2.2), higher temperature of magma, and shallower magma chamber with respect to the Agnano Monte Spina eruption. No need to invoke a role of much wider magma chamber is therefore necessary to explain the much higher mass flow-rate of the Campanian Ignimbrite eruption with respect to other explosive eruptions at Phlegrean Fields, implying that the depth of magma chamber and the kind of magma contained in it can be more crucial than the size of the chamber itself in determining a high or very high volcanic hazard.
Additional research in collaboration with R. Moretti (OV-INGV) and G. Ottonello (DIPTERIS Univ. Genova), which will be applied to Phlegrean Fields eruptions during the third year of project, has led to a new modelling and computer code for calculating the saturation surface of multicomponent H2O+CO2+S volatiles in natural magma as a function of magma composition. At present, this new model is being included within the magma ascent code, what will allow to get to a more reliable representation of the eruption dynamics for S-rich eruptions at Phlegrean Fields.

Research products

N. 2 publications in press in international journals
N. 2 publications submitted in international journals
N. 1 invited presentations at international meetings
N. 8 presentations at international meetings
N. 1 technical report
N. 1 published database of scientific publications on Phlegrean Fields (http://gnv.ingv.it)
N. 1 new computer code
N. 1 degree thesis (in preparation)

Publication list (papers sub-judice not included)

M. Polacci, M. Pioli, M. Rosi (2002a) The Plinian Phase of the Campanian Ignimbrite eruption (Phlegrean Fields, Italy): evidence from density measurements and textural characterization of pumice. Bull. Volcanol., in press.

Moretti R., P. Papale, G. Ottonello (2003) A model for the saturation of C-O-H-S fluids in silicate melts. In: *Volcanic Degassing: experiments, models, observations and impacts* (Eds. Oppenheimer C., Pyle D.M., Barclay J.). Geological Society of London. In press

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 2, Responsible: Mauro Rosi, Full Professor, Dipartimento di Scienze della Terra, University of Pisa

ACTIVITY REPORT –2nd YEAR

UR PARTICIPANTS:

Name-Position	Affiliation	Man/month
Mauro Rosi, Full Professor	Dipartimento di Scienze della Terra, Università di Pisa	3
Patrizia Landi, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	3
Antonella Bertagnini, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	3
Paolo Papale, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	0.5
Margherita Polacci, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	4
Augusto Neri, Head Researcher	CNR – Istituto di Geoscienze e Georisorse, Pisa	0.3
Daniele Giordano, post PhD	IMPG Univ. Munich	1
Andrea Di Muro, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	1
Laura Pioli, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	1

- II YEAR OBJECTIVES

Within TASK 1.1 - Selection of stratigraphic layers of major interest for the project, reconstruction of their stratigraphy and dispersal, and sampling: Stratigraphy, grain-size, componentry and sampling of the deposits of Monte Nuovo eruption; stratigraphy and sampling of the deposits of the Astroni eruption.

Within TASK 2.1 - Petrochemical study of volcanic products: Analyses on samples from Monte Nuovo eruption, to an advanced stage; MI studies on samples from Campanian Ignimbrite and Agnano Monte Spina eruptions.

- II YEAR RESULTS

TASK 1.1: The task objectives have been accomplished to an 80% level. Namely, the stratigraphy, componentry, grain-size, and sampling of the Monte Nuovo eruption, and the sampling of the Astroni eruption for laboratory tasks 2.1-6, have been accomplished. Additionally, further investigation of the Agnano Monte Spina eruption has been carried out, in order to investigate stratigraphic layers the origin of which was previously interpreted as from pyroclastic flows. Our new field investigation suggests instead a prevalent fallout origin, implying less strong implications for the volcanic hazard. The investigation of the Monte Nuovo eruption led us to define a lower (LM) and upper member (UM) in the stratigraphic succession. Mud-flow deposits and an erosion surface with gullies mark the boundary between the deposits of the LM and UM. The LM is mainly made up of massive to cross bedded ash and pumice deposits emplaced by pyroclastic density currents, alternating with accretionary-lapilli-rich ash fall layers. Medium sorted, rather continuous, clast supported pumice fall layers are present at different levels. Ballistic blocks and pumiceous bombs up to tens of decimetres are common and increase in the upper part of the sequence. Non juvenile material is scarce and surficial, being mainly constituted of fragments of yellow tuffs and pumice of the Averno eruption. On the whole the characteristics of deposits and some textural features such as presence of accretionary and armored lapilli, vesiculated tuffs suggest that the first phase of the eruption was dominated by pulsating, hydromagmatic, low-energy explosions originated by interaction with sea water and/or shallow aquifers. The UM consists of two main units which form the uppermost part of the Monte Nuovo cone and show a fairly radial dispersal. They are coarse, dark grey deposits with variable matrix content, mostly made up of juvenile clasts with variable density and vesicularity (see task 2.6). The characteristics of deposits suggest that they were emplaced through prevalent pyroclastic flow dynamics, and were originated by violent explosions of a magma plug, driven by exsolution and expansion of magmatic volatiles.

TASK 2.1: The task objectives have been accomplished to a 60% level. Namely, the petrochemical analysis of samples from the Monte Nuovo eruption has been conducted to an advanced stage. Whole rock major and trace element analyses, mineral chemistry, and compositions of microlites and glass of the groundmass were performed. All the products are trachytes/phonolites with slight peralkaline chemistry, and show subaphyric texture with rare phenoceysts of K-feldspar and subordinate amphibole, clinopyroxene, oxide and sphene. Plagioclase is found as crystals with large rims of K-feldspar, and in aggregates of crystals together with K-feldspar, oxide and sphene. Such aggregates, even if rare, are mainly found in the pumice of the LM. The groundmass ranges from glassy with scarce microlites of K-feldspar in vesiculated pumice, to nearly holocrystalline with abundant microlites, up to 300-400 μm, and grains of oxides in scoriae of the final activity. The cristallinity of the groundmass appears related to the vesicularity of the products (see task 2.6). As a whole, the erupted products cover a narrow compositional range. Mineral chemistry appears homogeneous throughout the entire sequence and consists of: K-feldspar Or 62-70, ferropargasitic amphibole, oxide Usp 32-33, clinopyroxene Fs 20.5-23.5, sphene with TiO2=35-36 wt% and plagioclase with antirapakivi texture An27-35. Crystals in aggregates have the same composition than the single crystals. Analyses of the groundmass highlight a wide compositional range of the matrix glasses, as a result of different crystallinity. Average compositions range from SiO2=59.3, Na2O+K2O=14.7 in the pumice of the Lower Member, to SiO2=57, Na2O+K2O=15.4 in the scoriae of the Upper member. Feldspars microlites range in composition from Or20-25, AN18-22 to Or55-60, An4-5 and, compared with those of the scoriae of the UM, mirolites of the pumice of the LM show higher content of CaO (Fig. 2). The variations in the content and composition of microlites in the groundmass of the products of LM and UM, associated with textural variations (see task 2.6), suggests sin-eruptive crystallization mainly due to different degassing modes, possibly related to changes in eruptive dynamics.

Research products

N. 2 degree thesis
Set of selected samples from Phlegrean Fields eruptions for laboratory investigations

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 3, Responsible: Claudia Romano, Researcher, Dipartimento di Scienze Geologiche, Università Roma Tre

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Claudia Romano, Researcher	Dipartimento di Scienze Geologiche, Univ. Roma Tre	2
Donald B. Dingwell, Professor	DEES, University of Munich	0.5
Carmela Freda, Contract Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Roma	3
Don Baker, Associate Professor	McGill University, Montreal	1
Daniele Giordano, Post PhD	DEES, University of Munich	3
Brent Poe, Associate Professor	Dipartimento di Scienze Geologiche, Università di Chieti	1
Valeria Misiti, PhD Student	Dipartimento di Scienze Geologiche, Univ. Roma Tre	0.5
Lucio Costa, PhD Student	Dipartimento di Scienze Geologiche, Univ. Roma Tre	0.5

- II YEAR OBJECTIVES

Within TASK 2.2 - Determination of magma viscosity: Parameterization of rheology of crystal-bearing magmas (in collaboration with RU 6).

Within TASK 2.5 - Determination of volatile diffusivity: Carbon dioxide diffusion experiments at constant pressure and different temperatures; analysis of the experimental products; determination of carbon dioxide diffusion coefficients.

- II YEAR RESULTS

TASK 2.2: The task objective has not been accomplished, due to much longer time than expected required to have the instrumentation available at the DEES of Munich University (RU 6). However, the research responsible and participants, together with research responsible of RU 6 collaborating to the research, do not feel the need for a re-modulation of the three-years research objectives. The instrumentation will be available in a short time since now (2 months), and more resources will be dedicated to the accomplishment of the second and third year objectives during the third year of project. The responsible of this RU and of RU 6 feel confident that the three years objectives will be fully accomplished.

During the second year of project the determination and parameterization of the viscosity-temperature-H_2O relationships for liquid magmas from Phlegrean Fields has been completed, by adding the Monte Nuovo and Astroni determinations to those of Agnano Monte Spina and Campanian Ignimbrite performed during the first year of project. Therefore, the first year objectives are now fully accomplished. The results show that although the viscosity of all analysed trachytes from Phlegrean Fields fall in a well defined region of viscosity-temperature-water content space, significant variations up to more than one order of magnitude in viscosity are possible depending on the specific composition (or eruption) considered. Since viscosity has a controlling role in the eruption dynamics (see task 3.1), it follows that knowledge of the specific composition of magma in the present Phlegrean Fields magma chamber is required to properly address future volcanic scenarios and forecast the volcanic hazard. Due to the above delay in setting up a procedure for the accomplishment of the 2nd year objectives, additional aspects of the physical properties of magmas from Phlegrean Fields were investigated. Namely, we determined the isobaric heat capacities of dry and hydrous liquids for products of Monte Nuovo and Campanian Ignimbrite eruptions. The isobaric heat capacity of silicate melts (Cpl) is a crucial property for modelling the thermal evolution of magma during volcanic processes, for phase equilibrium calculations, and for the theoretical investigation of the physical properties and structure of silicate liquids (Courtial and Richet, 1993; Yoder 1976; Carmichael et al. 1977). Our determinations of the hydrous heat capacities for natural magmas are among the first data of this kind in the international literature, and the first for trachytic compositions. The data are now being analysed in order to derive constitutive equations that can be used in energy balance calculations within the thermo-fluid dynamic modelling of volcanic eruptions at tasks 3.1 and 3.2.

TASK 2.3: The task objectives have been accomplished at a 90% level. We have performed all of the necessary experiments on CO_2 diffusion, but have not yet successfully analyzed the run products by ion microprobe. We are sending out the run products for analysis by another technique, FTIR, and expect the results before the end of February 2003. In addition to our experiments on CO_2 diffusion, we used our water diffusion data collected in the first year of the research project in order to achieve part of the third year milestone which is to determine diffusion as a function of water concentration at constant pressure in the trachytic melt. In addition to our work on CO_2 diffusion during the second year, we reduced our water diffusion data for the D1 composition from the Agnano Monte Spina eruption in order to obtain a general equation for the prediction of water diffusion in the trachytic composition at all conditions studied. Our results indicate that water diffusion coefficients for a trachytic composition vary from the minimum value of 5.99×10^{-12} m^2 s^{-1} at 1100 °C and 0.25 wt% of H_2O to the maximum value of 2.77×10^{-10} m^2 s^{-1} at 1400 °C and 2.0 wt% water. In the range of temperatures and water content we investigated, water diffusion is described by Arrhenius equations that has been combined to yield a general equation for the prediction of water diffusion in the trachytic composition at concentrations up to 2 wt%. Water diffusivities in trachytic melt were compared to water diffusivities in rhyolitic and basaltic melts. The activation energies for water diffusion in trachytic (this study) and basaltic (Zhang & Stolper 1991) melts at a water concentration of 0.25 wt% are comparable: 172±57 and 126±32 kJ mol^{-1}, respectively. The activation energy for water diffusion in the trachytic melt with 0.5 wt% water, 164±10 kJ mol^{-1}, is slightly higher than the activation energy of water diffusion in a haplogranitic melt with 0.5 wt% water, 147±42 kJ mol^{-1} (Novak & Behrens (1997). This behaviour results in the convergence of diffusion coefficients at lower (magmatic) temperatures and divergence at higher temperatures. The difference between water diffusivities in trachytic and haplogranitic melts becomes significant when 2 wt% water is added to the melts.

Research Products

N. 7 publications printed or in press in international books/journals
N. 4 publication submitted for international journals
N. 9 presentations at international meetings

Publication list (papers sub-judice not included)

8. C. Freda, D.R. Baker, C. Romano, P. Scarlato (2003). *Water diffusion in natural potassic melt*. In Volcanic Degassing: experiments, models, observations and impacts (eds. Oppenheimer C., Pyle D.M., Barclay J.). Geological Society of London. In press.
9. J.K. Russell, D. Giordano, K.U, Hess and D.B. Dingwell (2002) Modelling the non-Arrhenian rheology of silicate melts: numerical considerations. Eur. J. Mineral. 14, 417-427.
10. J. Gottsmann, D. Giordano and D.B. Dingwell (2002) Predicting shear viscosity during volcanic processes at the glass transition: a calorimetric calibration. Earth Planet. Sci. Lett. 198, 417-427.
11. D. Giordano and D.B. Dingwell (2003) Viscosity of Etna Basalt: implications for Plinian-style basaltic eruptions. Bull. Volcanol., in press – DOI format-published online.
12. D. Giordano and D.B.Dingwell (2003) The “kinetic” fragility of natural silicate melts: constraints using Vogel–Fulcher-Tammann equation. Jour. Phys.: Non-Cond. Matter, in press.
13. D. Giordano and D.B. Dingwell (2003) Non-Arrhenian Multicomponent Melt Viscosity: A Model. Earth Planet. Sci. Lett., in press.
14. C. Romano, D. Giordano, P. Papale, V. Mincione, D. B. Dingwell, M. Rosi (2003) The dry and hydrous viscosities of alkaline melts from Vesuvius and Phlegrean Fields. Chemical Geology, in press.

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 4, Responsible: Augusto Neri, Centro di Studio per la Geologia Strutturale e Dinamica dell'Appennino, CNR Pisa

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Augusto Neri, 1st Researcher	CNR – Istituto di Geoscienze e Georisorse, Pisa	4
Tomaso Esposti Ongaro, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	4
Andrea Di Muro, PhD Student	Dipartimento di Scienze della Terra, Univ. Pisa	4
Paolo Papale, Researcher	Istituto Nazionale di Geofisica e Vulcanologia, Pisa	1
Mauro Rosi, Full Professor	Dipartimento di Scienze della Terra, Univ. Pisa	1
Micol Todesco, Contract Researcher	Dip. Scienze Geologiche, Univ. Bologna	1
Dimitri Gidaspow, Full Professor	Illinois Institute of Technology, Chicago	1
Dario Del Seppia, PhD student	Dipartimento di Scienze della Terra, Univ. Pisa	2

- II YEAR OBJECTIVES

  Within TASK 3.2 - Numerical simulation of gas/pyroclast dispersion processes and pyroclastic flow dynamics:
  Simulations of the Agnano Monte Spina eruption with vent conditions from the magma ascent modeling.

- II YEAR RESULTS

TASK 3.2: The task objectives were fully accomplished. A total of 15 numerical simulations of gas-pyroclast dispersion dynamics in the atmosphere and along pyroclastic flows have been performed in order to investigate conditions pertaining to the Agnano Monte Spina eruption at Phlegrean Fields. Fortheen of them were performed by employing vent conditions as determined by numerical simulations of magma ascent dynamics at task 3.1. Main results include the followings: for both the B1 and D1 eruptive phases investigated, a water content between 4 and 6 wt% is required to reproduce the transitional eruptive style reconstructed from the field investigation at task 1.1; the uncertainty on mass flow-rate for each considered eruptive phase does not affect the above conclusion, but it significantly modifies the runout of pyroclastic flows and the details of the gas-pyroclast disperion dynamics; addition of carbon dioxide up to 2 wt%, although deeply changing the flow conditions in the deep conduit region (see task 3.1), does not significantly modify the sub-aerial eruption dynamics. In addition to the above simulations, several others were performed in order to investigate the partition of the mass of pyroclasts between the different regions of the sub-aerial gas-pyroclast dispersion. Simulation results allowed us to quantify the mass of pyroclasts of different sizes forming the pyroclastic density current, the phoenix column and the convective plumes rising from the proximal area of the flow and above the fountain. In particular the simulations allowed to better understand the dynamics of columns at the transition between the buoyant and collapsing regimes. Such a regime is characterized by greater collapse height, generation of dilute density currents, shorter flow runout, less steady behavior of the column, and intermittent feeding of the flows.

Research products

N. 4 papers printed or in press in international journals
N. 2 presentations at international meetings

Publication list (papers sub-judice not included)

5. Esposti Ongaro T., A.Neri, M.Todesco, G.Macedonio, Pyroclastic flow hazard at Vesuvius by using numerical simulations. II. Analysis of local flow variables. *Bull. Volcanol*. 64:178-191, 2002.
6. Neri A., T.Esposti Ongaro, G.Macedonio, D.Gidaspow, Multiparticle simulation of collapsing volcanic columns and pyroclastic flows. *J. Geophys. Res, in press.*
7. Neri A., A. Di Muro, M. Rosi, Mass partition during collapsing and transitional columns by using numerical simulations. *J. Volcanol. Geotherm. Res.,* 115:1-18, 2002.
8. Todesco M., A.Neri, T.Esposti Ongaro, P.Papale, G.Macedonio, R.Santacroce, A.Longo, Pyroclastic flow hazard at Vesuvius by using numerical simulations. I. Large-scale dynamics. *Bull. Volcanol.* 64:155-177, 2002.

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 5, Responsible: Malcolm J. Rutherford, Department of Geological Sciences, Brown University, RI - USA

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Malcolm J. Rutherford, Full Professor	Department of Geological Sciences, Brown University, RI	2
Angela Roach, PhD student	Department of Geological Sciences, Brown University, RI	8

- II YEAR OBJECTIVES

Within TASK 2.3 - Experimental Petrology Studies: Determination of the depth, temperature and volatile content in the pre-eruption magma storage zone; analyses of phenocrysts and melt inclusions in the Campanian Ignimbrite samples, and equilibrium experiments for these samples; possibly, similar analyses on younger eruptions.

- II YEAR RESULTS

TASK 2.3: The task objectives were accomplished at a 60% level. Volatile content analyses in glass inclusions from the Agnano Monte Spina eruption reveal the presence of abundant "minor" volatile components like F, Cl, and S, the roles of which in the magma and eruption dynamics should be evaluated. Water contents range from 1 to 3 wt%, and carbon dioxide contents up to 2000 ppm are found. Carbon dioxide turns out to be totally dissolved in the form of CO_3^{2-}. The volatile content of Agnano Monte Spina melt inclusions suggests a pre-eruption magma storage zone at ~80 MPa (Fig. 1). Our interpretation of the analytical data is that early-formed phenocrysts grew with both CO_3 and H_2O dissolved in the melt at a pressure of 80-100 MPa. A few melt inclusions in pyroxene were trapped in this environment. With continued crystallization, CO_2 was preferentially partitioned into an exsolved volatile phase and the volatiles remaining in the melt evolved to an increasingly water-rich and Cl-enriched composition (e.g. Wallace et al., 1995). Initially, we suggested that the magma storage region would be located at pressures >1kb due to the likelihood of leucite crystallizing at lower pressures. However, we have not produced leucite in experiments as low as 500 bar. Further, to obtain stable sanidine phenocrysts at temperatures as high as 890°C (as determined by P. Landi), the pressure must be less than ~90 MPa. This information, combined with the melt inclusion data, suggests that the magma storage region was located at ~80 MPa and that the melt was water-saturated at these conditions. We interpret the CO_2-rich melt to have been present at an earlier stage (time) of magma evolution, based on the lower Cl in the CO_3-bearing melt (glass) compared to the H_2O-rich melt, but a similar magma may have existed below the H_2O-enriched magma.

Research results

N. 1 technical report

Simulation of Eruptive Scenarios at Phlegrean Fields Based on Field, Laboratory, and Numerical Studies, and Implications for Volcanic Hazard

RU 6, Responsible: Donald B. Dingwell, Department of Earth and Environmental Sciences, Munich University

ACTIVITY REPORT –1° YEAR

UR PARTICIPANTS:

Name, Position	Affiliation	Man/month
Donald B. Dingwell, Full Professor	Department of Earth and Environmental Sciences, Munich University	2
Oliver Spieler, Researcher	Department of Earth and Environmental Sciences, Munich University	3
Sebastian Mueller, PhD student	Department of Earth and Environmental Sciences, Munich University	2
Bettina Schau, PhD student	Department of Earth and Environmental Sciences, Munich University	2

- II YEAR OBJECTIVES

Within TASK 2.2 - Determination of magma viscosity: Parameterization of rheology of crystal-bearing magmas (in collaboration with RU 3).

Within TASK 2.4 - Experimental determination of magma strength and fragmentation behavior: Parameterization of grain-size distribution-determining factors as a function of pressure, temperature, and rate of pressure decrease.

- II YEAR RESULTS

TASK 2.2: the results pertaining to this task are described in the Activity Report by the RU 3.

TASK 2.4: the task objectives have been accomplished at a 60% level, taking into account that results from the first year of investigation suggested a re-direction of task objectives for the second year, in order to understand them. Investigation to be performed during the third year of project will take into account, besides the objectives specific for that year, also the original objective for second year.

Fragmentation thresholds in terms of pressure differential determined for trachytic samples from Phlegrean Fields eruptions reveal too high values when compared to the general trend shown by several other natural samples of different composition. Due to this particular result, and to the great relevance that the modalities of magma fragmentation have on the eruptive dynamics, detailed investigation of the relationships between sample porosity and permeability were performed. Trachytic samples are indeed characterized by very large porosity, the highest among natural samples we have ever investigated for fragmentation in the lab. We have found that such a large porosity corresponds to comparative high values of permeability, possibly also enhanced by the presence of several cooling fractures in the analysed samples. The experimental data need comparison to textural and density information from field investigations. We found that the grain size of the experimentally produced fragments were larger than expected. Our interpretation takes the extreme high gas flow rate and the shape of the decompression front into account. The internal ΔP_{fr} is not exceeded in the expected geometry, since the decompression front will easily enter large pores. Since the gas can easily escape less mechanical energy of the expanding gas phase is applied to the glass matrix. The dependency of pore size and resulting fragment size needs closer examination.

Research products

N. 9 presentations at international meetings