# PROJECT V3

# Sub-Project V3_5 – Vulcano

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## State of the Art

Vulcano lays along a NNW-SSE oriented regional strike-slip fault acting on a thinned continental crust (18-20 km). The island covers an area of about 22 $km^2$ and is entirely made up of volcanic rocks. The last eruption (1888-90 A.D.) gives name to a peculiar type of explosive activity, which is characterized by numerous closely timed eruptive pulses (vulcanian activity).

At present, the island is site of intense fumarolic emissions, which are concentrated on the active crater of La Fossa cone, and of degassing activity on diverse areas of its northern sector. The high temperature of gas emissions, their chemical and isotopic composition and the knowledge of the hydrothermal and magmatic systems, leave no doubt on the presence of magmatic melts under the volcano, which in the future should give way to new eruptions.

Recent investigation that combine the geophysical information on the structure of the crust under the volcano and data deriving from the study of the fluid inclusions in crustal xenoliths, suggest the presence of various type of magmatic reservoirs at different depth, which were active in the recent past and likely represent the sites of preferential storage of present magmas. The eruptive activity of the subaerial part of the island dates back to more than 100 ka and has been characterized by the formation of various volcanic edifices that, over time, migrated from SSE toward NNW.

Recent eruptions, which were characterized by products of shoshonitic to rhyolitic composition, occurred inside a volcano-tectonic structure, La Fossa Caldera. The volcanic apparatus of Vulcanello (active between 183 B.C. and 1550 A.D.) formed along the continuation toward N of this structure. Inside this structure, in older times the most voluminous eruptions of Vulcano occurred, and later on La Fossa Cone formed, which has been the most active centre of the last 6 ka.

The eruptions of Vulcano were characterized by relatively small volumes of eruptive products (fractions of $km^3$) when compared with those of other Italian active explosive volcanoes. Anyway, the particular type of activity, which has been characterized by phreatomagmatic explosions generating pyroclastic density currents (with subordinate amounts of fallout products and lava flows), poses striking questions about the volcanic risk. This is due also to the peculiar distribution of the anthropic activities on the island (the majority of buildings is concentrated at the foot of the active cone of La Fossa) and to the fact that during summer time the population of the island grows up to many thousands people.

Studies on the eruptive mechanisms and on the volcanic hazard have been carried on in recent times at Vulcano, leading to the definition of quite coherent scenarios in the case of a renewal of the eruptive activity from the crater of La Fossa cone. However, eruptive scenarios for other areas of the island, in particular the northern sector of La Fossa Caldera, are lacking. In this area the ascent and eruption of new magma, both in subaerial and subaqueous conditions, needs to be

taken into account. The distinct probability that at longer terms it can lead to explosive activity spreading the products both over Vulcano and Lipari, as occurred in the past and testified by recent studies on the eruptions of Tufi di Grotte dei Rossi, needs to be assessed. Also, hazard maps on which are drawn the contour lines of the probability of the impact parameters expected in a future eruption represent new results to reach in this project. Furthermore, even though quite detailed studies on the structure of the volcano and on the hydrothermal–fumarolic system have been carried out in the recent past, synthetic elaboration of data leading to a clear picture of the levels of criticality of the volcano are lacking.

## Description of the Activities

In the time-span of a two years project, a significant improvement of the knowledge on the superficial and deep magmatic alimentation systems, on the volcanic hazard, and on the levels of criticality of Vulcano, can be reached only with a high level of coordination between diverse volcanological, geochemical and geophysical competences. The multidisciplinary approach that is needed for finalizing the project results to the Civil Protection requests, not only requires a tight integration and dissemination of results among research units, but also needs the focusing of efforts on specific priority tasks that then need to communicate and disseminate intermediate results in due time during the project. For this reason, the main themes of the research project are subdivided into three main tasks, each responding to particular requests and each having a coordinator that will serve as a link for the general project focusing and finalization. The three tasks are

Task 1. Eruptive products, eruptive scenarios and hazard
Task 2. Structure of the volcano

Task 3: Levels of criticality of the volcano

In the following we describe in more detail the structure of the Tasks and the relative aims

**Task 1. Eruptive products, eruptive scenarios and hazard**

RU coordinating (P. Dellino, University of Bari)
RU participating (De Astis, Osservatorio Vesuviano – Naples)

This task will be mainly devoted at understanding how the volcano worked during past eruptions, and which lesson we learn from Vulcano's past behaviour in order to forecast the type and intensity of activity in a future eruption. For this aim, the principal source of information are rocks and rock components. They will be studied by means of an integrated multidisciplinary approach that we hope will help in the products-process characterization, and in particular in constraining the relevant physical parameters representing the source of hazard, i.e. the impact parameters. After such a reconstruction, by means of experiments and calculations, scenarios will be drawn for constraining the possible impact parameters of a future eruption, and a range of expected values will be given and distributed over the territory with the eventual result of obtaining hazard maps.

The first step in this quest will be the precise stratigraphic reconstruction of deposits of the main eruptive periods, which will serve to categorize products as a function of eruptive and transportation processes and of timing and recurrence of eruptive types. This study will be carried on at La Fossa Cone by RU Dellino and at La Fossa Caldera and Vulcanello by RU De Astis.

Scenarios at short terms will consider La Fossa cone as the possible location of a new vent opening and as the most hazardous expected events the type and intensity of the recent

phreatomagmatic eruptions generating dilute pyroclastic density current will be considered. Scenarios at longer terms will consider the likelihood of the possible opening of new vents along the rims of La Fossa caldera and especially in its northern sector, which in the past probably was the source of the most intense explosive eruptions of Vulcano. The assessment of eruption characteristics of these distinct scenarios not only will consist of the volume calculation of products of past eruptions, their dispersal area and measurement of the main structural and textural features of pyroclasts (RUs Dellino and De Astis). A detailed sampling of the most significant eruptive units will also make available carefully selected material on which specific laboratory analysis will be carried on for quantitatively assessing the fragmentation and transportation dynamics of explosive events (multicomponent-multimodal grain size, shape, density and aerodynamic characterization - RU Dellino) and some processes occurred after the emplacement (alteration, pedogenesis - RU De Astis). On selected samples of pyroclastic material rheology and explosion experiments will be carried on (UR Dellino) for reconstructing both the various type of magma fragmentation processes and the budget of mechanical energy released during explosions at Vulcano. Particle characteristics will be also used for reconstructing, by numerical calculation methods, the impact parameters (velocity, particle concentration, density, dynamic pressure) of pyroclastic density currents of the most significant past eruptions. Mechanical energy information and particle characteristics will be also used as input parameters in multiphase numerical simulations, based on an Eulerian-Lagrangian approach, which will help understanding the time-space evolution of pyroclastic density currents and the distribution of impact parameters that we expect in the future scenarios. The simulations, which will be carried on by RU Dellino, will be particularly helpful in understanding the variability of the physical parameters of the currents as a function of vent location and actual topography.

Mesoscale experiments on the trasportation, dispersion and sedimentation of particles will be carried on by RU Dellino. They will involve hundreds of kilograms of actual pyroclastic particles, in a controlled environment, by forcing the flow of pressurized gas throughout a modified shock tube with initial pressure and volume of gas and particles suggested by field studies and fragmentation experiments. These experiments will be monitored by sensors, multipoint video analysis and ash trap devices and they will mainly serve for checking the sensitivity and variability of the parameters used in the numerical calculation and simulations, and eventually for validating models hypothesis and assumptions.

We believe that this multidisciplinary approach will lead to assess in a robust way the range of solutions of impact parameters for the expected scenarios and therefore to furnish statistically significant confidence intervals for the impact parameters. The sum of results will allow the obtainment of the distribution over the territory of the basic impact parameters (velocity, density, temperature, particle concentration, static and dynamic pressure) of the potentially dangerous events and this will lead to the construction of hazard maps for the emerging scenarios of explosive eruptions at Vulcano.

This task will strongly benefit from results of other tasks, and in particular from task 2 concerning the location, dimension and characteristics of magma batches located at various depth and from task 3 in understanding what kind of escalation is to be expected, starting from the present state of the volcano, for the triggering of new eruptions.

**Task 2. Structure of the volcano**

UR Coordinating: P. Bruno (INGV-OV, Naples)

UR Participating: Gambino (INGV- Catania), De Astis (INGV-OV, Naples), De Rosa (Università della Calabria- Cosenza), Romagnoli (University of Bologna) , Piscitelli (CNR – Institute of methodologies for environmental analysis, Potenza), Fedi (Università Federico II, Naples), Dellino (Università di Bari)

Previous volcanological and magmatic studies on young Vulcano products (20 ka to Present) suggest the presence of a complex magma feeding system underneath the present La Fossa Caldera (FC), including the cones of La Fossa and Vulcanello. In the last 20 ka, most of the eruptions occurred inside and along the rims (e.g. Mt.Saraceno, La Roja) of the present FC, involving both mafic and variably evolved magmas. Merging of geophysical and petrological data indicated that at different depths, between ~22 and ~1.3 km, four main crustal discontinuities exist. Potassic magmas can storage and evolve in these "reservoirs". Evidence of this type must be confirmed and supported by more detailed data coming from different disciplines. Therefore, the definition of the structural relationships between the deeper and the shallower reservoirs (sills, elongated dykes, etc.) is critical to evaluate the future evolution of the plumbing system, the possible upraising of new magmas to the surface, the possible new vents. Moreover, the possible renewal of activity on the island (pre-eruptive scenario and eruptive style) can be determined by the interaction of magmas with different composition (mixing and mingling processes) and by magma-water interaction (i.e. eruption in shallow water). In other words, potassic mafic magmas (Vulcanello type) coming rapidly from deeper levels could interact with the trachy-rhyolitic liquids located at shallower depths, or with sea-water due to vent opening under the sea-level. In this frame, structural and magmatic processes are tightly connected and can originate different kind of events.

In order to fully understand the influence of tectonic lineaments and magma transfer on the plumbing system behaviour and their mutual relationships, geophysical and petrological data have to be collected, processed and synthetically interpreted.

Seismic reflection and seismic refraction data, along 2 selected profiles, together with new high-resolution aeromagnetic surveys in the same areas will be collected (RU Bruno) and provide information on the shallower levels of the crust beneath the FC (main structural boundaries, active faults, buried small-scale structures, etc.). Along the same profiles, 2D high resolution ERT and SP measures will be performed with the same aim and integrated with sub-surface soil temperature (T) and soil gas (SG) measurements (RU Piscitelli). A detailed density imaging of northern FC sectors based on gravimetric survey (in about 100 stations) will be also carried out (RU Dellino), processed trough topographic correction and constrained by geo-vulcanological and structural evidence. Density contrasts will provide geometries of anomalous bodies underneath that area.

Investigations at larger and deeper scale on the Vulcano structures will be carried out by exploiting the already existing seismic, geodetic, magnetic and geo-electrical data using new powerful software and algorithm (RU Fedi, RU Gambino). A significant improvement in the knowledge of Vulcano seismic activity will be possible trough the acquisition of new data from broad band stations, that will replace the short periods ones at the very beginning of the project (RU Gambino). From the analysis of these data, important information on the Tindari-Letoianni regional dynamic and on the deeper crustal levels should derive. Discrete (GPS and levelling) and continuous (tilt and GPS) survey will provide information on the Lipari-Vulcano (i.e. Fossa Caldera) ground deformation pattern (RU Gambino).

The dynamics between different magma reservoirs and magma ascent up to the phases of eruption and emplacement will be studied by RUs De Rosa and De Astis that will operate in close cooperation both in the field work (measures and sampling of FC volcanic successions) and in the choices of products to be analysed. Quantitative description of the products will help in evaluating the magma supply from FC and possible rate in the last 20 ka. Laboratory investigations will increase the data set on the pre-eruptive volatile content of La Fossa and Vulcanello magmas, to constrain degassing processes and flow regime in the conduit. They also will provide a crucial parameter like viscosity with the final aim to know the rheology of the Vulcano melts at the storage depths (RU De Rosa). New geochemical and isotopic analyses on these and other selected FC products will be carried out (RU De Astis) to get a detailed record of the compositional

variations shown by the magmas erupted in the last 15-20 ka, also considering the already available compositional data.

As regard the knowledge of La Fossa structure not directly related to volcanic eruption, but with the dangerous NE sector of the edifice (see also task 3), a new survey of the submarine morpho-structural features will be carried out (RU Romagnoli) and will complete the data set already acquired trough the last GNV project.

A close cooperation between all the RUs involved in the Task - 2 aimed to identify the location, shape and features of magma batches located at various depth and the sectors with higher probability of vent opening - has been planned. Contributes to task 1 deliverables can be also foreseen.

**Task 3: Levels of criticality of the volcano**

UR Coordinating: Inguaggiato (INGV- Palermo)

UR Participating: Diliberto (INGV – Palermo), Gambino (INGV- Catania), Tommasi (CNR – IGAG, Rome), Capaccioni (Università di Urbino)

The present state of the volcano shows that the hydrothermal system is very active as testified by the strong variations in temperatures and fluxes occurred during the ’80 and ’90, up to present (2004). The increasing of these parameters (e.g. T=400-500°) indicates that the magmatic system is active and is responsible at least for some of the changes recorded at the surface. Furthermore, the dynamics related to the hydrothermal system can trigger further hazardous phoenomena. In fact, sources of risk at Vulcano Island are multiple and not only related to volcanic activity. They range from toxic gaseous phenomena to slope instability possibly affecting La Fossa cone flanks. Therefore, the definition of the critical levels approached by the different geophysical and geochemical parameters is a key-issue for the new researches on La Fossa and surrounding areas. New and already available data set will be elaborated in order to define the background level of the volcano and the criticality threshold that can lead to irreversible hazardous activities.

As regard Vulcano seismicity, earthquakes originating in the area of La Fossa could be associated with both fracturing and degassing processes. The former are likely represented by the occurrence of sporadic swarms of low-magnitude shocks, with shallow foci (< 4 km). The other type of events are related to the background seismic activity and are represented by weaker quakes, which originate at shallower depths (<1.5 km). However, it is difficult to discriminate between the two types and the seismic background level of the volcano is not really constrained, yet. Geophysical studies by RU Gambino are aimed to characterize the baseline dynamic of La Fossa cone trough the reinterpretation of the geodetic and seismic data set. A further better characterization of Vulcano local seismicity and a significant improvement of hypocenter location and source parameters will be carried out, even with the support of new data obtained by using a new broad-band array as already mentioned in task 2.

Levels of criticality deriving from heat flux measures (along vertical axis of the soil) will be studied by Diliberto’s RU. The comparison of the thermal gradient in the soil out of the fumaroles area with heat flux estimates obtained trough steam output measures and with fumaroles temperatures and even with local seismicity will provide estimation of the different quotes of energy release (heat, steam and CO2 flows). Interpretation and elaboration of these data, combined with other geochemical parameters deriving from fumaroles, will allow the investigations of trends in the time series, thus leading to the definition of the background levels and to infer on the possible anomalies to be expected close to critical thresholds of La Fossa hydrothermal system.

As regard the slope instability processes affecting the NE sector of La Fossa cone (P.te Nere, Le Forge), the RU Tommasi will study the geotechnical material properties and the weakening of the mechanical strength also due to the circulation of the hydrothermal fluids (in cooperation with

RU Diliberto) for assessing the likelihood of flanks failure.

The impact on the environment of light alkenes and aromatics released from fluids discharge will be evaluated trough discrete sampling and subsequent analyses by several methodologies (RU Capaccioni). The same RU will use remote sensing (infrared laser) and accumulation chamber with infrared sensor in order to better estimate the fluxes from La Fossa crater and surrounding areas. A final assessment of the toxic elements for human being will be possible.

New sampling methods and analytical techniques will be developed and tested, also by means of international inter-laboratory standardization for nitrogen isotopic composition (RU Inguaggiato). Coupled with noble gases, these isotopes seem to be very promising in identifying the magmatic imprinting on the fumarolic gases and, in particular, the component deriving from subduction-related processes. Based on 2-years sampling, background levels of $^{15}\mathbf{N}_{\mathbf{N2}}$values could also be defined and thus contributing to a better understanding of volcanic criticality.

Results from this task will greatly benefit task 1 for the investigation of the possible escalation toward pre-eruptive scenarios.

**List of Deliverables**

**Task 1. Eruptive products, eruptive scenarios and hazard**

1) Databases on the chemical-physical characters of eruptive products and melts

Major and trace elements of glass shards and mineral phases. Newtonian and non Newtonian viscosities of melts. Multimodal-multicomponent size characteristics of pyroclastic particles. Size-dependent density of pyroclastic particles. Hydraulic and aerodynamic coefficients of pyroclastic particles

2) Energy release of explosive eruptions

Budget of mechanical energy of impulsive eruptions subdivided into the shock-wave, fragmentation and transportation components

3) Graph and diagrams of expected scenarios based on probability density functions
4) Codes for the calculation of impact parameters of pyroclastic density currents and applications to the case of Vulcano
5) Hazard maps of pyroclastic density currents and vulcanian events for the short-term and the long-term scenarios.

**Task 2. Structure of the volcano**

1) 2D cartoon of depth and location of magma reservoirs
2) Map of possible vents opening derived from identification of horizontal and vertical structures (extended to the shallow su-marine sector around la Fossa cone)
3) Complete geochemical and isotopical data-set of the products erupted during the last 20 ka
4) Trends of temporal variation of magma supply rate during the last 20 ka

**Task 3. Levels of criticality of the volcano**

**1)** baseline of Vulcano seismicity with possible discrimination of source mechanisms (fracturing and degassing).
**2)** Characterization of the degassing hydrothermal system by Heat fluxes and geochemical parameters (Nitrogen, $CO_2$, toxic fluids) and definition of background levels and criticality thresholds.
**3)** Geotechnical characterization of the slopes of La Fossa cone for the assessment of the likelihood of flank failures (P.te Nere and Le Forge sectors)

# SUB-PROJECT V3_5 – VULCANO

**TABLE MAN/MONTHS**

| U.R | Institutions | Principal Responsibles | Task1 Scenarios and hazard | Task2 Volcano structure | Task3 Levels of criticality | Mesi p. cofin. | Mesi p. rich. |
|---|---|---|---|---|---|---|---|
| UR-1 | UniBa, Univ. Wuerzburg (D), Soc. Flowlab Na, INGV-OV | Dellino, La Volpe, Schiavone, Zimanowski, Loddo, Mele, Esti | @ | @ | | 95 | |
| UR-2 | INGV-OV, UniTo, Univ. Hawaii (USA), UniBo, Open Univ. London (UK), UniCal | De Astis, Piochi, Lanza, Zanella, Tranne, Lucchi | @ | @ | | 59 | 12 (borsa di studio UniTo) |
| UR-3 | INGV-OV, INGV-Rm, CRdC-AMRA Na, Univ Burgos (ES) | Bruno, Chiappini, De Ritis, Montenegro | | @ | | 33 | |
| UR-4 | UniBo, UniRm1, CNR-IGAG | Romagnoli, Chiocci | | @ | | 26 | |
| UR-5 | CNR-IMAA, CNRS-CEREGE (FR), INGV-PA, Imperial College London (UK) | Piscitelli, Lapenna, Matthai, Revil | | @ | | 59 | |
| UR-6 | UniNa, INGV-CT | Fedi, Di Maio | | @ | | 13 | |
| UR-7 | UniCal, INGV-Rm1, UniPi, Univ. Hannover (D) | De Rosa, Ventura, Mazzuoli, Holtz, Behrens, Gioncada | | @ | | 46 | 24 (UniCal) |
| UR-8 | INGV-PA, BGR (D), Unam-Mexico | Inguaggiato | | | @ | 20 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| UR-9 | UniUrb, UniFi, UniNaII, UniIns | Capaccioni, Vaselli, Tedesco | | | @ | 46 | |
| UR-10 | INGV-PA | Diliberto | | | @ | 14 | 12 (borsa di studio INGV-PA) |
| UR-11 | INGV-CT, INGV-OV | Gambino, Alparone, Mattia, Ursino, Calvari, Velardita | | @ | @ | 60 | |
| UR-12 | CNR-IGAG, INGV-OV, UniRm1, UniNaII, UniRm3, CNR-ISMAR | Tommasi | | | @ | 24 | |
| **Totale** | | | | | | 495 | 48 |

# SUB-PROJECT V3_5 – VULCANO

## Table RU and related funding request (Progetto V3_5)

| N. UR | Istituz. | Resp UR | Personale | | Missioni | | | | Consumi servizi | | Inventariabile | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Italia | | Estero | | | | | |
| | | | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 |
| UR-1 | UniBa | Dellino | | | 10000 | 10000 | 2000 | 2000 | 17000 | 17000 | 2000 | 1000 |
| UR-2 | INGV-OV | De Astis[1] | | | 7200 | 6000 | 1800 | 1000 | 12000 | 23000 | | |
| UR-3 | INGV-OV | Bruno | | | 6500 | 2500 | | | 27000 | 1000 | | 4500 |
| UR-4 | UniBo | Romagnoli | | | 4000 | 2000 | | | 29000 | 5000 | | |
| UR-5 | CNR-IMAA | Piscitelli | | | 4500 | 4500 | 2500 | 2500 | 3000 | 5000 | 2000 | 3500 |
| UR-6 | UniNa | Fedi | | | 1500 | 1500 | 1500 | 1500 | 2500 | 2500 | | |
| UR-7 | UniCal | De Rosa | 19000 | 19000 | 1000 | 1000 | 1500 | 2000 | 2000 | 5000 | | |
| UR-8 | INGV-PA | Inguaggiato | | | 2000 | 2000 | 7000 | 8000 | 3000 | 3000 | | |
| UR-9 | UniUrb | Capaccioni | | | 5000 | 5000 | | | 1000 | 1000 | | |
| UR-10 | INGV-PA | Diliberto | | | 4000 | 2000 | 1000 | 2000 | 9000 | 9000 | | |
| UR-11 | INGV-CT | Gambino | | | 8000 | 5000 | 2000 | 2000 | 5000 | 13000 | | |
| UR-12 | CNR-IGAG | Tommasi | | | 2000 | 1500 | | | 10000 | 9500 | | |
| | | **TOTALE** | **19000** | **19000** | **55700** | **43000** | **19300** | **21000** | **120500** | **94000** | **4000** | **9000** |
| **GRAN TOTALE: 404500** | | | | | | | | | | | | |

[1] 16000 euros (during the second year) included under the voice "Consumi e servizi" will be provided to Univ. of Torino, for the activation of a one-year "borsa di studio" dedicated to the research foreseen by the RU.