Sub-Project V3_2 - Campi Flegrei

Responsibles:

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The Campi Flegrei caldera is a nested and resurgent structure. Its magmatic system is still active, with the last eruption occurred in AD 1538, widespread fumaroles and hot spring activity, and important unrest episodes in the last 30 years which caused a maximum net uplift of about 3.5 m in the Pozzuoli area. The volcanic hazard in the caldera area is extremely high, also because of its explosive character and the frequent occurrence in the past of high-magnitude high-intensity eruptions. Close to 1.5 million people live within the caldera, with about 350,000 living in its most active portion. Due to the high volcanic hazard and the intense urbanization of the active caldera portion and its surroundings, the volcanic risk is extremely high.

Research activity at Campi Flegrei during last years has been conducted at national and international levels. In particular, the investigation developed in the frame of the 3-year program launched in 2000 by GNV, and within several EU projects, has largely improved the level of knowledge at Campi Flegrei on many aspects including the caldera structure, the volcanic history, the distribution, characteristics, and significance of volcanic deposits, the compositional variability of the erupted magmas, the genesis of magmas and magma chamber processes, the determination of relevant magma properties, the eruption magnitude variation through time over the past 15 ka, the definition of the low-, medium- and high-magnitude expected eruption, the elaboration of hazard maps for opening of a future vent, tephra fallout and pyroclastic currents flowage, the numerical simulation of eruptive scenarios, the definition and zoning of volcanic hazard, and many others. At the same time, new important results from recent tomographic campaigns are substantially modifying our view of the deep structure of Campi Flegrei caldera and size and location of shallow regions of magma storage, requiring a re-consideration of many studies developed before those results were produced. Additionally, recent advances in the simulation of the eruption dynamics provide new tools for the investigation of time-dependent, multi-phase, 2D/3D magmatic and volcanic processes at the global scale from deep magma chambers into the atmosphere and along pyroclastic currents. Finally, a quantitative probabilistic approach to the assessment of the volcanic hazard and definition of critical levels for the state of Campi Flegrei is still missing.

The present project is organized in 7 Tasks, grouped in 3 Research Lines devoted to a) the definition of the present state, b) the identification and quantification of precursory signals and associated probability of occurrence of volcanic events, and c) the definition of the eruptive scenarios and related probability, and quantitative estimate of the volcanic hazard. The specific Tasks are devoted to: 1) establish a detailed three-dimension geophysical image of the volcanic structure, including the possible location and geometry of the reservoirs as they can be inferred today from the available geophysical studies and, in the past, from the melt inclusions data, 2) define the hydrologic and geothermal system, and model the hydrothermal circulation and the thermal state of the caldera, 3) identify and quantify precursory signals and simulate the pre-eruptive magma dynamics, 4) identify the scale and typology of the expected eruptions, 5) extend the determination of relevant physical and chemical properties of Campi Flegrei magmas, 6) perform numerical simulations of coupled magma chamber + volcanic conduit + atmospheric eruption dynamics, and define deterministic and probabilistic eruptive scenarios, and 7) integrate the whole information and assess the volcanic hazard.

Research line 1: Present state of Campi Flegrei

The definition of the present state of the volcanic area of Campi Flegrei requires multidisciplinary investigation aimed at the quantitative definition of the feeding system, the caldera and lithosphere structure, and the hydro-geologic and geothermal setting.

Task 1. Definition of the magmatic system and of the caldera and lithosphere structure

The location and evolution in time and space of the deep magmatic system determines the type and volume of magmas which in turn rise at shallow depth, forming, in most of the cases, shallow reservoirs feeding the eruptions, and drives the kind of signals associated with the renewal of the volcanic activity, and the phenomenology of volcanic eruptions. Knowledge of the location, size, geometry, and composition, as well as of the thermal and compositional evolution of magmas, is critical for the optimization of the monitoring network and for the formulation of hypotheses on the future evolution of the magmatic and volcanic system and on pre-eruptive and eruptive scenarios.

The location of feeding dykes and vents associated with future volcanic activity are the results of complex interactions between regional tectonic structures and structural elements associated with the caldera structure. Critical factors are represented by the heterogeneous nature of the lithosphere and the location and rank of its major structural elements, as well as the location and rank of the major structural elements of the caldera edifice including its submerged portion. Knowledge of the caldera and lithosphere structure, and of the physical properties and mechanical behaviour of rocks at various depths is essential for the location of earthquake hypocenters and the interpretation of their time-space distribution and associated waveforms, as well as for the modelling and interpretation of the geophysical and geochemical signals from the monitoring network.

WP1.1: Magmatic system

Deliverables:

1. Depth, size, geometry and distribution of intra-crustal magma storage regions
2. Time scales of magma storage and differentiation prior to eruptions of different magnitude/intensity, and P-T estimate of magma storage regions
3. Petrologic models for the evaluation of the composition, magmatic components and history (recharge, mixing/mingling, diffusion, contamination) of the deep and shallow magma chambers feeding the activity of the last 15 ka, aimed at inferring the possible composition of the magma which will feed the next eruption
4. Evaluation of the kind and amount of volatile species in intra-crustal magma storage regions

WP1.2: Structural model of Campi Flegrei

Deliverables:

1. Refining of the structural map of the Campi Flegrei caldera
2. 3-D model of Campi Flegrei caldera and lithosphere below it
3. Distribution of the probability of future vent opening in the Campi Flegrei area

Task 2. Hydrologic and hydrothermal setting

The physico-chemical characteristics of fluids emitted at the surface are related to the hydrologic and hydrothermal setting of the caldera. Knowledge of the mass and energy transport mechanisms and dynamics, and of the location, size, and physico-chemical characteristics of deep aquifers and geothermal system is crucial for the interpretation of the geochemical, geodetic, seismic, and gravimetric signals registered at the surface. The interaction between aquifers and heat/mass flows associated with magma movement can lead to phreatic or phreatomagmatic explosions.

WP2.1: Location, size, physico-chemical characteristics and dynamics of the geothermal system and aquifers

Deliverables:

1. Definition and quantification of the magmatic and non-magmatic components of fluids emitted at the surface, and of associated uncertainties
2. 2/3D model of the geothermal system
3. 2/3D conductive-convective thermal and hydrothermal model of the caldera
4. Modelling of the relationships between hydrothermal circulation, rock deformation, seismicity, and geochemical and gravimetric changes registered at the surface

Research line 2: Precursory signals and probability of occurrence of eruption phenomena

The investigation of precursory signals implies their identification and quantification, and the modelling of the physical and chemical processes generating them. The possible future identification of relationships between precursory signals and kind and scale of the expected events is of crucial importance. Data and knowledge from the monitoring network are obviously of primary importance.

Task 3. Identification and quantification of precursory signals

The knowledge of the background level of the volcano represents the starting point for the identification of possible precursory signals. Such an identification can be done on the basis of phenomenological, physical, and stochastic models for the behaviour of the complex system of Campi Flegrei. The production of multi-parametric databases of unrest at Campi Flegrei and at other calderas in the world allows a significant improvement in the identification and quantification of precursory signals, and in the set up of methods for the estimate of the probability of occurrence of possible events over different temporal scales.

WP3.1: Background level at Campi Flegrei

Deliverables:

1. Definition of the range of variations of geochemical, geodetic, seismic, and gravimetric signals representing the background level at Campi Flegrei

WP3.2: Identification of precursory signals

Deliverables:

1. Database of geological and structural data on processes and phenomena preceding past eruptions
2. Creation of a multi-parametric database of unrest at Campi Flegrei and at other active calderas in the world (principally Long Valley and Rabaul)
3. Stochastic model for the identification and quantification of precursory signals at Campi Flegrei
4. 2-3D modelling of transient magma chamber dynamics and associated changes of the background level
5. 2-3D modelling of dyke propagation and associated changes of the background level
6. Deterministic/stochastic modelling of the probability of occurrence of possible events in the short (< 10 years) time scale, associated with possible associations of signals from the monitoring network

Research line 3: Definition of eruptive scenarios and estimate of the volcanic hazard

An eruptive scenario is constituted by the succession of events and the spatial and temporal distribution of the physical quantities characterizing the eruptive phenomena. The probabilistic definition of scenarios leads to the quantification of the volcanic hazard, or the probability of occurrence of an hazardous event in a given spatial and temporal range. Knowledge of the past history of the volcano, identification of the scale and typology of expected events, and physico-mathematical simulation of the dynamics of these events, are all necessary in order to determine the eruptive scenarios.

Task 4. Identification of the scale and typology of expected events

The quantitative description of volcanic deposits and reconstruction of past eruptions is essential for the identification of the expected phenomena, their temporal relationships, and the minimum areas which were subject in the past to the volcanic phenomena, as well as for the validation of the results from the numerical simulation of eruptive dynamics.

WP4.1: Eruptive history and expected events

Deliverables:

1. Stratigraphic, sedimentological, morphometric and geochemical data on poorly known ash layers distributed in mid-distal areas (Campanian Plain and Apennines), and definition of the impact of their deposition on landscape
2. Determination of the intensity and magnitude, and of associated uncertainties, of the major eruptive phases of the last epoch of activity (< 5000 BP) and the AD 1538 eruption of Monte Nuovo
3. Definition of the intensity, magnitude, typical characteristics including magma composition, volatile content, and grain-size distribution, and identification of possible sequences of major events, for reference low, medium, and high intensity expected eruptions at short-mid terms

Task 5. Determination and modelling of magma properties and magma behaviour

Knowledge of the physical and chemical magma properties, including the melt structure, and of magma behaviour is necessary for the simulation of the pre-eruptive and eruption dynamics and scenarios at Tasks 3 and 6, and for the formulation of models of deep and shallow magmatic system at Task 1. Therefore, they must be determined and modelled in the range of *P*-*T*-*f*O_2-composition conditions covering those of interest for the present state and pre- sin-eruptive dynamics modelling. Detailed knowledge of the relationships between magma properties and phase distribution and composition is required to assess the role of compositional changes of the erupted magma on the volcanic scenarios.

WP5.1: Chemical and physical properties and processes

Deliverables:

1. Experimental determination of glass structure and distribution of hydrous species, aimed at defining the cooling dynamics and degassing processes of uprising magmas
2. Experimental determination and parameterization of multi-component solid-liquid-gas phase equilibria, and of phase and interface enthalpies, with associated uncertainties
3. Experimental determination and parameterization of crystal/gas bubble growth dynamics with variable rates of cooling, depressurization, and degassing
4. Experimental determination and parameterization of dry and hydrous multiphase, non-Newtonian viscosities, and of viscosities and associated phase distributions and textures under dynamic cooling conditions, with associated uncertainties
5. Experimental determination and parameterization of thermal conductivity of liquid and multiphase magma, and of country rocks at the relevant *P*-*T*-composition conditions, with associated uncertainties
6. Development and application of multi-component phase equilibrium models for the estimate of past and present volatile contents and degassing history of magmas

Task 6. Eruption dynamics and scenarios

The time-space distribution of the physical quantities characterizing the expected events and scenarios is based on the physico-mathematical modelling and numerical simulation of the sin- and post-eruption dynamics. The definition of appropriate initial and boundary conditions for the simulations derives from the studies at Tasks 1-4. Coupling of models describing the dynamics in different domains such as the magma chamber, volcanic conduit or fissure, surrounding rocks and geothermal system, atmosphere, leads to numerical simulations of volcanic eruptions and scenarios at the global scale.

WP6.1: Numerical simulations of 2D magma chamber and 1-2D volcanic conduit dynamics

Deliverables

1. Implementation of physical and chemical properties of single-phase and multi-phase magma from Task 5 within numerical codes of magma chamber and volcanic conduit dynamics
2. Evaluation of the conditions under which pre- and sin-eruptive magma mixing can efficiently occur, and of the roles of different initial *P*-*T*-composition conditions on the dynamics of transient opening phases and steady conduit flow phases of expected eruptions
3. Production and analysis of sets of numerical simulations for low, medium, and high intensity eruptions, and definition of appropriate sets of vent

conditions for the simulation of the atmospheric eruption dynamics at WP6.2
4. First production of numerical simulations of coupled 2D magma chamber and volcanic conduit dynamics, for the transient opening phases of expected volcanic eruptions at Campi Flegrei

WP6.2: Numerical simulations of 2-3D volcanic jet and pyroclastic current dynamics in the Campi Flegrei caldera environment

Deliverables

1. 2D numerical simulations of volcanic jet and pyroclastic current generation and propagation along selected sectors of the Campi Flegrei caldera, according with the areas with maximum probability of vent opening defined at Task 1, and with selected vent conditions from numerical simulations of magma chamber and conduit flow dynamics at WP6.1
2. Analysis of time-space distribution of hazardous quantities, and of the capability of pyroclastic currents to surmount topographic obstacles and impact different areas within and outside the caldera
3. First production of numerical simulations of pyroclastic current generation and propagation in the 3D caldera floor environment

WP6.3: Numerical simulations of tephra accumulation and fall-out from volcanic eruption plumes

Deliverables

1. 2-3D numerical simulations of transport and fallout of pyroclasts and ash from volcanic columns for reference low, medium, and high intensity expected eruptions at short-mid terms, with wind velocity distribution from real data
2. Production of probability maps for ash loading for different types of eruptions

Task 7. Assessment of the probability of occurrence of future eruptions, and of the volcanic hazard

The assessment of the probability of occurrence of future eruptions is based on statistical laws which integrate the knowledge of the history and behaviour of the volcano as well as of other similar volcanoes, its present state, the physical laws which govern the occurrence of given phenomena, and the observed precursory signals. Reference to different possible scenarios, each characterized by a probability of occurrence and a sequence of expected phenomena, and integration with the results from the numerical simulations of the eruption dynamics, leads to the assessment of the volcanic hazard. A probabilistic definition of the volcanic hazard allows handling the uncertainties associated with the complex behaviour and limited knowledge of the volcanic system of Campi Flegrei.

WP7.1: Probability of occurrence of future eruptions

Deliverables:

1. Determination of the constrained probability of occurrence of the expected events, and of their probability of occurrence over the short-medium time scale (1 to 100 years), with reference to low, medium, and high intensity eruptions

WP7.2: Volcanic hazard

Deliverables:

1. Definition of a method for the integration of data and knowledge from different disciplines, for the assessment of the volcanic hazard at Campi Flegrei
2. Production of thematic maps of volcanic hazard due to pyroclastic currents propagation and tephra accumulation, integrating the bulk of data and knowledge on Campi Flegrei from this project and from the literature
3. First-stage evaluation of if and how real time data and observations can modify the expected eruptive scenarios and the volcanic hazard