Proposal theme (select from Multidisciplinar or Innovation Technology or Seismological or Volcanological or Environmental Themes)

Volcanological - VT
Focused on subtheme 2 (Characterization of the unrest dynamics of volcanoes and eruption forecasting), but involving both modelling and data gathering, thus transversal over the 3 subthemes.

Proposal title and acronym

Toward a Wider Understanding of Vulcano - WUnderVul

Keywords *(at least 6)*

Vulcano
Unrest dynamics
Fluid circulation
Phreatic Eruptions
Conceptual modelling
Data recovery and analysis

COORDINATOR

Name and surname, INGV Division/'Sezione'

Jacopo Selva, Sezione di Bologna

Job title

☐ **INGV technologist permanent contract**

X **INGV researcher permanent contract**

Curriculum vitae *(30 rows, including H-Index)*

Jacopo Selva has been a researcher at the INGV since 2005, graduated in Physics with honour in 2001, and discussed the PhD in Geophysics in 2004. JS's main research fields are Multi-hazard and risk, probabilistic volcanic, tsunami, and seismic hazard analyses; expert elicitation; systemic risk analyses; precursory patterns of eruptions.

Institutional coordination: JS has been a member of the INGV coordinating body for the Italian National Tsunami Warning Center (CAT) since 2017; JS was formerly responsible for Sector "V3 – Eruptive Dynamics and Scenarios" of INGV (2014-2017). JS acts as Shift Volcanic Hazard Leader within ARISTOTLE-ENHSP since 2018. WIthin the INGV/DPC agreements, JS coordinated many tasks since 2016 for volcanic and tsunami hazard (2019-2022: Tasks 1 and 2 - Ob. 3; 2018-2019: Task 3 - Ob. 4; Tasks A2 and A4; 2016-2017: Task C of Ob. 4). JS participated in crisis management groups for Ischia and Vulcano, coordinated several working groups, including one for the 2021 Vulcano unrest.

Teaching and experience abroad: Since 2020, JS has been a contract professor at University of Bologna (2020/21, 2021/22) and at University of Perugia (2019/20), and teaches at the PhD course in Geophysics of the University of Bologna since 2021. JS was visiting researcher at the University of Thessaloniki (GR), guest Ph.D. student at the University of Ulster (UK), and collaborator at AMRA.

Project coordination: JS covered coordination roles in several Italian and European competitive projects, as Principal Investigator for INGV (EuroHPC-eFlows4HPC, PRIN-2017CEYPS8, FP7-STREST), WP/Task leader (PRIN-2017CEYPS8, H2020-ChEESE, COST-AGITHAR, DGECHO-TSUMAPS-NEAM, FP7-ASTARTE, FP7-STREST), and coordinator (FIRB-"Futuro in Ricerca"-RBFR0880SR).

Editorial and Referee Activity: JS is Associated Editor in Frontiers in Earth Science - Geohazards and Georisks (since 2022), and was guest editor for 2 special issues in Frontiers Earth Science. JS acted as referee for project proposals for international agencies and for scientific papers for international journals. JS participated in the scientific committee and acted as session convener for several national and international conferences.

Scientific production: JS is the author of more than 90 papers in journals and book's chapters. H-index (23/05/2022): 25 in Scopus with 1965 citations; 24 in Web of Science Citations with 1606 citations; 30 in Google Scholar with 2743 citations.

Five project-related papers

1. Selva J , Bonadonna C, Branca S, De Astis G, Gambino S, Paonita A, Pistolesi M, Ricci T, Sulpizio R, Tibaldi A, Ricciardi A (2020), Multiple hazards and paths to eruptions: a review of the volcanic system of Vulcano (Aeolian Islands, Italy). Earth-Science Reviews 207, 103186, https://doi.org/10.1016/j.earscirev.2020.103186
2. Chiodini G, Selva J, Del Pezzo E, Marsan D, De Siena L, D'Auria L, Bianco F, Caliro S, De Martino P, Ricciolino P, Petrillo Z (2017), Clues on the origin of post-2000 earthquakes at Campi Flegrei caldera (Italy) , Scientific Reports 7: 4472, https://doi.org/10.1038/s41598-017-04845-9
3. Marzocchi W, Selva J, Jordan TH (2021), A Unified Probabilistic Framework for Volcanic Hazard and Eruption Forecasting, Natural Hazards and Earth System Sciences 21, 3509-3517, DOI https://doi.org/10.5194/nhess-21-3509-2021
4. Selva J, Marzocchi W, Papale P, Sandri L (2012), Operational eruption forecasting at high-risk volcanoes: the case of Campi Flegrei, Naples, J. Applied Volcanology 1:5, https://doi.org/10.1186/2191-5040-1-5
5. Marzocchi W, Sandri L, Selva J (2008), BET_EF: a probabilistic tool for long- and short-term eruption forecasting, Bull. Volcan., 70, 623 632, DOI:10.1007/s00445-007-0157-y

RESPONSIBLE FOR WP (MAX 5 WP)

Name and surname, INGV Division/'Sezione', WP

Gianfilippo De Astis, Sezione di Roma 1, WP1

Job title

☐ **INGV technologist permanent contract**

X **INGV researcher permanent contract**

Curriculum vitae *(15 rows, including H-Index)*

Degree in Geological Science with honour, PhD in Earth Science, two scholarships at NIGL (Isotope Labs of the BGS - Keyworth, UK), on specific magmatological research projects. Currently senior researcher at INGV.

Projects: a) national co-leader of the INGV-DPC V3_5 – Vulcano project, INGV Agreement - Civil Protection 2004-2006; b) participant and field-surveyor in the Geological CARtography Project (CARG) "Aeolian Islands - Sicily" (2007-2013); c) participant to biennial MIUR-COFIN: "Genesis of Cenozoic-Quaternary Magmatism of Central Ethiopia:..."; d) INGV-ProCiv V3 "Multi-disciplinary analysis of the relationships between tectonic structures and volcanic activity" (2012-2014); e) Italy-Argentina Univ. Consortium, on the geothermal area of Tocomar (NE Argentina). Shift Volcanic Hazard Leader within ARISTOTLE-ENHSP Project since 2018.
Member of: a) Working Table for Vulcano, Conv. B2 - 2016 Ob. 4 Volcanic Hazard Center Task C; b) Emergency Unit established by INGV (DP n.48 2021) during the 2021 unrest at Vulcano. Contract Professor at La Sapienza University (2017/18, 2018/19, 2019/2020).. Reviewer for several international journals. Author of more than 60 papers in journals and book's chapters and 4 geological maps. H-index (30/05/2022): 28 in Google Scholar with 2244 citations.

Five project-related papers

1) De Astis G., La Volpe L., Peccerillo A., Civetta L. (1997). "Volcanological and petrological evolution of Vulcano Island (Aeolian Arc, southern Tyrrhenian Sea)." J. Geophys. Res., Vol. 102, pp. 8021-8050. https://doi.org/10.1029/96JB03735

2) Peccerillo A., Frezzotti M.L., De Astis G., Ventura G., (2006) Modeling the magma plumbing system of Vulcano (Aeolian Islands, Italy) by integrated fluid inclusion geobarometry, petrology, and geophysics. Geology v. 34; no. 1; pp. 17–20. https://doi.org/10.0030/G22117.1

3) De Astis G., Lucchi F., Dellino P., La Volpe L., Tranne C. A., Frezzotti M. L. and Peccerillo A. (2013). Geology, volcanic history and petrology of Vulcano (central Aeolian archipelago) Geological Society, London, Memoirs, v.37; 281-349. https://doi.org/10.1144/M37.11

4) Palenzuela Baena J.A., Scifoni S., Marsella M., De Astis G., Irigaray Fernández C. (2019). Landslide susceptibility mapping on the islands of Vulcano and Lipari (Aeolian Archipelago, Italy), using a multi-classification approach on conditioning factors and a modified GIS matrix method for areas lacking in a landslide inventory. Landslides 16, pages 969–982. https://doi.org/10.1007/s10346-019-01148-0

5) Selva J., Bonadonna C., Branca S., De Astis G., Gambino S., Paonita A., Pistolesi M., Ricci T., Sulpizio R., Tibaldi A., Ricciardi A. (2020), Multiple hazards and paths to eruptions: a review of the volcanic system of Vulcano (Aeolian Islands, Italy). Earth-Science Reviews 207, 103186, DOI: https://10.1016/j.earscirev.2020.103186

Name and surname, INGV Division/'Sezione', WP

Micol Todesco, Sezione di Bologna, WP2

Job title

☐ **INGV technologist permanent contract**

X **INGV researcher permanent contract**

Curriculum vitae *(15 rows, including H-Index)*

MT has a degree in Geological Science, a PhD in Earth Science and is senior researcher at INGV. Her research focuses on numerical modelling of volcanic phenomena, in particular hydrothermal fluid circulation and the associated signals. She published 39 scientific articles and 29 other contributions (extended abstracts, reports, and outreach publications). Visiting scholar at UCSB, Santa Barbara California; LBNL, Berkeley; and CSIC, Barcelona. Associated Editor for JGR (2010-2019) and Geofluids (2016-2018). Currently Review Editor of Frontiers in Earth Science. Research projects' reviewer for the Academy of Science of the Czech Republic, the Swiss National Foundation and the Icelandic Research Fund. National coordinator of the INGVvulcani communication group and of the Phreatic explosion working group. Participant in the emergency unit established during the 2021 unrest at Vulcano. Participants in many national and international projects (most recently WP leader in EU SOCIETY n. 101061722, and INGV projects: PD-TV3; FIRST and WADE-Water Driven Eruption).

Her H-index ranges from 18 to 20 (1220-1607 citations) depending on the source (Scopus, Google Scholar, respectively).

Five project-related papers

1. Todesco M. (1997). Origin of fumarolic fluids at Vulcano (Italy). Insights from isotope data and numerical modeling of hydrothermal circulation. J. Volcanol. Geotherm. Res., 79, pag. 63-85.
2. Todesco M., Chiodini G. e Macedonio G. (2003) Monitoring and modeling hydrothermal fluid emission at La Solfatara (Phlegrean Fields, Italy). J. Volcanol. Geotherm. Res., 125, 57-79.
3. Todesco M., Rutqvist J., Chiodini G., Pruess K., e Oldenburg C. M. (2004) Modeling of recent volcanic episodes at Phlegrean Fields (Italy): geochemical variations and ground deformation. Geothermics, 33,531-547, doi:10.1016/j.geothermics.2003.08.014.
4. Todesco M., e Berrino G. (2005), Modeling hydrothermal fluid circulation and gravity signals at the Phlegraean Fields caldera, Earth Plan. Sci. Lett., 240, 328-338.
5. Todesco, M. (2021) Caldera's breathing: poroelastic ground deformation at Campi Flegrei (Italy). Front. Earth Sci. 9: 702665. doi: 10.3389/feart.2021.702665.

Name and surname, INGV Division/’Sezione’, WP

Cinzia Federico, Sezione di Palermo, WP3

Job title

☐ **INGV technologist permanent contract**

X INGV researcher permanent contract

Curriculum vitae *(15 rows, including H-Index)*

Cinzia Federico graduated in Geology with honour in 1994, and pursued the PhD in Geochemistry in 2000. She is Researcher at INGV since 2003, and Senior Researcher since 2021. *Research interests*: modeling processes of volcanic gas scrubbing in the hydrothermal environment; CO2 degassing from the soil in active volcanic areas; modeling of gas transport in porous and fractured media; modeling of gas-water-rock interaction; source and mobility of trace elements and REE; plume chemistry. Fellowship at the Laboratoire des Sciences du Climat et de L’Environnement, CNRS-CEA, Saclay (Francia). CF coordinated research units, tasks and work packages in national and international projects (DPC-INGV agreements, Harmonization Group HG09 -Geochemical Data in the EPOS-IP; Hazard from EtnA Volcanic EmissioNs – HEAVEN; IMPACT; EUROVOLC; SEW "Save the Etna world, Vulcamed). *Editorial and Referee Activity**:*** CF is in the editorial board of the journals Geofluids (since 2016) and Journal of Volcanology and Geothermal Research (since 2018). Reviewer for several international journals. Scientific production: CF is co-author of 57 SCI articles and book’s chapters.

H-index (30/5/2022): 28 in Scopus (2272 citations); 26 in Web of Science (2049 citations); 30 in Google Scholar (2878 citations).

Five project-related papers

1. Inguaggiato, S., Diliberto, I. S., Federico, C., Paonita, A., & Vita, F. (2018). Review of the evolution of geochemical monitoring, networks and methodologies applied to the volcanoes of the Aeolian Arc (Italy). Earth-Science Reviews, 176, 241-276.
2. Capasso, G., Federico, C., Madonia, P., & Paonita, A. (2014). Response of the shallow aquifer of the volcano-hydrothermal system during the recent crises at Vulcano Island (Aeolian Archipelago, Italy). Journal of volcanology and geothermal research, 273, 70-80.
3. Paonita, A., Federico, C., Bonfanti, P., Capasso, G., Inguaggiato, S., Italiano, F., ... & Sortino, F. (2013). The episodic and abrupt geochemical changes at La Fossa fumaroles (Vulcano Island, Italy) and related constraints on the dynamics, structure, and compositions of the magmatic system. Geochimica et cosmochimica acta, 120, 158-178.

4. Federico, C., Capasso, G., Paonita, A., & Favara, R. (2010). Effects of steam-heating processes on a stratified volcanic aquifer: Stable isotopes and dissolved gases in thermal waters of Vulcano Island (Aeolian archipelago). Journal of Volcanology and Geothermal Research, 192(3), 178-190.
5. Aiuppa A., C. Federico, G. Giudice, S. Gurrieri, M. Valenza (2006) Hydrothermal buffering of the SO2/H2S ratio in volcanic gases: evidence from La Fossa Crater fumarolic field, Vulcano Island. Geophys. Res. Lett., 33, L21315, https://doi.org/10.1029/2006GL027730

Objectives (max 2 pages)

Periods of volcanic unrest are times of great uncertainty. System conditions may change at rates that are difficult to anticipate and may reflect the onset of eruptive activity or fade into a new dormant stage after a period of non-eruptive unrest. These phases generate a wide range of signals and may culminate in hazardous phenomena, like phreatic eruptions or landslides, even in absence of eruptive activity. The presence of a hydrothermal system further complicates the interpretation of monitoring data, as it may mask, distort or amplify what happens at depth. This proposal stems from the fruitful experience of the working groups that were formed to address the interpretation of the 2021 unrest, one of the most significant unrest at Vulcano in the last decades, and aims at updating the interpretative framework developed in 2017 to meet needs of the national Department of Civil Protection (DPC) accounting for the new evidences emerging from the unprecedented multiparametric record that the ongoing unrest is producing.

WUnderVul focuses on the conditions and processes that control the system's transition to different states of activity and aims at a better understanding of the volcano-hydrothermal system of Vulcano. To this aim, we propose a multidisciplinary approach based on:

- organising, integrating and extending the spatio/temporal coverage of the data available for Vulcano, planning specific campaigns and laboratory experiments to collect new data that fill existing gaps;
- identifying, adapting and further developing the modelling strategies to enhance the comprehension of the physical processes that control volcanic unrest episodes and associated phenomena at Vulcano;
- promoting the development of alternative conceptual models that describes the main drivers of unrest episodes at Vulcano, also identifying volcanic analogues to Vulcano to acquire a more general perspective on the problem and enlarge the possibility of model testing and unrest interpretation
- promoting multi-parametric data analysis and interpretation to link monitoring to the developed conceptual models, and track Vulcano dynamics during unrest episodes;
- favouring the scientific exchange through seminars and yearly workshops, involving the extended scientific community working on Vulcano and/or on analogue volcanoes and organising ad hoc elicitation experiments;

Over these general objectives, **WUnderVul** will activate a process of community building that will promote scientific discussions about Vulcano and data sharing, keeping to the highest level the scientific attention to a system that is presently in unrest and it may remain so for years. To enhance the scientific comprehension of Vulcano, it is indeed fundamental to organise a steady flux of scientific debate, to discuss old and new data, observations, interpretations, and physical models. Strengths and weaknesses of alternative hypotheses must be explored and potential approaches that may help discriminating among them discussed. This requires the gathering of a wide and diverse scientific community available to participate in the process and collaborate to identify credible alternative interpretations that are based on an updated and complete scientific background and are not falsified by observations.

To meet these general objectives, **WUnderVul** will foster new research to fill the existing gaps in data and observations, and will further develop physical modelling of unrest phenomena and related outcomes. Modelling efforts will be constrained by *ad hoc* laboratory experiments. These activities will redefine the existing interpretation framework for the volcano-hydrothermal system that controls the unrest dynamics. Based on this, **WUnderVul** will propose alternative conceptual models that will be openly discussed within the extended scientific community and linked to potential changes in monitoring observations, as identified by innovative multi-parametric analyses.

More specifically, we will collect and reorganise all available datasets for Vulcano, including historical and geological data of its past activity, monitoring data covering past unrest episodes since the first monitoring systems deployed in the 1970s, up to the data collected during the 2021 unrest. All available data will be organised to facilitate future data exploitation, and a significant effort will be dedicated to homogenise time series. Such datasets will be expanded by specific campaigns targeting relevant locations or specific parameters. Data from analogue volcanoes will be examined too, to gather further insights to constrain the physical processes that guide volcanic unrest and have led to phreatic explosion in the past. Numerical modelling will be used together with field data to identify conditions that favour the onset of unrest phases, generating a variety of signals and possibly culminating with phreatic events. **WUnderVul** will focus in particular on the study of hydrothermal fluid circulation, investigating the conditions that generate the observed changes in gas composition and flow rates, and the corresponding poro-elastic deformation. Specific attention will be dedicated to explore the conditions that promote the onset of phreatic events and study the propagation of fluid-filled fractures within the island’s specific tectonic setting. Existing data will be integrated by laboratory experiments designed to provide information on material properties and system conditions that promote slope instabilities and rock fragmentation. All the information gathered from data, experiments and modelling will be combined and integrated into possible conceptual models of the volcano and its evolution. This development will be organised within a multiple-expert context, in which the exchange of opinions and alternative hypotheses is favoured through seminars and workshops, as well as the organisation of specific elicitation experiments. Such conceptual models will allow to identify potential analogues from worldwide volcanoes, allowing to extend the possible testing of modelling and of alternative hypotheses. On the other hand, linking monitoring anomalies and significant patterns to conceptual models will improve our capacity to identify the timing and the phenomena that characterise the system transition from one state of activity to another, contributing to a more effective, possibly real-time interpretation and tracking of the evolution of the volcanic system.

State of the art, background ***(max 4 pages including figures)***

Vulcano is the southernmost island of the Aeolian archipelago, and it is associated with a significant risk, especially during tourist season (Selva et al. 2020; Bonadonna et al. 2021).

The volcanic record

An extensive literature exists about its volcanic activity, eruptive style and dynamics, magmatology and geology (Selva et al. 2020; De Astis et. 2013 and references therein). The last of its eight eruptive epochs (De Astis et al. 2013) generated eruptions ranging from Strombolian and effusive activities to Vulcanian eruptive cycles, including few large phreatomagmatic eruptions (refs. in Selva et al. 2020), with vents active within La Fossa Caldera. The stratigraphic records also report large phreatic explosions that involved the hydrothermal system, producing extensive eruption-like phenomena featuring convective columns, ballistic ejection and pyroclastic density currents (such as the Breccia di Commenda event; Frazzetta et al., 1983; Di Traglia et al., 2013; Rosi et al., 2018; Selva et al., 2020) from La Fossa cone (LFc).

Since the last eruption (1888-1890), LFc and some areas at its foot have been the site of a continuous gas discharge, featuring two fumarolic fields (one on the active crater rim, and another near the Levante shore) and widespread diffuse degassing through the soil, both on the crater rim and at a few sites on the Caldera floor around LFc. In the last three decades, the progressive strengthening of the monitoring system has provided evidence that the volcanic system experienced episodes of remarkable change. Unrest phases (the first closely monitored episode occurred in 1988) have been characterised by the increase of the fumarole temperature, the enlargement of the fumarolic area, larger gas output rates, and changes in gas composition as well as ground deformation and seismicity.

The monitoring system

Since 1984, a comprehensive geochemical and geophysical surveillance network has been deployed. From 1987/1988, an EDM network covering the LFc was installed. GPS monitoring began only in the early 2000s, and even more recently the analysis of satellite data. The seismic network, after the installation of four stations made in late ‘70s, was implemented in 2006 with the setup of a broadband network (Alparone et al., 2010) and, during the last unrest event, with the installation of 7 mobile stations.

Geochemical monitoring is dealing with different critical areas: LFc rim, il Faraglione, Spiaggia/Baia di Levante (BdL), Palizzi, and some locations within Vulcano Porto village. The monitoring system was initially based on a network of stations for real-time monitoring of fumarole outlet temperatures (Barberi et al., 1991). Periodic field surveys (weekly to two-monthly) addressed the chemical and isotopic composition of fumarolic gases from the vents (e.g. Badalamenti et al., 1991). Since 1977, the systematic monitoring of thermal wells in Vulcano Porto revealed variations in water chemistry and stable isotopes. These changes were synchronous with those of crater fumaroles several times since 1979 (Inguaggiato et al., 2018 and refs. therein). More recently, permanent instruments record temperature, water level and conductivity in some thermal wells.

CO_2 diffuse degassing through the soil has been monitored since 1984 (Badalamenti et al., 1988, Badalamenti et al., 1991, Baubron et al., 1990). Periodic measurements in Vulcano Porto and at the base of LFc (Grotta dei Palizzi) revealed significant changes during unrest periods (Diliberto et al., 2002). More recently, a permanent network of automatic stations for soil CO_2 flux measurements has been implemented (Camarda et al., 2019). SO_2 output in the crater plume is continuously surveyed by UV scanner permanent stations (Inguaggiato et al., 2018). The Levante beach area also hosts hydrothermal activity such as low-temperature fumaroles, submarine gas vents, and steaming ground. Here, only a discontinuous record is available on the compositions of the fumaroles and the CO_2 output through the soil.

Overall, a complete collection of the data regarding Vulcano is lacking, whereas a systematic and homogeneous dataset, as well as additional investigations, would be crucial to shed light on some uncertain points, like the involvement of the magmatic source along with the hydrothermal system during crises, and their possible evolution towards volcanic events.

Physical modelling of the system

Numerical modelling and experimental research provided a significant contribution to the understanding of the physical processes dominating unrest at Vulcano, allowing to compare and test different theoretical hypotheses. Physical modelling of multi-phase and multi-component fluid flow through porous media was used to describe the propagation of magmatic gases within a shallow and heterogeneous hydrothermal system (Todesco, 1995a,b; 1997). These early works already showed how rock permeability and its spatial distribution may affect the evolution of the system, controlling the temperature and pressure distribution within the system and the characteristics of surface emissions, in terms of spatial extent, flow rate, temperature and composition of discharged gases. Fluctuations of the magmatic source can explain not only the observed compositional changes (Chiodini et al., 2003) but also changes in geophysical signals (Todesco and Berrino, 2005; Fournier and Chardot, 2012; Currenti and Napoli, 2017). Hydrodynamic models were later coupled with geomechanical models to investigate the thermo-hydro-mechanical interactions between the circulating fluids and the porous matrix (Rutqvist et al., 2002). Applications to volcanic environments constrained the role of hydrothermal fluids in driving poroelastic deformation, especially within caldera settings (Todesco et al., 2004; Ingebritsen et al., 2010; Rinaldi et al., 2010; Coco et al., 2016; Todesco, 2021). A recent application on the island of Vulcano confirmed the relevance of permeability distribution in controlling not only the evolution of fumarolic activity during the unrest, but also the observed ground deformation (Currenti et al., 2017; Stissi et al., 2021). Numerical simulations also highlighted the relevance of permeable channels to discharge fluids and prevent pressure build up within the system, but it remains an open question what controls the development of preferential pathways for the ascent of magmatic gases. The role of local stress field, as in crack propagation, dyke emplacement and vent position, is probably fundamental (Rivalta et al., 2019; Davis et al., 2021), but was never considered to constrain the position of fumaroles, nor to estimate the degree of interaction between shallow and deep fluid components.

Hydrothermal fluids may also fuel phreatic explosions, driven by the rapid gas expansion upon sudden decompression or extreme heating. In general, fluid expansion can be accommodated by a combination of poroelastic deformation and fluid discharge. However, fluid expansion rate may be too high and cause rock fragmentation, leading to a phreatic eruption. A physical model of Eulerian–Eulerian, two-phase, non-equilibrium gas-particle fluid, with coupled Lagrangian ballistic blocks was applied to study the phreatic event of Commenda, at Vulcano (Rosi et al., 2018). Results showed that hydrothermal explosions may include block and ash fallout and the generation of pyroclastic density currents that may reach and overcome the caldera boundary. The hazard associated with these phenomena is significant and suggests a careful assessment.

The application of physical models to the study of volcanic phenomena requires a careful definition of material properties and system conditions. To properly describe the hydrothermal activity, we need new geological and rock mechanics knowledge to understand the sealing, pressurisation and failure thresholds of hydrothermal reservoirs. This new knowledge can be pursued by combining novel laboratory experiments with geological and rock mechanics techniques to i) track mechanical responses of essential hydrothermal reservoir lithologies according to their alteration, ii) define critical pressure/temperature conditions and deformation rate for which reservoir rocks overcome failure thresholds, leading to a phreatic eruption.

X-ray tomography is an innovative imaging technology for the study of rocks in 3D and non-destructively in the digital rock physics framework. Rock are investigated through apposite image analysis workflows, which include segmentation of digital rocks (i.e., different phases are identified and labelled) and numerical simulations (e.g., based on lattice Boltzmann or finite volume methods) on segmented images to obtain hydraulic, elastic and electrical properties, using open and commercial codes. Deep learning approaches (e.g., super-resolution) can be also employed to optimise their characterization. These workflows will be applied to rock samples from Vulcano bedrock and outcrops to produce a systematic dataset, useful to constrain numerical modelling and geophysical prospections. Such new knowledge will boost actual models of hydrothermal system instability and eruption dynamics, and help forecasting instabilities in volcanic settings.

Conceptual model & the 2021 ongoing unrest

Monitoring data and numerical modelling results can be integrated and interpreted only within the framework of an appropriate conceptual model. A careful review of known eruptive and non-eruptive phenomena involved in the evolution of the volcanic system of Vulcano was performed by a working group established in 2016 within the agreement between INGV and DPC (Selva et al. 2017,2020). The developed conceptual model, building on Paonita et al. (2013)

interpretative framework, is based on the interaction between magmatic and shallow/deep hydrothermal systems, and allowed the definition of paths-to-eruption delineating potential unrest types linked to different physical states of the system. Present day alert levels and DPC planning is deeply connected to this interpretative framework.

The still ongoing 2021 unrest, larger than all recent minor crises, has been recorded with the present multi-parameter monitoring system, providing a unique opportunity to better constrain the physical phenomena at play, and to challenge the existing conceptual model. The unrest showed a remarkable increase of the degassing activity, both from the crater fumaroles and through the soil. Fumarole composition revealed a drastic increase of the magmatic component, while the temperature increased by some tens of Celsius degrees. Local seismicity sharply increased and was characterised by the appearance of VLP events (peak freq. 0.2-0.3 Hz), never recorded since the broadband network installation in 2006. These events were associated with a source (750 m bsl) located below the Forgia Vecchia crater and roughly corresponding to the area of maximum deformation revealed by GPS, tiltmeter and InSAR data. In October 2021, massive gas discharge impacted areas at the cone foots and by early November the SO_2 flux in the crater plume reached one order of magnitude above the background. At present (May 2022), the recorded anomalies are still evident and, also in the last few days, increased hydrothermal activity is observed in BdL.

These new observations challenge the state of knowledge about Vulcano, and the simplified scheme of the dynamics processes that drive Vulcano's evolution. New data add a significant amount of information that, with time, will contribute to building new conceptual models. The development of multivariate analyses of available time series will lead to the interpretation of the ongoing unrest and the establishment of links between observed changes and the transition between different states of the system. Focused field-measures will foster the scientific debate.

The need of a multiple expert process

The involvement of a large sector of the scientific community in the discussion about the system evolution and the appropriate conceptual models is crucial to discuss alternative interpretations, giving us access to "the center, the body, and the range of technical interpretations that the larger technical community would have if they were to conduct the study" (Budniz et al. 1997; Bommer and Scherbaum, 2008; Marzocchi et al. 2015,2021). Repeated discussions followed by elicitation experiments will collect the group opinions avoiding the potential cognitive biases that may emerge in group interaction (Aspinall, 2010; Aspinall and Cooke, 2013; Bedford and Cooke, 2001; Cooke, 1991; Selva et al. 2012; Bevilacqua et al. 2015). Through this approach, we will build a common background to interpret the volcanic system, based on multi-parametric data and multidisciplinary knowledge (Selva et al., 2012), that favours a mutual acknowledgement of the different positions and the rationale behind them. The identification of a reasonable range of alternative conceptual models for Vulcano will enhance the system comprehension and focus future research effort toward the solution of controversial hypotheses.

Applied research methodologies described as WPs, integration among WP, project risk analysis *(max. 8 pages including figures and conceptual scheme)*

The project is organised in four work packages (WP) (**Figure 1A**): WP1 is dedicated to collect and organise existing data, and to produce of new observations to fill specific gaps; WP2 is focused on laboratory experiments and physical modelling of unrest phenomena; WP3 is devoted to the refinement of the conceptual models used to interpret the unrest dynamics, linking such models to existing patterns and anomalies in the monitoring observations. WP4 is dedicated to coordination of the project, organising internal meetings and workshops, and favouring the exchange of data and information

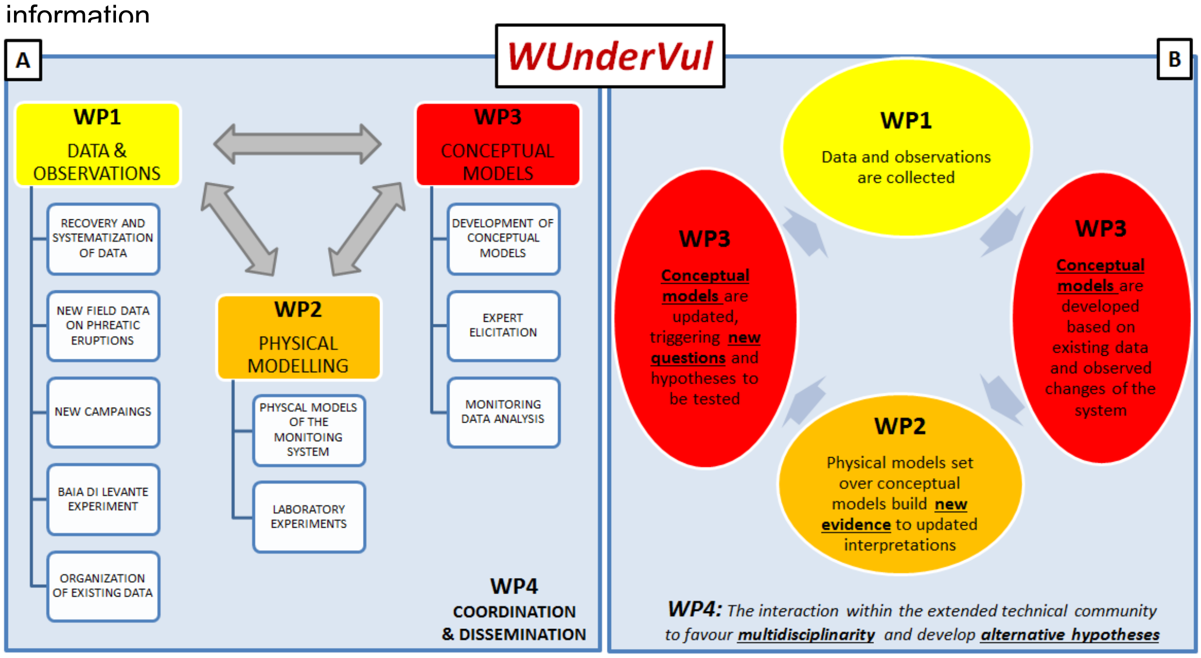

Figure 1. (a, left) The **WUnderVul** WPs. (b, right) Scientific growth based on the exchange of information among data (WP1), physical modelling and laboratory experiments (WP2), and interpretative frameworks (WP3), nested into a multiple expert framework (WP4).

*The integration of WPs and their role in **WUnderVul***

The integration among the WPs is coordinated by WP4, to guarantee the cross feeding among data (WP1), modelling (WP2), and interpretative frameworks (WP3) to enhance the comprehension of the Vulcano system (**Figure 1B**). All available data (WP1), including field observations, geological and historical reconstructions, monitoring observations, etc., will concur in building an updated understanding of the volcano-hydrothermal system. This knowledge will be made explicit by formulating conceptual models (WP3) that provide an interpretative framework for the main physical states of the volcano and for transitions among different states. Monitoring observations will be analysed to recognize patterns and anomalies that track the changes of the system. The conceptual models will inform physical models and laboratory experiments (WP2) that, in turn, will build new evidence, especially on features that are poorly constrained by data. This new evidence will contribute to the interpretation of the system (WP3), and eventually prompt the production of new data (WP1), to constrain system properties and conditions or to discriminate among alternative hypotheses. The WP activities will be immersed into an open framework of interaction with a wider scientific community that extends outside the project. This will favour multidisciplinary interpretation and to generate alternative scientific hypotheses to be challenged with new data and observations.

Description of the Working Packages

WP1. Data acquisition and organisation (Coord. G. De Astis)

Main Objectives:

- Unravelling and organising the past monitoring datasets;
- Field-survey on LFc phreatic deposits, on hydrothermally altered soil/rocks and their sampling (in situ and lab analysis);
- Mapping of LFc sectors susceptible to instability and landslides triggering;
- Multi-disciplinary “experiment” on BdL.

Participants: INGV-RM1/PA/OE/OV/PI, Uni-Ba/Bo/Camp/Pa/Pi/Sap, CNR, PoliMex

Description: WP1 deals with data collection, systematisation and processing, in the entire spectrum of physico-chemical parameters that characterise the LFc and caldera system, especially those possibly related to phreatic eruption and slope instability. In both cases, the goal is understanding the triggering conditions, also accounting for the possible transition from landslides to phreatic events. WP1 plans a close collaboration between different groups to build a dataset that integrates: a) the monitoring data of the last 40 years; b) litho-stratigraphic data on the rocks emitted in the last 1000 years; c) mineralogical, geotechnical, microstructural analyses of the rocks. A multiparametric acquisition of geophysical and geochemical data is planned within the BdL, to provide a shallow structural scheme in input to WP2. WP1 activities are organised in 5 tasks.

Task 1.1 is dedicated to collect and systematise the multi-parametric monitoring data of the last 40 years, as specified below. The resulting dataset will include all data produced during the project.

(a) Satellites time series including the analysis of INSAR data of past decades and the evaluation of the existing/recent field geomorphological survey, redefining the areas prone to active deformation, combined with slope instability;
(b) Existing cartography on LFc fumarolic fields;
(c) Ground deformation data collected since the 1970s by discrete levelling measurements, EDM/GPS surveys and continuous tilt.
(d) Time series of seismic data acquired since the late 1980s up to present time.
(e) Chemical-physical parameters of thermal groundwater of the Vulcano Porto area, including selected thermal wells, acquired in over 35 years of monitoring;
(f) Fumarolic gas chemistry, including the new acquisitions in the crater fumaroles and in the bubbling pools and fumaroles in the Levante beach area; the time series of SO_2 plume data from last 15 years (NOVAC SO_2 network); the time series of continuous soil CO_2 flux data.

(g) Soil CO_2 flux and air gas concentration (CO_2, SO_2 and H_2S) from periodic campaigns on target areas of Vulcano Porto.

Task 1.2 is focused on field-data on phreatic eruptions. Phreatic deposits related to the last 1000 yr of LFc activity will be investigated on the field. The study will include phreatic events and the initial phreatic phases of eruptions that later involved a magmatic component (e.g. Pietre Cotte). Rock-samples will be analysed to understand the processes triggered when magma presence and/or arrival close to the surface occurs. Comparisons with similar deposits outcropping on other volcanoes of Mediterranean area, characterised by hydrothermal systems at different scales, will be considered. These data from analogue volcanoes will be evaluated and discussed with the participants from WP2 and WP3.

Task 1.3 is focused on field campaigns and new data collection. This is a strongly multi-discipline task aimed at improving the existing database on slope instability and LFc shallow structure, including the interplay between field-data and modelling.

(a) Meteo station installation aimed to know the water content in the soil and its variation, and the relationship with landslides triggering;
(b) Geo-Morphological survey of LFc and BdL and merging with both InSar data and modelling of rainfall-induced sediment erosion that evaluates the volumes of erodible fragmental material;
(c) Morphological and morphometrical analysis of the most recent high resolution topography of the island for identifying the areas more prone to instability slopes and landslides triggering;
(d) Analysis of LIDAR data (if available) and supervised classification, based on field survey of volumetric soil moisture content, for the reconstruction of the spatial distribution of areas prone to hydrothermal vapour condensation;
(e) Analysis of PRISMA hyperspectral data and supervised classification, based on sampling and XRD rock analysis, for the reconstruction of the spatial distribution of hydrothermal alteration facies;
(f) Soil and pyroclastic rock sampling and analysis (on site and in the lab) for the geotechnical parametrization of the volcanic deposits of LFc and BdL area;
(g) Mapping the fluids circulation through GNSS survey of low and high temperature fumarolic fields at LFc and in the BdL area, and creation of the related geodatabase;
(h) GNSS and optical levelling surveys for the reconstruction of marine erosion and relative sea/land elevation changes in the BdL area.
(i) Strategic field-survey to collect ERT data, to better comprehend the shallow structure of La Fossa Caldera northern sector, where a strong interaction between fluids and shallow altered rocks occurs. 4 ERT profiles are planned - together with electrical chargeability, self-potential (SP) and temperature surveys acquired through the same array - which will provide structural info down to about 200 m depth.

(j) A muon detector will be installed at the northern extreme of LFc, at sea level. The muon-tomography (Bonechi et al., 2020) will provide info on structure, average compositions and rock density of LFc northern flank/crater with its fluid content evolution. Continuous measurements of the muon flux in different directions will be used to highlight sectors with higher collapse hazard and to quantify possible density changes inside the crater.

Task 1.4 organises specific data acquisitions on BdL, to fill the existing gaps in an area prone to gas emissions and potential phreatic explosions during unrest.

(a) CO_2 output measurements aimed at: estimating the gas mass rate from the bubbling gas emissions in the Vasca mud pool; defining the CO_2 average concentration in air along some optical paths, by using IR diode lasers and retrieving the gas mass rate, after inversion of these data and acquisition of the local wind velocity. A comparison of these measures with direct measurements of CO_2 gas mass rate achieved through an accumulation chamber connected with a floating platform, will be done.

(b) Measurements of reducing capacity in fumaroles of Levante beach: the reducing capacity of volcanic gases can help to track the magma degassing evolutions. After the design of a prototype of the monitoring station based on both electrochemical, optical and resistor sensors, to measure the concentration of H_2, CO and CO_2, we will proceed with the installation in one site in the Levante beach area and data processing.

(c) High frequency acquisition of soil temperature along a 100 m long transect, with a spatial resolution of 1 m, by the mean of a optic fibre laser system;

(d) 3D tomography of dissolved CO_2 and physical-chemical parameters in the BdL by means of a remote controlled Catamaran, during 2 to 3 measurement surveys in the BdL sea to provide a 3D tomographic view of the distribution of dissolved CO_2, pH, T, EC and Eh.

(e) Strategic campaigns to collect ERT data focused on Levante beach and muddy pool. These ERT data will be used to reconstruct a 3D model of the subsoil resistivity down to a 100 m depth in a 500 × 500 m^2 area.

(f) Seismic data to be acquired through additional seismic and infrasonic stations (INGV-OE mobile networks) that will be installed close/around to the muddy pool.

(g) GPS and gravimetric data to be acquired with the temporary installation of the GPS station and gravimeter close/around to the Levante beach mud pool.

Task 1.5 is dedicated to collect and organise in a repository all project's data. All the types of data will be dealt with the support of the data producers, to produce metadata and make them fruible. Data representing time series will be harmonised to be compliant with the database framework developed at INGV-OE for monitoring purposes. This will facilitate a possible use in real time of the algorithms developed within the project. Project's data will follow the principles of the INGV Data Policy (https://data.ingv.it/docs/implementation/).

WP2. Hydrothermal system instabilities and phreatic events (Coord. M. Todesco)

Objectives

- Fluid dynamic modelling of hydrothermal fluid circulation;
- Modelling of fluid filled crack propagation;
- Modelling of phreatic eruptions;
- Laboratory experiments to better constrain models' parameters;

Participants: INGV-BO/OE/OV/PI, UniBo, LMU

Description*:* The WP explores the conditions under which hydrothermal fluids generate instabilities and cause phenomena of volcanic unrest. Laboratory experiments and physical modelling will constrain material properties and system conditions that are consistent with the observed evolution. Results will be interpreted based on available data (WP1) and will focus on the transitions from quiet to unrest, to eruptive activity. The WP will also address the onset and evolution of phreatic events. Comparison with analogue volcanoes will improve our understanding and will contribute to the development of the conceptual models (WP3). Two tasks are foreseen:

Task 2.1 is dedicated to laboratory experiments, and is organised in two steps:

(a) Multiscale characterization of petrophysical properties of representative rock samples with X-ray microtomography to obtain high-resolution (1 μm) 3D digital images of rock samples. In- and ex-situ experiments will allow 4D time-resolved imaging. A database of microstructural parameters (e.g., pore and crystal content and size distribution) and physical properties (e.g., permeability, electrical resistivity, elastic moduli, Vp/Vs) will be transferred to WP1. The data will allow examining physical and chemical processes from core- to pore-scales. Tomographic investigations will be integrated with petrophysical, mineralogical-petrological and high resolution textural analyses (optical, XRPD, EDS microanalysis and BSEM investigations), in continuity with the activities started in Task V2, Pianeta Dinamico project (2020-2022).

(b) Laboratory experiments will be performed at the INGV-OV through a HT (up to 250 °C) – HP (uniaxial compression/tension, up to 5 kN) cell, under dry or partially/totally saturated conditions; ex-situ core flooding experiments up to even higher T-P can be also planned. The aim is to explore how subsurface rocks behaviour can influence volcanic unrest and monitoring signals. By leveraging the use of the world's largest physical decompression apparatus in Munich (LMU), we will also complete a series of experimental tests using the well-characterised Vulcano samples, to capture the transition from outgassing to fragmentation and ejection during explosive events. Experimental hydrothermal explosions will be performed at the P/T conditions estimated for Vulcano's past eruptions. Field and laboratory data will inform on eruptive scenario(s), and on P/T conditions that theoretically led to past hydrothermal eruptions.

Task 2.2 is focused on modelling of the hydrothermal system and will target three phenomena: (a) hydrothermal fluid circulation; (b) fluid-filled cracks propagation, and (c) phreatic eruptions:

(a) The geophysical and geochemical time series acquired during the 2021 crisis (WP1) will be used to validate the in order to estimate the P,T variations generated during unrest. Simulations will provide clues on the rate at which water phase change may occur upon heating or decompression, as a function of rock properties and initial and boundary conditions.
(b) Simulation of propagation of fluid-filled fractures through the crust and LFc will be carried out to better understand distribution of fumaroles. Fluid composition and properties will be constrained according to the available data and the equation of state. The stress field on the island may be estimated from the volcano structure and history and validated based on geophysical data. Results will refine the permeability distribution and identify the presence and geometry of preferential channelways for fluid ascent.
(c) Phreatic eruption modelling will be carried out to investigate the dynamics of phreatic events, particularly for what concerns the initial stages of the explosion, in which the expansion energy is taken from overpressured gases and/or overheated liquid water. The role of the rock's physical characteristics will also be investigated. Benchmarking of the numerical models will be carried out against laboratory experiments.

WP3. Development of Conceptual Models and link to monitoring (Coord. C. Federico)

Objectives

- Conceptual models and interpretative framework for monitored parameters;
- Definition of analogue volcanoes;
- Organisation of the elicitation experiments;
- Analysis of monitoring data and link to conceptual models.

Participants: INGV-PA/OE/BO/PI/RM1, Uni-Ba/Na, UniGeneve

Description: The need to implement a conceptual model upon La Fossa volcano-hydrothermal system is related to i) the ascertainment of the change from the state of rest, ii) the comprehension of the volcano dynamics during the so-called crises and iii) their significance in terms of volcanic unrest evolution. This would allow ascribing a physical meaning to the monitored parameters, and evaluating the possible evolution of the ongoing phenomena. The WP3 is organised in three tasks.

Task 3.1 is dedicated to the development of conceptual models. A working group will formulate conceptual models out of old and new data, to be discussed at meetings and workshops (WP4) and will define analogue systems of Vulcano worldwide, where unrest phenomena have been recently monitored. To better cover the possibility of alternative working hypotheses and of up-to-date scientific developments, this WP will foster the largest involvement of expert scientists organising a cycle of specific seminars. The working group will also organise the discussion of alternative models / hypotheses within the workshops organised by WP4.

Task 3.2 is dedicated to elicitations. Elicitations help the community to focus discussions and reach procedural consensus on subjective issues that cannot be univocally set quantitatively based on data or modelling. This task is developed in two main activities:

(a) It will be developed a new web-based tool for elicitation for the project, i.e. ELICIPY https://github.com/demichie/elicipy, to be applied during the project. The tools will include online forms for remote counselling and fast data processing, including the management of the weights of the experts and MC sampling features to feed uncertainty analysis.
(b) Elicitation experiments will be designed to quantify the credibility of alternative conceptual models, to link the conceptual models to monitoring anomalies, and to define thresholds to identify anomalies. Further elicitation experiments on possible different topics will be defined during the project based on the needs that will emerge.

Task 3.3 is focused on multivariate analyses of existing monitoring. The goal is to extract further clues to connect the monitoring data to the physical states of conceptual models, as the first step to track the state of the system based on monitoring. This task encompasses four different activities:

(a) We will implement an analytic formulation of the well-known Failure Forecast Method (FFM) to track the evolution of a volcanic unrest by modelling the acceleration of monitoring data. In particular, we will focus on the analysis of the temporal rates of monitoring data (namely ground displacement data and seismicity) during the 2021-2022 unrest. A retrospective daily analysis of the FFM estimates will be performed, providing an acceleration index that tracks the potential waiting time, highlighting the most critical phases and their temporal evolution.
(b) We will look for multivariate anomalies (when the values of various features, taken together, are anomalous even though individual parameters are not), simultaneously examining all values and verifying when combinations are unusual (multivariate outlier). Without sufficient a priori knowledge on the dynamics of Vulcano, we will use unsupervised techniques for anomaly detection such as Inter-Quartile Range, Isolation Forest, KNN, Auto Encoders, One-Class SVM. These techniques are predominantly used on data different from time series, thus we will first need to address possible auto- and cross- correlations, non-linear relationships and nonstationarities to avoid spurious results.
(c) We will produce pattern classification of multivariate data to identify relevant groups of data in whatever data streams, either geophysical, geochemical or others, taking advantage of the multidisciplinary multi-year datasets prepared in WP1 adopting unsupervised techniques like Self-Organizing Maps, Centroid-Based Clustering as well as Density Based Cluster Analysis, using ready-to-use software packages. Supervised pattern recognition may be applied once relevant categories are identified and can be used as target information, using sophisticated techniques such as Multilayer Perceptrons or Support Vector Machines can be considered.
(d) In close interaction with WP1/WP2, we will evaluate the impact of using different features (e.g., existing fractures from WP1, or magma propagation modelling from WP2) in determining the location of a future magmatic event, testing the results against available data. The selection of the relevant features will be made in cooperation with the project's community, possibly subject

to an ad hoc elicitation (Task 3.2). We will possibly account for the directionality (e.g. for fractures), in case they are deemed as a proxy for the unclumping normal stress.

WP4. Coordination, Workshop & Dissemination (Coord. J. Selva)

Objectives

- Continuous monitoring to delivery objectives;
- Organisation of kickoff and of 3 open workshops;
- Monitoring and fostering the dissemination of project's results.

Participants: INGV-BO*,* All partners

Description: The dissemination and communication will go in parallel with other WPs to obtain up-to-date information on the achievements of the project in order to disseminate them to the appropriate audiences. Two tasks are foreseen:

Task 4.1 will organise the kickoff meeting, involving all the projects' participants, and 3 workshops, inviting also the scientific community outside the project. Workshops will start when a sufficient amount of new information will be available from WP1, WP2, and WP3, thus workshops are foreseen from the second year. The style of workshops (open, invitation list, etc.) and the list of participants will be discussed at the kickoff meeting.

Task 4.2 will coordinate internal communication and dissemination. A website for the exchange of material and data (e.g. Drive) will be organised within the first six months of the project (M4.2), collecting also the main findings of the project (deliverables, papers, data, etc.). The main achievements in terms of papers, presentations, and other impacts will be collected in a short final report to be delivered at the end of the project (D4.4).

Risk Analysis

The main risks that may impact the achievement of the project activities are the following:

- *Administrative delays in purchasing new instruments, goods or services*. This is a medium/high risk, mostly due to the overcharge INGV administrations. The risk is decreased by early planning of purchase procedures. Single delays are not critical and will not compromise the project.
- *Delays in getting authorizations to access the sites*. This is a low risk, because many sites are already accessed by INGV scientists for volcanic monitoring or the access can be requested to legal administrations (e.g., Court; Carabinieri).
- *Difficulty in performing the survey and instrument installations*. Eventual evolution of the ongoing volcanic crisis towards unsafe working conditions. In this case, the activity will proceed with the study of data already available and of analogous volcanoes.
- *Coordination difficulties, related to the size of the project and the diversity of backgrounds.* Frequent project meetings, together with yearly workshops will help the coordination effort.

Expected results, list of products and potential impact of the proposed project ***(expected results for each WP and full project results, Gantt chart, max. 4 pages including figures)***

<u>Impact</u>

WUnderVul will have a significant impact on the studies regarding the volcanic system of Vulcano. To enhance the comprehension of the volcano-hydrothermal system producing the Vulcano's unrest episodes, **WUnderVul** relies on a process of community building around Vulcano or analogue volcanoes. This process is based on multiple interactions among experts within the project, as well as with the wider scientific community outside the project. This will generate a common multidisciplinary background on existing observations and models, on shared and alternative interpretations, as well as new ideas and running hypotheses to be tested. To this end, **WUnderVul** intends to initiate a process of scientific growth (**Figure 1B**) with a potential impact that goes well beyond the temporal limits of the project. Notably, a significant number of participants working on Vulcano represent not only the INGV, but also the Academia (20 partners from 15 institutions), and were directly involved in the project to guarantee from the very beginning the achievement of this very important task.

Also the specific results and products of **WUnderVul** will have a significant impact. At first, the design of a comprehensive data collection, gathering the data produced by different research groups during the last four decades, including the most recent monitoring data, could be an operative instrument, which could be readily accessed by the scientific community to speditive assessments in case of unrest. Moreover, the experimental tests of new measurement systems will provide the background for additional parameters to be eventually included in the monitoring network.

Another potentially impacting result of **WUnderVul** is the formulation of a list of existing conceptual models and their connection to monitoring, and the building of a community trained to elicitation tools. This may strongly implement, with new scientific inputs, all operative and pre-operative activities organised for DPC, as the ones foreseen in Attachments A and B of the Convention between INGV and DPC.

The refinement of the conceptual model will improve the interpretative framework to link the observed trends and eventual anomalies in the monitored parameters to the ongoing processes, reducing the cognitive gap between the observations and forecasts. This process, basically well-founded on the experience and skills of involved scientists, will also feed typical quantitative forecasting methods (e.g. Bayesian Event Tree, Bayesian Belief Networks, etc; Aspinall et al. 2003; Marzocchi et al., 2008, 2010; Hincks et al., 2014; Rouwet et al. 2014; Tonini et al., 2016) strongly rely on the adopted conceptual model and on its connection to monitoring. The possibility to implement alternative conceptual models will allow an effective exploration of existing epistemic uncertainty, that is the uncertainty deriving from "alternative but technically defensible interpretations” (from Budnitz et al. 1997). This is fundamental to produce an ensemble of alternative implementations (Marzocchi et al. 2021), allowing the effective inclusion of uncertainty in the decision-making process, leading to the possibility of effectively optimising the desired policy defined by decision-makers (Selva et al. 2020).

WUnderVul will also produce web-based elications tools, training the extended community toward the use of such tools and the rationale behind elicitation experiments. This may have a major impact on the potential management of the definition of consensus forecasting models (e.g. Selva et al. 2012; Neri et al. 2008; Marzocchi et al. 2008). These methods may also be used to favour the involvement of the larger community in case of prolonged crises, especially if something completely unexpected happens. Notably, this will also be a benefit that goes beyond Vulcano, as similar methods may be easily extended also to other volcanoes.

WUnderVul Results

All deliverables and milestones are specifically described in **Table 1**. For each deliverable and milestones, it is reported expected delivery time, the institution responsible for the delivery, the type of deliverable (e.g. report). In **Table 2**, we report the temporal organisation of the activities in the four WPs of **WUnderVul**, and the temporal production of specific results in terms of deliverables and milestones.

Table 1: Deliverable and Milestones, responsible and delivery time (month of the project)

WP1: Data acquisition and organisation

Deliverables

- D1.1 (M12, INGV-OE/PA): Seismic, ground deformation and geochemical data review (dataset)
- D1.2 (M24, INGV-RM1, UniBO, UniBA): Field investigations on phreatic deposits (report)
- D1.3 (M12, INGV-OE/PI): Updated geodatabase of the fumarolic fields at La Fossa cone and Baia di Levante (dataset).
- D1.4 (M12, INGV-OE, CNR): La Fossa meteorological data publicly available (website)
- D1.5 (M24, ONT, INGV-OE/PI, UniPA, CNR, PoliMex) Geodatabases of existing InSAR and geomorphological cartography, and preliminary map for slope instability (report).
- D1.6 (M35, INGV-RM1/OE, CNR-IGAG, UniSap, UniCamp): Geodatabases of spatial distribution of soil moisture contents, hydrothermal alteration facies and geotechnical parameters related to La Fossa cone;
- D1.7 (M35, INGV-OE/PI/OV, UniPA, CNR-IGAG, PoliMex): Final geodatabase of areas prone to slope instability at La Fossa Cone and sea erosion at Baia di Levante
- D1.8 (M30, INGV-OE/OV/BO/PA): Integrated geodatabase of measures performed at Baia di Levante that will contain: a) 2D electrical resistivity tomography (ERT) of the subsoil and 3D ERT of a restricted area (muddy pool); b) 3D tomographic view of the distribution of dissolved CO_2, pH, T, EC and Eh; c) transect of soil Temperature; d) time-series of seismic, deformation and soil gas flux; e) results on seismic imaging and infrasonic measurements test and gas output measurements;
- D1.9 (M35, INGV-OE, all participants to WP1) Final collection of project’s data.

Milestones:

- M1.1 (M9-M18, INGV-OV/OE/RM1, UniBO, UniBA, CNR): Update of the data collection;

- M1.2 (M12, INGV-OE/RM1/PI/OV/ONT): Data and maps related to slope instability and fumarolic fields. Meteo station at La Fossa cone installed and fully operative - M1.3 (M18, INGV-OE/PA/BO/OV/OE, UniPA): Data acquisition at Baia Levante starting - M1.4 (M24, INGV-OE/PA/BO/OV): Data processing at Baia di Levante completed - M1.6: (M24-M36, INGV-OE/PA/BO/OV/OE, UniPA, CNR, UniSap, UniCamp): Data collected and processed in any task, presented at Workshops
WP2: Hydrothermal system instabilities and phreatic events *Deliverables* - D2.1 (M18, INGV-OV/LMU): Petrophysical data (report) - D2.2 (M24, INGV-OV/LMU): Laboratory experiments (report) - D2.3 (M36, INGV-BO/OE) Numerical simulation of hydrothermal circulation (report) - D2.4 (M36, UNIBO): Modelling of fluid-filled cracks (report) - D2.5 (M36, INGV-PI): Modelling of phreatic eruptions (report) *Milestones* - M2.1 (M6, INGV-OV; LMU): Sample acquisition - M2.2 (M18, INGV-BO/OE): Setup of physical models based on conceptual model - M2.3 (M30, INGV-PI): Model benchmarking with laboratory experiments and field data
WP3: : Development of Conceptual Models and link to monitoring *Deliverables* - D3.1 (M36, INGV-PA,all): Conceptual models for Vulcano (Report) - D3.2 (M24, INGV-PI/BO): Web-based elicitation tool (Software) - D3.3 (M33, UniNa,INGV-BO/PI): Elicitation experiments for Vulcano (report or paper draft) - D3.4 (M18, INGV-PI/CT): Analysis of accelerations (report or paper draft) - D3.5 (M30, INGV-CT/BO): Automatic processing of anomalies (report or paper draft) - D3.6 (M30, INGV-CT): Pattern classification of multivariate data (report or paper draft) - D3.7 (M35, INGV-BO): Vent opening & anomalies (report or paper draft) *Milestones* - M3.1 (M12, M24, M36): Lists of potential conceptual models, presented at Workshops - M3.2 (M14) Provisional implementation of the elicitation tool for the first elicitation - M3.3 (M15, M30): First elicitation experiments - M3.4 (M15, M30): Second elicitation experiments
WP4: Coordination, Workshop & Outreach *Deliverables* - D4.1 (M16, INGV-BO/RM1/PA): Report on Workshop #1 - D4.2 (M26, INGV-BO/RM1/PA): Report on Workshop #2 - D4.3 (M36, INGV-BO/RM1/PA): Report on Workshop #3 - D4.4 (M36, INGV-BO/RM1/PA): Report on achievement in dissemination *Milestones* - Milestone 4.1 (M6, INGV-BO/RM1/PA): Kickoff meeting - Milestone 4.2 (M15, INGV-BO/RM1/PA): Workshop #1 - Milestone 4.3 (M25, INGV-BO/RM1/PA): Workshop #2 - Milestone 4.4 (M35, INGV-BO/RM1/PA): Workshop #3 - Milestone 4.5 (M6, INGV-BO/RM1/PA): Website for file exchange

Table 2. WUnderVul's GANTT, indicating also the delivery time of deliverables (D) and milestones (M). Deliverables and Milestones are better defined in Table 1.

	M1-6	M6-12	M13-18	M19-24	M25-30	M31-36
WP1: Data acquisition and organisation						
Task 1: Recovery, re-organization and systematisation of available monitoring data		D1.1				
Task 2: Field-data on phreatic eruptions		M1.2		D1.2		
Task 3: Field campaign and data collection		D1.3, D1.4		D1.5		D1.6, D1.7
Task 4: Data acquisition on Baia di Levante			M1.3	M1.4	D1.8	
Task 5: Data Management		M1.1		M1.1		D1.9
WP2: Hydrothermal system instabilities and phreatic events						
Task 2.1 (a) Petrophysical data	M2.1		D2.1			
Task 2.1 (b) Laboratory experiments				D2.2		
Task 2.2 (a) Hydrothermal system modelling			M2.2			D2.3
Task 2.2 (b) Crack propagation						D2.4
Task 2.2 (c) Phreatic eruption modelling					M2.3	D2.5
WP3: : Development of Conceptual Models and link to monitoring						
Task 1: Conceptual model		M3.1		M3.1		D3.1
Task 2: Elicitation Tool		M3.2		D3.4		
Task 2: Elicitation experiments			M3.3		M3.4	D3.3
Task 3a: Acceleration			D3.4			
Task 3b: Anomaly analysis					D3.5	
Task 3c: Multivariate PR					D3.6	
Task 3d: Vent Opening						D3.7
WP4: Coordination, Workshop & Outreach						
Coordination & Workshop	M4.1	M4.2, D4.1		M4.3, D4.2		M4.4, D4.3
Dissemination		M4.5				D4.4

List of ongoing projects by coordinator

- Principal Investigator (PI) for INGV and Task Leader of the EuroHPC project eFlows4HPC (Enabling dynamic and Intelligent workflows in the future EuroHPC ecosystem), https://eflows4hpc.eu. The project started in 2021 and will end in Feb. 2024. The task and the connected deliverable under INGV responsibility have been already concluded.
- Principal Investigator (PI) for INGV and Work Package leader (WP1: Specific characterization of natural hazards on industrial sites) in the PRIN2017-NaTech project (Assessment of Cascading Events triggered by the Interaction of Natural Hazards and Technological Scenarios involving the release of Hazardous Substances). The project started in 2019 and will end in March 2023. The WP coordinated by INGV has been already concluded.
- Co-Task Leader, along with Dr. A.M. Lombardi, of Task ’Statistical Analyses (Analisi Statistiche)’ in MACROAREA: Seismic, Geodetic and Acoustic Monitoring (Monitoraggio Sismico, Geodetico, Acustico) of projects ’Reti Multiparametriche’ and ’Progetto Centro Italia (DL50)’, funded by INGV. The task started in 2022 and will last three years.

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PARTICIPANTS

(Requirements: following the guidelines in the document Procedura_Progetto_Pianeta_Dinamico_2023_2025)

INGV Staff (Only Technologist and Research Permanent position (I-III level); technical-administrative positions can not be reported)

Name and surname		UR		2023	2024	2025	**TOT**
		(i.e., INGV division/'sezione')	WP **(*)**	months/yr	months/yr	months/yr	months
Bevilacqua	Andrea	PISA	WP3	1	1	1	3
Bilotta	Giuseppe	OE	WP2	0.5	1	1	2.5
Bisson	Marina	PISA	WP1,WP3	0.5	1	1	2.5*f*
Bruno	Valentina	OE	WP3	0.5	0.5	0.5	1.5
Camarda	Marco	PALERMO	WP1,WP3	0.5	0.5	0.5	1.5
Cannavò	Flavio	OE	WP1,WP3	0.5	1	1	2
Cantucci	Barbara	ROMA1	WP2	1	1	0,5	2
Capasso	Giorgio	PALERMO	WP1	0,5	0,5	0,5	0
Carapezza	Maria Luisa	ROMA1	WP1,WP3	1	1	1	3
Cerminara	Matteo	PISA	WP1,WP3	0,5	0,5	0,5	0
Chiodini	Giovanni	BOLOGNA	WP3	0,5	0,5	0,5	0
Cocina	Ornella	OE	WP1,WP3	1	1	1	3
Currenti	Gilda	OE	WP2	1	1	1	3

De Astis	Gianfilippo	ROMA1	WP1,WP3, WP4	2	1	1	4
De Gregorio	Sofia	Palermo	WP1	0.5	0.5	0.5	1.5
de' Michieli Vitturi	Mattia	PISA	WP3	0.5	0.5	0.5	1.5
Di Giuseppe	Maria Giulia	OV	WP1	1	1	1	3
Di Vito	Mauro	OV	WP1	1	1	1	3
Diliberto	Iole Serena	PALERMO	WP1	1	1	1	3
Esposti Ongaro	Tomaso	PISA	WP2	1	1	1	3
Falsaperla	Susanna	OE	WP1, WP3	2	2	2	6
Federico	Cinzia	PALERMO	WP1,WP3	1	2	1	4
Ferrari	Ferruccio	OE	WP1	0,5	0,5	0,5	0
Gambino	Salvatore	OE	WP1	0,5	0,5	0,5	0
Gattuso	Alessandro	PALERMO	WP1	0,5	0,5	0,5	0
Garcia	Alexander	BOLOGNA	WP3	0,5	0,5	0,5	0
Gurrieri	Sergio	PALERMO	WP1	0.5	0.5	0.5	1.5
Inguaggiato	Salvatore	PALERMO	WP1	1	1	1	3
Langer	Horst	OE	WP3	0,5	0,5	0,5	0
Madonia	Paolo	OE	WP1,WP3	1	1	1	3
Mattia	Mario	OE	WP3	0.5	0.5	0.5	1.5
Napoli	Rosalba	OV	WP2	1	1	1	3
Paonita	Antonio	PALERMO	WP1,WP3	1	1	1	3
Pappalardo	Lucia	OV	WP1	0.5	0.5	0.5	1.5

Pecoraino	Giovannella	PALERMO	WP1, WP3	1	1	1	3
Rouwet	dmitri	BOLOGNA	WP1,WP3	0.5	0.5	0.5	1.5
Sandri	Laura	BOLOGNA	WP3	0,5	1	1	2
Scaltrito	Antonio	OE	WP1, WP3	1	1	1	3
Sciotto	Mariangela	OE	WP1	0,5	0,5	0,5	0
Selva	Jacopo	BOLOGNA	WP1,WP3	2	2	2	6
Spampinato	Salvatore	OE	WP1,WP3	1	1	1	3
Spinetti	Claudia	ONT	WP1	0,5	0,5	0,5	0
Todesco	Micol	BOLOGNA	WP2.WP3	1	1	2	4
Vita	Fabio	PALERMO	WP1	1	1	1	3

(*) All participants are involved in WP4's workshops

EXTERNAL PARTICIPANTS (UNIVERSITY,RESEARCH CENTERS, ETC.) with letters of agreement (attached to the proposal)

Name and surname (or contract type)	Institute/University	WP (*)
Aiuppa Alessandro	University of Palermo (UniPa)	WP4
Bonadonna Costanza	University of Geneva - Switzerland (UniGene)	WP3
Bonasia Rosanna	Polytechnic Institute of Mexico City, Mexico (PoliMex)	WP1
Calusi Elisabetta	University of Florence (UniFi)	WP4
Di Maggio Cipriano	University of Palermo (UniPa)	WP1

Fulignati Paolo	University of Pisa (UniPi)	WP4
Giocanda Anna	University of Pisa (UniPi)	WP4
Lanzo Giuseppe	University La Sapienza - Rome (UniSap)	WP1
Lucchi Federico	University of Bologna (UniBo)	WP1
Marzocchi Warner	UniNa - University of Naples, Federico II (UniNa)	WP3
Montanaro Cristian	University of Munich, Germany (LMU)	WP2
Montegrossi Giordano	CNR-IGG	WP1
Olivares Lucio	University of Naples, "Luigi Vanvitelli" (UniCamp)	WP1
Pistolesi Marco	University of Pisa (UniPi)	WP1, WP4
Rivalta Eleonora	University of Bologna (UniBo)	WP2
Rosas-Carbajal Marina	Associate Scientist at CNRS / IPGP	WP1
Scheu Bettina	University of Munich - D (LMU)	WP2
Sulpizio Roberto	University of Bari (UniBa)	WP1, WP3
Tommasi Paolo	CNR-IGAG	WP1
Tranne Claudio	University of Bologna (UniBo)	WP1

(*) All participants are involved in WP4's workshops

GENDER BALANCE:

Provide a gender balance (women in %). Applicants should seek at having a balanced participation, as close as possible to 50/50, of both men and women in the teams and among the leading roles.

- Coordination: 2 out of 4 (50%)
- Involved personnel: 18 out of 44 (41%)
- Person months: 48 out of 95.5 (48%)

SUMMARY OF COST (by year, in EURO)

	2023	2024	2025
Consumabili/Consumables			
Carta, cancelleria e stampati /Stationery, office supplies and miscellaneous consumables	**4,500**	**4,000**	**1,000**
Materiale informatico consumabile/Computer equipment consumables	**6,500**	**1,500**	**2,000**
Altre Spese/Other expenses			
Pubblicazioni/Publication costs	**0**	**5,500**	**20,000**
Licenze d'uso per software/Software licenses	**3,000**	**2,000**	**0**
Allestimento e manutenzione di osservatori e siti delle reti (materiale NON inventariabile)/ Preparation and maintenance of observatories and networks (non-inventory material)	**5,500**	**3,500**	**1,500**
Convenzioni/Prestazioni tecnico-scientifiche a fini di ricerca /Agreements and technical-scientific services	**47,500**	**78,500**	**40,000**
Missioni e Organizzazione eventi / Conference Planning & Travel Expenses			
Indennità di missione e trasferta - Personale INGV/ Travel Expenses - INGV Staff	**70,500**	**74,500**	**80,000**
Indennità di missione e trasferta - Altro Personale/ Travel Expenses Other	**13,000**	**15,000**	**19,500**
Organizzazione manifestazioni e convegni / Conference planning	**0**	**10,000**	**20,000**
Beni materiali - Inventariabile / Inventory Materials			
Attrezzature scientifiche/Scientific equipment	**20,000**	**0**	**0**
Hardware	**20,500**	**0**	**0**
TOTAL (by year)	**191,000**	**194,500**	**184,000**
REQUIRED FINANCIAL SUPPORT (FULL PROJECT)	**568,500**		

JUSTIFICATION OF COSTS AND SUSTAINABILITY OF INFRASTRUCTURES (max 1 page)

- For each activity:
    - If the activity does not include missions for field-survey, we indicatively considered a cost of approximately 17,500 euros, evaluated as:
        - 3,500 euro per year to cover travel costs, for 1 trip abroad (2,500 euro) and 4 domestic trips (250 euro);
        - 3,000 euro for 1 computer and accessories (2,500 + 500 consumables), only in the first year (if specifically requested);
        - 4,000 euro for 2 publications, only in the last two years;
    - For each activity with monitoring and/or field surveys, specific costs have been established according to the effective needs of the activity;
- For each of the 3 workshops organised by WP4 (1 in second year, and 2 in third year), we considered 10,000 euro for the organisation and travel costs of 30 invited persons, which include project's participants involved only in WP4 and other experts external to the project (250 euro each; total 7,500 euro; 40% INGV and 60% for others).
- For the working group foreseen in WP3, we considered a total of 9 meeting (3 per year) in person, with travel costs for 10 persons (10x250 euro).
- To engage the academic community, the proposal includes a significant amount of resources for 15 external institutions (166,000 euro). Specific agreements are foreseen for 4 of these institutions, to favour a deeper involvement for some key partners on specific initiatives. This includes:
    - 40,000 euro with the University of Lion to organise the muon campaign (WP1);
    - 3 agreements of 35,000 (sized as to co-fund an Italian PhD grant) with:
        - University of Munich for laboratory experiments (WP2);
        - University of Bologna for physical modelling (WP2);
        - University of Naples Federico II for elicitation experiments (WP3).
- Other expense for external personnel regard:
    - 12,000 euro for realising the campaigns of electric resistivity (WP1);
    - 5,000 euro for acquisition of high-resolution topo-bathymetric data (WP1);
    - 4,000 euro for acquisition of high-resolution satellite data (WP1) .

All the foreseen infrastructures are considered experimental, thus they are temporary and do not need long-term maintenance.

PROPOSAL FOR RESEARCH GRANT

We do not require any additional temporary position for the project.

Several groups asked to extend the contract of existing personnel that are already working at INGV, and whose potential contributions to the project are in perfect continuity with present activities. In particular, we require the extension of the following research grants:

- Chiara Stissi, for 2 years (total 54,000 euro). Specific Research Topic: Physical models of hydrothermal circulation
- Gianmarco Buono, for 1 year (total 27,000). Specific Research Topic: Laboratory analysis
- Susanna Saitta, for 2 years (total 48,000). Specific Research Topic: Statistical data analysis and Machine Learning modelling for Geophysics

Bari, 30/05/2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

With this letter, I confirm my intention to take part as researcher in the INGV project "**WUnderVul - Toward a Wider Understanding of Vulcano**", which will be submitted by Dr. Jacopo Selva (coordinator), Dr. Gianfilippo De Astis, Dr. Micol Todesco, and Dr. Cinzia Federico, for the call "Pianeta Dinamico/Working Earth" INGV.

The project aims to deepen the understanding of the volcanic system of Vulcano, Aeolian Islands, and its unrest phases. Given the mutual interest in developing these research topics, I support the proposal submission and confirm the intention to take part in the research activities, if the proposal will be funded.

Sincerely,

Dr. Bonasia Rosanna, PhD

Professor and Researcher at the Polytechnic Institute of Mexico City, SEPI, ESIA-UZ, Mexico

Firenze, 30/05/2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

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The project aims to deepen the understanding of the volcanic system of Vulcano, Aeolian Islands, and its unrest phases. Given the mutual interest in developing these research topics, I support the proposal submission and confirm the intention to take part in the research activities, if the proposal will be funded.

Sincerely,

Dr. Calusi Benedetta

Research Fellow, University of Firenze, Italy

Benedetta Calusi.

Palermo, 26 May 2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

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Sincerely,

Cipriano Di Maggio

Ph.D. Cipriano Di Maggio

Associate Professor of Geomorphology, Dipartimento di Scienze della Terra e del Mare – Università degli Studi di Palermo, Italy

Place, date

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

With this letter, I confirm my intention to take part as researcher in the INGV project "**WUnderVul - Toward a Wider Understanding of Vulcano**", which will be submitted by Dr. Jacopo Selva (coordinator), Dr. Gianfilippo De Astis, Dr. Micol Todesco, and Dr. Cinzia Federico, for the call "Pianeta Dinamico/Working Earth" INGV.

The project aims to deepen the understanding of the volcanic system of Vulcano, Aeolian Islands, and its unrest phases. Given the mutual interest in developing these research topics, I support the proposal submission and confirm the intention to take part in the research activities, if the proposal will be funded.

Sincerely,

Person in charge (Title, Surname, Name)

Associate Professor, LANZO GIUSEPPE

Role in the Organization (function, name of the institution, country)

Execution of laboratory geotechnical tests, Sapienza University of Rome, Department of Structural and Geotechnical Engineering, Rome, Italy

Giuseppe Lanzo

Bologna 25/06/2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

With this letter, I confirm my intention to take part as researcher in the INGV project "**WUnderVul - Toward a Wider Understanding of Vulcano**", which will be submitted by Dr. Jacopo Selva (coordinator), Dr. Gianfilippo De Astis, Dr. Micol Todesco, and Dr. Cinzia Federico, for the call "Pianeta Dinamico/Working Earth" INGV.

The project aims to deepen the understanding of the volcanic system of Vulcano, Aeolian Islands, and its unrest phases. Given the mutual interest in developing these research topics, I support the proposal submission and confirm the intention to take part in the research activities, if the proposal will be funded.

Sincerely,

Prof. Federico Lucchi

University of Bologna, Department of Biological, Geological and Environmental Sciences, Italy

Federico Lucchi

prof. Warner Marzocchi
E-mail: warner.marzocchi@unina.it
Tel. +39 081 2538136

Napoli, 06.03.2019

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

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Sincerely,

Warner Marzocchi

Prof. Warner Marzocchi

University of Naples, Federico II,
Dept. of Earth, Environmental, and Resources Sciences
Complesso di Monte Sant'Angelo,
Via Vicinale Cupa Cintia, 21
80126 Napoli, Italy

Aversa (CE), Italy, 27/5/2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

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Sincerely,

Prof. Lucio Olivares

Full professor, University of Campania “Luigi Vanvitelli”, Italy.

Consiglio Nazionale delle Ricerche

Istituto di Geologia Ambientale e Geoingegneria

Rome, 26/05/2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

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Sincerely,

Eng. Paolo Tommasi

Researcher, Istituto di Geologia Ambientale e Geo-Ingegenria, del Consiglio Nazionale delle Ricerche, Rome, Italy

DIPARTIMENTO DI SCIENZE BIOLOGICHE GEOLOGICHE
E AMBIENTALI

Bologna 25/06/2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

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Sincerely,

Dr. Tranne Claudio Antonio

Researcher, University of Bologna, Department of Biological, Geological and Environmental Sciences, Italy

ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA
PIAZZA DI PORTA SAN DONATO, 1 - 40126 BOLOGNA - ITALIA - TEL. 051-2094900 - FAX 051-2094904 - email: dipterra.info@unibo.it

Firenze, 25/05/2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

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Sincerely,

CTER IV, Head of "Laboratorio di Calcolo" (Numerical Modeling Lab) in Florence,

Institute of Geosciences and Earth Resources (IGG), National Research Council of Italy (CNR)

Montegrossi Giordano

Munich, 25.05.2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

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Sincerely,

Prof. Dr. Bettina Scheu
Experimental Volcanology,
Leader of FragLab (laboratory for exp. volcanology)
Earth and Environmental Sciences,
Ludwig-Maximilians-Universität München
Germany

Paris,
May 30th, 2022

Istituto Nazionale di Geofisica e Vulcanologia
Italy

Marina Rosas-Carbajal
Institut de physique du globe de Paris
Associate Scientist at CNRS
+ 33 (0)6 10 05 1454
rosas@ipgp.fr

Letter of Agreement to participate to Pianeta Dinamico project proposal

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Best Regards,

Marina Rosas-Carbajal
Associate Scientist at CNRS / IPGP

UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

DIPARTIMENTO DI SCIENZE DELLA TERRA E GEOAMBIENTALI

Bari, May 26, 2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

With this letter, I confirm my intention to take part as researcher in the INGV project "**WUnderVul - Toward a Wider Understanding of Vulcano**", which will be submitted by Dr. Jacopo Selva (coordinator), Dr. Gianfilippo De Astis, Dr. Micol Todesco, and Dr. Cinzia Federico, for the call "Pianeta Dinamico/Working Earth" INGV.

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Sincerely,

Prof. Roberto Sulpizio

Full Professor of Geochemistrry and Volcanology, Dipartimento di Scienze della Terra e Geoambientali, University of Barri, Italy

Campus, Via Orabona 4 70125 Bari (Italy)
tel. (+39) 0805442557-fax (+39) 0805442625
michele.laricchia@uniba.it
c.f. 80002170720 p. iva 01086760723

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
DEPARTMENT OF PHYSICS AND ASTRONOMY
"AUGUSTO RIGHI"

Prof. Eleonora Rivalta
Section of Geophysics
V.le Berti Pichat 8
40127 Bologna
Italy

24 May 2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

With this letter, I confirm my intention to take part as researcher in the INGV project "WUnderVul – Toward a Wider Understanding of Vulcano", which will be submitted by Dr. Jacopo Selva (coordinator), Dr. Gianfilippo De Astis, Dr. Micol Todesco, and Dr. Cinzia Federico, for the call "Pianeta Dinamico/Working Earth" INGV.

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Yours faithfully,

Prof. Eleonora Rivalta
Associate Professor

Viale Berti Pichat 6/2 - 40127 Bologna - Italia - tel. +39 051 2095162
Via Irnerio 46 - 40126 Bologna - Italia - tel. +39 051 2091004
Via Gobetti 93/2 - 40129 Bologna - Italia - tel. +39 051 2095701
difa.direzione@unibo.it - difa.dipartimento@pec.unibo.it
https://fisica-astronomia.unibo.it/it

UNIVERSITÀ DEGLI STUDI DI PALERMO

Dipartimento di Scienze della Terra e del Mare (DiSTeM)
COD. FISC. 80023730825 ~ P.IVA 00605880822

Palermo, 25 May 2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

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Sincerely,

Prof. Alessandro Aiuppa

Prof. Alessandro Aiuppa
Professor, Volcanology and Geochemistry
Dipartimento di Scienze della Terra e del Mare (DiSTeM)
Università degli Studi di Palermo

Prof. Alessandro Aiuppa - Via Archirafi, 36 - 90123 Palermo – Tel. +39 09123861624 –
Fax. +39 0916168376 – e-mail: aiuppa@unipa.it –

DIPARTIMENTO DI SCIENZE DELLA TERRA
UNIVERSITÀ DI PISA
www.dst.unipi.it

Pisa, 28 may 2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

With this letter, we confirm our intention to take part as researchers in the INGV project "**WUnderVul - Toward a Wider Understanding of Vulcano**", which will be submitted by Dr. Jacopo Selva (coordinator), Dr. Gianfilippo De Astis, Dr. Micol Todesco, and Dr. Cinzia Federico, for the call "Pianeta Dinamico/Working Earth" INGV.

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Sincerely,

Prof. Marco Pistolesi

Prof. Anna Gioncada

Dr. Paolo Fulignati

Earth Sciences Department - University of Pisa (Italy)

UNIVERSITÉ
DE GENÈVE
FACULTÉ DES SCIENCES
SECTION DES SCIENCES DE LA TERRE
ET DE L'ENVIRONNEMENT
DÉPARTEMENT DES SCIENCES DE LA TERRE

Costanza Bonadonna
Professeure

Geneva, 25 May 2022

Object: Letter of Agreement to participate to Pianeta Dinamico project proposal

To Whom it may concern:

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Sincerely,

Costanza BONADONNA

Rue des Maraîchers 13, CH-1205 Genève, Suisse
costanza.bonadonna@unige.ch
Tél. +41 22 379 30 55 - Fax +41 22 379 32 10
http://www.unige.ch/hazards/About/People/Bonadonna.html