

MISCELLANEA INGV

2025 ANNUAL REPORT

HPHT Laboratory:
High Pressure High Temperature

LNTS: Laboratory of New Technologies
and Instruments



ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

108



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ISTITUTO NAZIONALE **DI GEOFISICA E VULCANOLOGIA**

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HPHT Laboratory: High Pressure High
Temperature Laboratory of experimental
volcanology and geophysics

LNTS: Laboratory of New Technologies and
Instruments

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Cover Scanning electron microscope image of the outer surface of a lapilli from the 2025 Kilauea eruption. Credits: J. Taddeucci | *In copertina*
Immagine al microscopio elettronico a scansione della superficie esterna di un lapillo dell'eruzione del Kilauea del 2025. Crediti: J. Taddeucci

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Preface

This 2025 Annual Report provides a comprehensive overview of the facilities, research activities, and scientific outputs of the **High Pressure High Temperature Laboratory (HPHT Lab)** and the **Laboratory of New Technologies and Instruments (LNTS)**. This year marks a significant milestone as the report is officially integrated into the **INGV Miscellanea series**, a transition aimed at enhancing the visibility and formal dissemination of the laboratories' progress within the broader scientific community.

The HPHT Lab stands as a facility of excellence and an international benchmark for the experimental study of the physico-chemical processes governing Earth's dynamics. Serving as a cross-departmental hub, the laboratories actively support INGV's **Earthquake, Volcano, and Environment** departments. By integrating high pressure/high temperature simulations, advanced petrological analyses, and multi-parametric field monitoring, the research group effectively bridges the gap between natural observations and the theoretical understanding of volcanic and seismic phenomena.

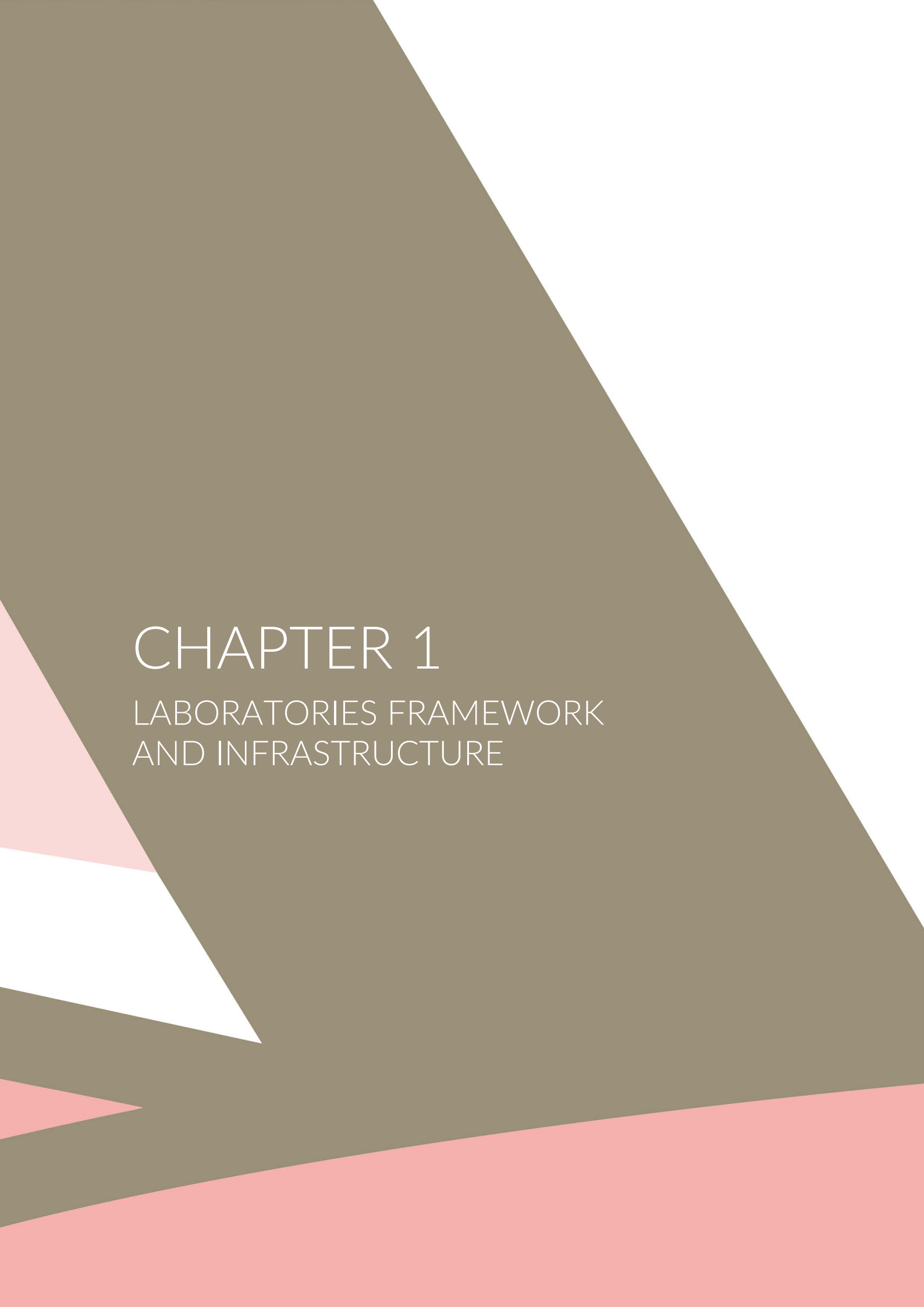
The LNTS lab integrates expertise in the fields of electronics and mechanics, and employs infrastructure resources such as an electronics laboratory, a mechanical workshop and equipment for systems development. The laboratory develops mechanical and electronic technologies for the design of new electronic and mechatronic systems, prototypes equipment, and sensors for geoscience research. The LNTS carries out activities related to the development and integration of payloads aboard stratospheric platforms, for scientific activities in polar regions, and of UAVs. It is characterized by its strongly multidisciplinary nature; this inherent interdisciplinary ensures that its technological development activities effectively support the experimental research connected to all three departments of the INGV (Earthquake, Volcano, Environment). The laboratory is also part of the COS (Center for Space Observation), providing its expertise for technological development in the space sector to support Earth Observation from space.

In 2025, the research framework expanded to include **21 funded projects**, underscoring the laboratories' competitive edge in securing high-level funding. **A primary highlight of 2025** is the start of two prestigious ERC Starting Grants awarded to academic personnel, where the HPHT Lab serves as a key secondary beneficiary: **FORESEEING** (FrOm RupturE to Earthquake Early warING, P.I. S. Colombelli) and **OMEN** (Observing the Mechanisms of Earthquake Nucleation, P.I. G. Pozzi). **Chapter 1** outlines this infrastructural framework, highlighting the growth of the network through these ERC grants, alongside major European projects (e.g., **EXCITE2**) and national PNRR initiatives (e.g., **MEET-ILGE**). These collaborations consolidate the laboratories' role as a primary node for trans-national scientific exchange and a dedicated hub for the development of new generations of researchers.

The extensive scientific output, amounting to **32 publications** in high-impact journals and numerous contributions to major international conferences (EGU, IAVCEI, Goldschmidt), reflects a constant commitment to advancing research on key topics, from the dynamics of active volcanoes to the mechanics of the seismic cycle. **Chapter 2** provides a technical breakdown of these results, offering a solid foundation of data and interpretations essential for hazard assessment and the mitigation of natural risks.

Special thanks go to all the staff, researchers, technicians, and external collaborators whose dedication ensures that the HPHT and LNTS laboratories remain at the forefront of global scientific innovation.

Keywords Experimental volcanology; High pressure high temperature; Experimental geophysics; Earthquakes and volcanoes dynamics; Rock mechanics; Microanalysis; Imaging of geomaterials; Laboratory infrastructure; Technological development; Mechanical and electronic Technologies; Geoscience Sensors



CHAPTER 1

LABORATORIES FRAMEWORK AND INFRASTRUCTURE

1.1 Personnel

HPHT laboratory

Piergiorgio Scarlato | Research Director | Head of the HPHT Laboratory
Stefano Aretusini | Researcher (Contract)
Emanuela Bagnato | Researcher
Riccardo Civico | Researcher
Chiara Cornelio | Researcher (Contract)
Gianfilippo De Astis | Senior Researcher
Elisabetta Del Bello | Senior Researcher
Fabrizio Di Fiore | Researcher (Contract)
Giuseppe La Spina | Researcher
Valeria Misiti | Senior Technologist
Manuela Nazzari | Researcher
Francesco Pennacchia | Technician (Contract)
Alessio Pontesilli | Researcher (Contract)
Tullio Ricci | Senior Researcher
Elena Spagnuolo | Senior Researcher
Laura Spina | Researcher
Jacopo Taddeucci | Senior Researcher
Giancarlo Tamburello | Senior Researcher

Laboratory of New Technologies and Instruments (LNTS)

Alessandro Iarocci | Senior Technologist | Head of the LNTS Laboratory
Catello Acerra | Technician
Giuseppe Di Stefano | Senior Technologist
Massimo Mari | Technician
Francesco Pongetti | Engineer Technician
Giuseppe Spinelli | Engineer Technologist
Massimiliano Vallocchia | Engineer Technologist (Contract)

Associated researchers

Cristiano Collettini | Full Professor | Sapienza University of Rome, Italy
Frances M. Deegan | Researcher | Uppsala University, Sweden
Giancarlo Della Ventura | Full Professor | Roma Tre University, Italy
Giulio Di Toro | Full Professor | University of Padua, Italy
Silvio Mollo | Full Professor | Sapienza University of Rome, Italy
Giacomo Pozzi | Associate Professor | University of Padua, Italy
Giovanni Romeo | Associated Researcher | INGV

1.2 Instruments and facilities

HPHT laboratory

- Multiple press 840 ton | Voggenreiter
- Piston cylinder - 3/4" and 1" pressure plates | Voggenreiter
- Multianvil - Walker type 6/8 | Voggenreiter
- Quick Press - Piston Cylinder 3/4" and 1" pressure plates | Depth of the Earth
- Tri-Axial Press BRAVA: Brittle Rock deformation Versatile Apparatus | RMP - INGV
- Rotary shear apparatus SHIVA: Slow to High Velocity Apparatus | RMP - INGV
- Multiaxial direct shear apparatus MEERA: Mechanics of Earthquakes and Extended Rupture Apparatus | TEES - INGV
- Electron microprobe equipped with 5 WDS and 1 EDS | JEOL JXA-iSP100
- Focused Ion Beam Scanning Electron Microscope equipped with EDS, EBSD, CL and STEM detectors | ThermoFisher Scios 2 LoVac
- Turbo Sputter and Carbon Coater | Quorum Q150TES Plus
- Auto Carbon coater | JEOL JEC-530
- Ion Beam Cross Section Polisher™ | JEOL IB-19530CP
- High temperature muffle oven | Lenton
- Impedance analyzer | Solartron SI1260
- Digital oscilloscope | Tektronix DPO4032
- Wave generator | Agilent 33250A
- H-Frame presses 10 ton | Enerpac
- Precision balance | Sartorius BCE623I-1S Entris® II
- Precision balance | Sartorius QUINTIX65-1S
- Optical and stereo microscopes | Leica DMRXP and Euromex
- Ultra-high velocity, intensified, gated digital camera | Cordin 204-2
- Stereomicroscopes | Leica MZ 9.5
- Semiautomatic polisher | Struers LaboPol-5
- Semiautomatic polisher | Struers LaboPol20
- Semiautomatic polisher | Struers Tegramin30
- Automatic cleaning unit | Struers Lavamin
- Ultrasound machine | Argo lab DU-100S
- Ultrasound machine | Argo lab DU-32S
- Semiautomatic polisher | Buehler Minimet 1000
- Power Supply | Agilent 6575A
- Helium Pycnometer | Anton Paar Ultrapyc 5000
- Permeameter with double intensifier | Rock Physics
- Rheometer MCR 301 Physica | Anton Paar
- Vertical Furnace RHTV 120-300/18 | Nabertherm
- High Temperature Furnace LHT 04/18 | Nabertherm
- Cecchi data acquisition system | Applied Seismology
- Rock drilling, cutting, and grinding equipment for samples preparation
- Thermal High speed camera | FLIR SC 645
- Welder PUK U3 | Lampert
- Laser line generator | Edmund optics
- Precision test sieves | Endecotts
- Laser MGL-III, 532nm 200mW, PSU-III-LED/Unit | Changchun New Industries
- Multi-Wavelength Analyser with Particle sizing according to ISO 13317 | LUMiReader
- Low-frequency microphone calibrator 42AE, Sound pressure level: 140 dB Freq range:

0.01 to 250 Hz. | G.R.A.S.

- Two 1/2" CCP Free-field Standard Microphones, Low Freq. 46 AZ | G.R.A.S.
- Ext. Polarized Pressure Microphone 46DP-1 1/8", High Freq. (6.5Hz -140kHz) | G.R.A.S.
- Vacuometro Pirani PVG-500
- Petrographic microscope ECLIPSE E-50i POL | Nikon
- Drying oven UF 75 | Memmert
- 4K digital camcorders | Sony
- Shock-tube apparatus (Jet-Buster) | INGV
- High speed digital camcorders | NAC 512 SC, Optronis CR600x2, NAC HX6, NAC HX3
- Laser range finder | Vectronix VECTOR 21
- Time Lapse Camera with 24-70 lens | Brinno TLC200 Pro
- Precision Syringe Pumps | ISCO 500D, SYRIXUS 260X
- Ash dispersal/settling apparatus (Ash-Buster) | INGV
- Drone Matrice 300 RTK | DJI
- Drone Mavic 2 Pro | DJI
- Drone Phantom 4 RTK | DJI
- Drone Mini 2 | DJI
- Drone Mavic 3 Pro | DJI
- Drone Mavic 3T RTK | DJI
- Drone Mavic 3E RTK | DJI
- Dual UV cameras 340 UVGE | Thorlabs
- Laboratory sieve shaker Octagon 200 | Endecotts
- Optical Profilometer Modus6ZS-3D | DeltaPIX
- Triaxial ICP accelerometer | PCB Plezotronics
- Three high frequency ICP pressure sensors | PCB Plezotronics
- Three ceramic shear ICP accelerometers PCB Plezotronics
- Absolute pressure Sensor, 200 psia | PCB Plezotronics
- Acquisition system SIRIUS-HS-8xACC-8xAO, 8 channel differential SIRIUS High Speed slice for Voltage, IEPE, 8x Analog Output, 1xCAN; USB2 | Dewesoft
- Rechargeable single channel signal conditioner, input binder conn, bridge output via BNC jack, gain x1, x10, x100 | PCB Plezotronics
- Two 4-channel ICP sensor signal conditioners | PCB Plezotronics
- High-temperature, vacuum, inert, and reactive gas furnace
- Microdriller for experimental glasses | ARNOLD 561/01
- Mortar grinder for experimental glasses | PULVERISETTE 23 FRITSCH
- SKO-D XL Orbital Shaker | SKO
- Centrifuge Neya 8 Basic | NEYA
- DANTE | Carbolite Gero | Verder Scientific
- SKATE (Setup for the Kinematic Acquisition of Explosive Eruptions) | INGV/T.E.E.S.
- Drone Matrice 300 RTK with thermal, visible and lidar sensors | DJI
- FBG interrogator DM-8120 | SENTEA

Laboratory of New Technologies and instruments (LNTS)

- Analog Oscilloscope | Iwatsu SS5710
- Analog Oscilloscope | Tektronix
- Power supply | Elind HL series
- Power supply | Elind 6TD20
- Power supply | DC DF1731SB

- Function generator | HP3325A
- Multimeter | HP3478A
- Milling machine for printed circuit boards | LPKF S64
- Soldering Reworking station | JBC advanced AM6800
- Soldering Nano rework station | JBC NASE 2C
- Soldering High precision hot air | JBC JNA
- Oscilloscope | HP54602b
- Oscilloscope | Picoscope
- Oscilloscope portable| Scopemeter FLUKE 199C
- Oscilloscope portable| Scopemeter FLUKE 192
- Oscilloscope | Tektronix DPO4000
- Oscilloscope | Tektronix MSO4034
- Oscilloscope with wave surfer | LeCroy 44MXs-A
- Calibrator | FLUKE 5700 (series II)
- Signal generator | HP8656A
- Function generator | HP33120
- Function generator | AGILENT 33250 A
- Waveform generator | Agilent 33210 A
- PXI Industrial computer with I/O boards | National Instruments
- Universal counter | HP53131A
- Industrial multichannel data acquisition system with adapters | SIRIUS Dewesoft
- Drone with termination system | Phantom 3 pro
- Power supply (4 items) | RSPRO-3005D
- Spectrum Analyzer | Rohde&Swartz FPC1500, 3GHz
- Digital microscope | Vision Engineering VE CAM 50
- Stereo microscope | Vision Engineering Mantis elite

Machine shop

- Lathe | Grazioli Fortuna
- Small lathe | Ceriani
- Small milling machine | Schaublin
- Cutting machine | Ercoletta
- Bending machine | Ercoletta
- Drill press | Serrmac
- Small drill press | Webo
- Bandsaw | Femi
- Extractor hood | Filcar
- Inverter welding machine | Tecnica
- TIG welding machine | Cebora
- Miter saw | M.A.L.
- Numerically controlled milling machine | CST

1.3 Laboratory activities

Experimental laboratory

Analog modeling laboratory

During 2025, more than 100 experiments were conducted using the shock tube. An initial set of experiments investigated the effects of varying amounts of microspherical glass beads (0-10 g), used to mimic the solid loading of volcanic jets, under a range of initial pressures representative of subsonic to supersonic volcanic flow regimes. Three microphones, three accelerometers, and one pressure sensor were employed to characterize the elastic response of each run. The experimental dataset was subsequently replicated with the addition of a high-speed camera coupled with a double-mirror Schlieren system, enabling direct visualization of the jet structure.

Within the framework of the TNA project, we carried out 42 analogue laboratory experiments designed to simulate both discrete (Strombolian-type) and pulsed (Vulcanian-type) VVR injections. Discrete experiments involved the injection of hot VVRs using a spring-loaded plunger, while pulsed experiments produced regular vortex trains through organ-pipe resonance within a shock tube. All experiments were documented using high-speed and thermal imaging, and laser sheet illumination was employed to enable detailed two-dimensional flow analysis.

Experimental petrology

Superpress | End loaded Piston cylinder-Multi anvil

In 2025 the Eurotherm PID controller has been substituted to ensure the operativity of the instrument. The controller is under testing thus few experiments have been carried out to test it.

Quick press | Non-end loaded Piston cylinder

In 2025 several experiments were performed. These were conducted to investigate the solubility of water in Etnean magmas and the relation between water content upon quenching and melt structure. Further experiments were performed to investigate the nanostructure of hydrous synthetic rhyolitic melts after changing p-T-t experimental paths.

DANTE | Dynamic sAmple traNsfer system for high Temperature, gas mixing, and vacuum Experiments

Experiments have been performed to explore the range of T and fO_2 necessary to synthesize impurity-free glasses.

High temperature furnaces. Numerous high temperature runs have been performed to degas and synthesize experimental glasses, mainly to be used as starting materials for other experimental techniques. In December 2025, a 1-year long post-lauream scholarship (Marco Paccapelo, La Sapienza University of Rome, Italy) has begun under the supervision of Silvio Mollo and Alessio Pontesilli, utilizing the vertical-quench furnace for high-temperature experiments under controlled atmosphere conditions to investigate clinopyroxene iron speciation and cation distribution as well as transport behavior of metals during degassing.

BRAVA | Brittle Rock deformAtion Versatile Apparatus

Several experiments were conducted on the BRAVA apparatus in 2025. Both natural and synthetic fault materials were tested across a wide range of experimental configurations, including double direct shear, single direct shear, uniaxial, triaxial, and Brazilian tests. The main research topics were:

- Fluid-induced fault reactivation in ternary mixtures of calcite, quartz, and illite, aimed at investigating the mechanisms controlling stable versus unstable slip behavior, in collaboration with Ph.D. candidate L. Coppola (La Sapienza University of Rome, Italy).
- Frictional behavior of natural fault gouge from the Pohang Enhanced Geothermal System (EGS) site, to elucidate the fault properties responsible for one of the largest induced earthquakes, in collaboration with Ph.D. W. Sangwoo (Gyeongsang National University, South Korea).
- Healing behavior of pozzolanic mortars under very low normal stresses, to investigate time-dependent strength recovery mechanisms, in collaboration with Ph.D. G. Volpe (La Sapienza University of Rome, Italy).
- Characterization of the relation between temperature and frictional properties of crystalline rocks targeted by fluid injections in the context of the FORGE Enhanced Geothermal Systems (Utah-USA), in collaboration with Ph.D. R. Affinito (GFZ, Potsdam, Germany).

SHIVA | Slow to High Velocity Apparatus

Several experiments were conducted on the SHIVA apparatus in 2025. The main research topics were:

- Fluid-saturated frictional behavior of bituminous dolostone gouges, in collaboration with Ph.D. candidate M. Chinello (University of Padova, Italy).
- Fluid-saturated frictional behavior of subduction decollement samples from JTRACK IODP3 Exp. 502E, in collaboration with Prof. P. Vannucchi (University of Firenze, Italy), Prof. F. Funiciello (University of Roma 3, Italy), Dr. F. Corbi (CNR-IGAG, Italy), Master student A. Campana (University of Roma 3, Italy).

MEERA | Mechanics of Earthquakes and Extended Ruptures

MEERA is a multi axial direct shear apparatus built on funds granted by the Civil Protection Department (DPC) under the project EXTEND. The set up of the MEERA apparatus has been finalized in 2025 and the first experiments have been carried out. The main research line is addressed to study the dynamic rupture on extended faults and the relationship between the superficial deformation and deformation at depth.

To this end, during the course of the current year, two main topics have been addressed:

- Digital Image Correlation technique applied to visualization of the displacement field in laboratory experiments on seismic rupture, in collaboration with MSc student Niccolò Cavaliere (University of Padova, Italy).
- The role of fault heterogeneity in Stick-Slip events: DIC and AEs analysis, in collaboration with Contract Researcher A. Kiss and Prof. S. Colombelli (Università degli Studi di Napoli Federico II).

Microanalytical laboratory

During 2025, 220 days of FIB-SEM and EMPA analysis were carried out within the framework of the following 18 research proposals, plus 6 TNA projects (EXCITE² and MEET ILGE, described

in Chapter 1.7: 'Visiting Scientists').

- Textural characterization of mafic lava flows: new insights on the emplacement dynamics and solidification path of lava flows from rheological modelling. *F. Di Fiore* | INGV Roma1.
- Deciphering CO₂ emissions during earthquakes nucleating along carbonate-hosted faults. *M. Curzi - Pontesilli A.* | Sapienza University of Rome - INGV Roma1.
- MISS: Mineralogy, injection, and structure role on fault stability. *G. Pozzi* | University of Padova - INGV Roma1.
- Exploring Volcanic Rock Textures: Integrating 2D and 3D Analyses. *G. Buono - F. Di Fiore* | INGV OV - INGV Roma1.
- Temperature and oxygen fugacity changes decoded from the glass and mineral record. *A. Pontesilli* | INGV Roma1.
- Natural Hydrogen for Energy trAnsiTion (NHEAT). *G. Schirripa - G. Pozzi - F. Di Fiore* | Sapienza University of Rome - University of Padova - INGV Roma1.
- UNO - UNderstanding the Ordinary to forecast the extraordinary: An integrated approach for studying and interpreting the explosive activity at Stromboli volcano (2020-2024). *P. Scarlato* | INGV Roma1.
- U-Pb dating of the Tolfa-Ceriti and Sabatini volcanic complexes. *F. Rossetti - F. Di Fiore* | University of Roma Tre - INGV Roma1.
- Analyses of tephra products from the recent eruption of Cumbre Vieja volcano. *J. Taddeucci* | INGV Roma1.
- Unravelling the processes behind the explosive to effusive transition during the Accademia volcanic eruption of Campi Flegrei, southern Italy. *E. Pooria - F. Di Fiore* | University of Naples - INGV Roma1.
- Earth degassing in seismic and volcanic regions: How do mantle fluids move to the atmosphere? *A. Caracausi - M. Nazzari* | INGV Palermo - INGV Roma1.
- Volcanic hazard assessment at Mt. Etna and Stromboli volcanoes: a time-integrated, polybaric and polythermal perspective. *P. Moschini - F. Di Fiore* | University of Pisa - INGV Roma1.
- Enhancing the Durability of Earthen Materials: A Study on Stabilized Adobe Bricks Under Simulated Rainfall Conditions. *G. Della Ventura - M. Nazzari* | University of Roma Tre - INGV Roma1.
- Tectono-stratigraphic evolution of the Ligurian Accretionary Complex, southern Apennines (Italy). *S. Vitale - Di Fiore* | University of Naples - INGV Roma1.
- Research project SMEEGOL - historical Sources, Mineral microanalysis, Experimental pEtrology and numerical modellinG to unravel the precursor phenomena Of voLcanic eruptions: the case of the neapolitan volcanoes. *I. Arienzo - M. Nazzari* | INGV OV - INGV Roma1.
- From lithium-bearing ignimbrites to world-class lithium brine deposits. The role of magmas and hydrothermal fluids in the mineralization genesis. *A. Renzulli - M. Nazzari* | University of Urbino - INGV Roma1.
- Decoding the physico-chemical conditions of magmas triggering the 2022 eruption of Hunga Tonga-Hunga Ha'apai. *E. Califano - F. Di Fiore* | Sapienza University of Rome - INGV Roma1.
- Are large effusive eruptions produced by magma accumulation within the shallow crusts or fed from the mantle? Implication for Sabatini volcanic system. *Arzilli-Morganti - F. Di Fiore* | University of Camerino - INGV Roma1.

Material characterization lab (Helium pycnometer and rheometer)

In 2025, the Helium Pycnometer was accessed by both internal and external users. Below is a

list of the projects hosted by the Helium Pycnometer:

- Density and porosity in Vesuvius 1944 lava and spatter samples following high-temperature deformation experiments. T. O. Grillo - A. Vona | Roma Tre University.
- Porosity measurements on “Brown Tuff” samples from Lipari within the framework of the IRGIE project for geothermal potential evaluation. B. Cantucci Marini | INGV Roma1.

Field data acquisition of volcanic activity

Field activities in 2025 continued within the framework of the UNO, DYNAMO, SOMBRERO and PRIN2022 projects, aimed at refining the understanding of explosive volcanic phenomena through multiparametric monitoring. The following campaigns were conducted throughout the year:

- Fuego, Guatemala: 17-28 January
- Iceland: 18-26 August
- Panarea: 8 April
- Stromboli, Italy: 9-10 April; 13-15 May; 3-10 June; 2-4 July; 7-14 October; 10-11 December
- Tarumae, Usu (Hokkaido), Japan (Gas Workshop): 1-8 September (activity focused exclusively on the use of FLIR thermal and UV cameras)
- Vulcano: 7-8 April; 11-12 December

SKATE System | Setup for the Kinematic Acquisition of Explosive Eruptions)

A new monochromatic camera (Dewesoft DSCAM 1100) was tested for the integration into SKATE. This camera is to be used alternatively with the existing DSCAM 600 color camera. The inclusion of the monochromatic DSCAM 1100 provides superior sensitivity and higher frame rates at megapixel resolution, optimizing high-frequency kinematic analysis under diverse field conditions.

UVIR-cam | UltraViolet and InfraRed Fast Cameras Setup

The UV system was upgraded with 12 mm wide-angle lenses (41°x31° FOV), providing a wider alternative to existing 25 mm lenses (21°x16° FOV). The 2025 campaigns further expanded the gas emission dataset, notably during the Hokkaido (Tarumae) Gas Workshop. By integrating high-speed UV and thermal imaging with DOAS, direct sampling, and Multi-GAS, these synergistic datasets are being processed for a forthcoming collaborative publication.

Unoccupied Aircraft Systems (UASs)

Surveys were conducted during the campaigns on active and quiescent volcanoes in Guatemala, Stromboli, Vulcano, Panarea and Iceland and were used to produce very high-resolution Digital Elevation Models (DEMs) and orthophotos derived from acquisitions with visible, thermal, and LiDAR sensors. In addition, volcanic activity was characterised through video recordings.

1.4 Research projects

International Projects

- **ERC Synergy Grant | FEAR** - Fault activation and Earthquake Rupture | P.I. D. Giardini, F. Amman, M. Cocco, S. Wiemer.
- **ERC Starting Grant | FORESEEING** - FrOm RupturE to Earthquake Early warING | P.I. S. Colombelli.

- **ERC Starting Grant | OMEN** - Observing the Mechanisms of Earthquake Nucleation | P.I. G. Pozzi.
- **European Research Project | EXCITE²** - Enhanced X (cross)-disciplinary Community-driven Imaging Technologies for Earth and Environmental material research | P.I. O. Plümper.
- **Horizon Europe | MSCA-ETN IMPROVE** - Innovative Multi-disciplinary European Research training network on VolcanoEs | P.I. P. Papale.
- **Horizon Europe | MSCA-IF ENDGAME** - Experiments, Numerical modelling and field observations of basaltic magma fragmentation | P.I. J. Taddeucci, G. La Spina.

National Projects

- **PNRR - Next Generation EU | MEET** - Monitoring Earth's Evolution and Tectonics | WP 3 Integrated Laboratories for the Geosciences and the Environment (ILGE) | WP leaders: P. Scarlato, F. Funicello.
- **MUR - PRIN 2022 | PROVES** - An integrated PetRO-Volcanological monitoring approach applied to Mt. Etna and Stromboli | P.I. M. Masotta.
- **ASI-INAF Project | Esopianeti** | P.I. G. De Astis.
- **MASE | IRGIE** - Inventario delle Risorse Geotermiche delle Isole Eolie: stima del potenziale e proposte di utilizzo | P.I. M. Procesi.

INGV Strategic & Departmental Projects

- **INGV Departmental Strategic Project | UNO** - UNderstanding the Ordinary to forecast the extraordinary: An integrated approach for studying and interpreting the explosive activity at Stromboli volcano | P.I. P. Scarlato.
- **INGV Earth Telescope | SAKURA** - From Mantle Flow to Magma Migration | P.I. J. Taddeucci, F. Di Fiore.
- **INGV Earth Telescope | TESI** - Study of Geospheres Interactions in the Earth System / Fluid mobility and storage in crustal faults | S. Mittempergher, A. Caracausi, E. Spagnuolo.
- **INGV Earth Telescope | DEMETRA** - Investigating the Interplay Between Volcanic Activity and Climate Change | P.I. V. Zago, D. Zanchettin.
- **INGV Pianeta Dinamico | DYNAMO** - DYNAMics of eruptive phenoMena at basaltic vOlcanoes | P.I. L. Zuccarello.
- **INGV Pianeta Dinamico | SIBILLA** - Radon and VLF time series, a robust monitoring infrastructure vs a potential short term seismic hazard assessment tool | P.I. A. Pignatelli.
- **INGV Pianeta Dinamico | PROMUD** - Definition of a PROmultidisciplinary monitoring protocol for MUD volcanoes | P.I. A. Sciarra.
- **INGV Pianeta Dinamico | CAVEAT** - Central-southern Aeolian islands: Volcanism and tEARing in the Tyrrhenian subduction system | P.I. M. Palano.
- **INGV Ricerca Libera 2024 | PARADE** - Degassing PArAmeterization of StRombolian explosions through high-frequency thermAl and UV Data time sEries | P.I. E. Bagnato.
- **INGV Ricerca Libera 2024 | ENDGAME2** - Laboratory Experiments, Numerical moDellinG and field observAtions of basaltic Magma fragmentation 2 | P.I. G. La Spina.
- **INGV Ricerca Libera 2024 | CARONTE** - Crystal-melt-gAs equilibria: Record of Oxygen fugacity in Nature deciphered Through Experiments | P.I. A. Pontesilli.
- **INGV Ricerca Libera 2024 | PANTAREI** - Polydisperse ANalog experiments based on Textural chAracterization of mafic lavas: Rheology, Emplacement mechanisms, and flow Inundation risk | P.I. F. Di Fiore.

- **INGV Ricerca Libera 2024 | SOMBRERO** - StrOMBoli moRphology changEs and dROnes
| P.I. T. Ricci.

1.5 Partner laboratories and institutions

- **BGRL (Borehole Geophysical Research Laboratory)** | Karad | India
- **Catania University** | Dipartimento di Scienze Biologiche, Geologiche e Ambientali | Italy
- **Durham University** | Department of Earth Science / Rock Mechanics Laboratory | UK
- **EPFL** | LEMR | Lausanne | Switzerland
- **ETH Zurich** | Institute of Geochemistry and Petrology / Rocks Physics and Mechanics Laboratory (RPML) | Switzerland
- **Ferrara University** | Dipartimento di Fisica e Scienze della Terra | Italy
- **IFREMER** | Laboratoire Aléas Géologiques et Dynamique Sédimentaire | France
- **Instituto Volcanológico de Canarias (INVOLCAN)** | Spain
- **Ludwig Maximilians Universität München** | Experimental & Physical Volcanology | Germany
- **Natural History Museum** | Volcano Petrology Group | UK
- **Padova University** | Dipartimento di Geoscienze | Italy
- **Perugia University** | Petro-Volcanology Research Group (PVRG) | Department of Physics and Geology | Italy
- **Roma Tre University** | Dipartimento di Scienze | Italy
- **RWTH Aachen University** | Geotechnical Lab | Germany
- **Sapienza University of Rome** | Laboratorio di Fisica delle Rocce | Italy
- **UCL Earth Sciences** | Rock Mechanics Laboratory | UK
- **Universidad Carlos III Madrid** | Departamento Tecnología Electrónica | Spain
- **University of Aarhus** | Planetary Environmental Facilities | Department of Physics and Astronomy | Denmark
- **University of Hawaii** | Department of Geology and Geophysics, SOEST | USA
- **University of Otago** | Department of Geology | New Zealand
- **University of Queensland** | School of Earth and Environmental Sciences | Australia
- **University of Texas at Austin** | Jackson School of Geosciences | USA
- **USGS** | HVO Hawaiian Volcano Observatory | USA
- **Utrecht University** | Department of Earth Sciences | Netherlands

1.6 Seminars and teaching

Training

- **Catanese, S.** | Stage | Analisi della sedimentazione di piroclasti (ceneri e lapilli fini) da immagini ad alta velocità | Supervisors: J. Taddeucci (INGV), D.M. Palladino (Sapienza University of Rome).
- **Innocenti, S.** | Stage | Analisi di video nell'infrarosso ed esperimenti di laboratorio sulla formazione dei Volcanic Vortex Rings | Supervisors: J. Taddeucci (INGV), F. Funicello (Roma Tre University).
- **Minardi, A.** | Stage | Analisi di video nell'infrarosso ed esperimenti di laboratorio sulla formazione dei Volcanic Vortex Rings | Supervisors: J. Taddeucci (INGV), F. Funicello (Roma Tre University).

Master theses

- **Calagreti, C.** | Master Thesis | Flow-induced crystallization of Stromboli basalts | Roma Tre University | Supervisors: A. Vona, F. Di Fiore (Roma Tre University, INGV).
- **Campana A.M.** | Master Thesis | The role of fluids in subduction zones: from plate velocities to seismic velocities, the frictional behaviour of sediments from deep drilling | Roma 3 University | Supervisors: Funicello F. (Roma 3), Aretusini S. (INGV), Spagnuolo E. (INGV), Corbi F. (CNR), Vannucchi P. (UniFI).
- **Cavaliere, N.** | Master Thesis | Digital Image Correlation technique applied to visualization of the displacement field in laboratory experiments on seismic rupture | University of Padova | Supervisors: G. Di Toro, C. Cornelio (University of Padova, INGV).
- **De Min, G.** | Master Thesis | Reconstructing the evolution of Stromboli's magmatic feeding system through oxygen isotope characterization: a geochemical investigation of four paroxysmal eruptions over the past two decades (2003-2024) | Sapienza University of Rome | Supervisors: L. Dallai, S. Mollo, A. Pontesilli (Sapienza University of Rome, INGV).

PhD projects

- **Biensan, C.** | PhD | Linking styles of active magma degassing with fragmentation dynamics for mafic magmas: a multiparametric approach | Sapienza University of Rome | Supervisors: D. Palladino (Sapienza University of Rome), J. Taddeucci (INGV).
- **Chinello M.** | PhD | formation of polished surfaces in natural rocks: Experimental and Field constraints | Padova University | Supervisors: Di Toro G. (UniPD), Spagnuolo E. (INGV), Tesei T. (UniPD).
- **Coppola, L.** | PhD | Mineralogy, structures and fluid injection role in fault stability: implications for CO₂ storage | Sapienza University of Rome | Supervisors: C. Collettini (Sapienza University of Rome), G. Volpe (INGV).
- **Califano, E.** | PhD | Decoding the physico-chemical conditions of magmas triggering the 2022 eruption of Hunga Tonga-Hunga Ha'apai | Sapienza University of Rome | Supervisors: S. Mollo (Sapienza University of Rome), A. Pontesilli (INGV).
- **Giuliani, G.** | PhD | Magma-carbonate interaction under dynamic conditions: experimental insights on crystallization kinetics and multiphase rheology | Roma Tre University | Supervisors: A. Vona, C. Romano, F. Di Fiore, D. Di Genova (Roma Tre University, INGV, CNR-ISSMC).
- **Guarnieri, G.** | PhD | Modeling spatio-temporal variations in Strombolian to Vulcanian-Strombolian eruptive activity | Sapienza University of Rome | Supervisors: G. Sottili (Sapienza University of Rome), J. Taddeucci (INGV).
- **Iezzi, F.** | PhD | Active degassing and Volcanic Vortex Rings: implications for the state of the volcano and its eruptive behaviour | Sapienza University of Rome | Supervisors: D. Palladino (Sapienza University of Rome), J. Taddeucci (INGV).

Post-Doc projects

- **Woo, S.** | Post-Doc | Experimental characterization of the fault stability of the materials from the Pohang EGS Site - South Korea | Sapienza University of Rome | Supervisors: C. Collettini (Sapienza University of Rome), G. Volpe (INGV), M. Son (Pusan National University).

1.7 Visiting scientists and Trans-National Access (TNA)

European Project EXCITE²

The EXCITE² project was launched on April 1, 2024, as a unified European infrastructure offering transnational access (TNA) to advanced imaging technologies. The EXCITE² Network consolidates 40 research facilities across 12 European and associated partner countries, providing cutting-edge imaging tools to researchers. This initiative focuses on chemical and physical processes related to environmental toxicity, critical metal extraction for renewable energy, and Earth materials for long-term climate gas storage. EXCITE² also emphasizes interdisciplinary collaboration, artificial intelligence integration, and citizen science engagement to ensure broader societal impact. In 2025, the microanalytical facilities at INGV-Roma 1 (FIB-SEM and EMPA) hosted researchers under the EXCITE² project for a total of 15 delivered access units.

ILGE | Integrated Laboratories for Geosciences and Environment network

Within the framework of the MEET (Monitoring Earth's Evolution and Tectonics) project - WP3, a collaborative effort was established among key Italian infrastructures dedicated to the study of Solid Earth processes: the National Institute of Geophysics and Volcanology (INGV), Roma Tre University (UniRomaTre), the National Research Council (CNR), and the National Institute of Oceanography and Applied Geophysics (OGS). The ILGE network comprises 23 laboratories and 102 affiliated researchers and technicians. These facilities, distributed across the partner institutions, encompass a wide range of Earth Science disciplines, including high-pressure/high-temperature experimental volcanology and geophysics, experimental tectonics, paleomagnetism, geochemistry, optical and scanning electron microscopy, core logging, and site effect investigations. In 2025, seven projects were conducted at the HPHT laboratory under the 2nd ILGE call for Transnational and National Access (TNA/NOA). These activities were distributed across various facilities-including microanalysis, the analog laboratory, rock mechanics, and experimental petrology-for a total of 37 access days.

User Name	Affiliation	Project Title	Equipment	Access Period (2025)	Days
D. Malcoeffe (EXCITE ²)	Université de Toulouse (France)	MEMO - TiMescalEs of Magma dynamics at StrOmboli volcano	FIB-SEM Scios 2 LV, EPMA JXA-iSP100	03 - 14 March	10
C. M. Petrone (EXCITE ²)	Natural History Museum (London, UK)	Paroxysm - The build-up of the 11 July 2024 paroxysm at Stromboli volcano	EPMA JXA-iSP100	26 - 30 May	5
A. Cinquegrani (ILGE)	University of Palermo (Italy)	PANTMIX - Magma mixing in the 'Daly Gap' of peralkaline volcanic complexes	EPMA JXA-iSP100	19 - 23 May	5
R. Cavallera (ILGE)	University of Camerino (Italy)	ERUPTIVES - Textural and chemical analyses of phonolitic eruptions: Mt. Vesuvius	EPMA JXA-iSP100	05 - 09 May	5
C. Calagreti (ILGE)	Roma Tre University (Italy)	STIR - Stirring Induced Crystallization in basalts	FIB-SEM Scios 2 LV	26 May - 04 June	7

M. Cassetta (ILGE)	University of Torino (Italy)	BOLLE - Bubble Onset and Lifetime from Liquids to Ejecta	Quickpress	26 - 30 May	5
J. Gilchrist (ILGE)	University of Oregon (USA)	MOVE - MOdelling volcanic Vortex rings in the atmosphere	Shock-tube system	16 - 20 June	5
A. Karaoui (ILGE)	Moulay Ismail University (Morocco)	DEMAGMA - Decoding the late Ediacaran multistage magma system, Anti-Atlas	EPMA JXA-iSP100	23 - 27 June	5
S. Abeykoon (ILGE)	University of Camerino (Italy)	HYDROETNA - Glass and melt properties of hydrous Etna trachybasalt	Quickpress	21 - 27 July	5

Table 1 Visiting scientists who successfully concluded their visits during 2025.

1.8 Meetings, Workshops and Symposia

Workshop Physics of Volcanoes, Aachen (Germany), 5-7 March

- **Taddeucci, J.** | *The when, why, and where of mafic magmas fragmentation: examples from Cumbre Vieja, Stromboli, Etna.*

Advanced Visualization Tools in Heritage Science, Ljubljana (Slovenia),
13-15 March

- **Casarin, A.**, Repič, R., Mancini, L., Iezzi, G., Radica, F., Galderisi, A., Bravo, M., De Brito, J., Brando, G., Nazzari, M., Scarlato, P. | *Integrated 2D and 3D texture analysis of a mortar.*

Schatzalp 4° Workshop on Induced Seismicity, Davos (Switzerland),
18-21 March

- **Spagnuolo, E.**, Aretusini, S., Cornelio, C., Pozzi, G., Selvadurai, P., Cocco, M. | *Fault core structure and the behavior of fault slip during fluid injection: insights from laboratory friction experiments.*

77th Geological Congress of Turkey, Ankara (Turkey), 14-18 April

- **Özsoy, R.**, Sunyé-Puchol, I., Bolós, X., Akkas, E., Costa, A., Tavazzani, L., Miggins, D.P., Nazzari, M., Bachmann, O., Scarlato, P., Mollo, S. | *New Findings from the Ulukışla Caldera in the Hasandağ Volcanic Complex (Central Anatolia).*

EGU General Assembly 2025, Vienna (Austria), 27 April-2 May

- **Aretusini, S.**, Cornelio, C., Spagnuolo, E., Volpe, G., Pozzi, G., Dal Zilio, L., Selvadurai, P., Cocco, M. | *Fault core structure and the fault slip behavior during fluid injection: insights from laboratory friction experiments.*
- **Buono, G.**, Maccaferri, F., Pappalardo, L., Tramelli, A., Caliro, S., Chiodini, G., Pinel, V., Rivalta, E., Spagnuolo, E., Trasatti, E., Di Vito, M.A. | *Weak crustal layer beneath Campi Flegrei (Italy) identified: what's its impact on unrest?*
- **Davoli, R.**, Tamburello, G., Ricci, T., Montanaro, C., Murphy, B., Jones, T., Brooks, I., Cronin, S., Scheu, B. | *Impact of alteration and soil properties on geothermal gas emissions at Rotokawa, New Zealand.*
- **Di Fiore, F.**, Vona, A., Di Genova, D., Caracciolo, A., Pontesilli, A., Calabrò, L., Giuliani, G., Mollo, S., Bondar, D., Nazzari, M., Romano, C., Scarlato, P. | *Impact of Cooling Rate on Rheology and Emplacement Dynamics of Basaltic Lava Flows: Insights from the 2023-2024 Sundhnúksígur Eruption (Iceland).*
- **Di Luccio, F.**, and the The CAVEAT Team | *The Tyrrhenian Sea under watch: multinational, multiscale seismic monitoring across the Aeolian Islands, southern Italy.*
- **Hung, C.C.**, Niemeijer, A., Aretusini, S., Spagnuolo, E., Chen, J., Hamers, M. | *Thermo-hydro-mechanical mechanisms in sandstone-derived fault gouges during simulated small-magnitude earthquakes from experiments and models.*
- **Jalali, M.**, Gischig, V., Selvadurai, P., Spagnuolo, E., Meier, M.-A., Dal Zilio, L., Roskopf, M., Obermann, A., Rinaldi, A. P., Gholizadeh Doonechaly, N., Bröker, K., Osten, J., Hertrich, M., Maurer, H., Giardini, D., Wiemer, S., Cocco, M., and Amann, F. and the FEAR Team | *Hydraulic Stimulations with Hydro-Mechanical Pre-Conditioning at the BedrettoLab.*
- **Lambiase, A.**, Meier, M.A., Spagnuolo, E., Nikkhoo, M., Rinaldi, A.P., Gischig, V., Selvadurai, P.A., Giardini, D., Wiemer, S. | *Induced fault slip events and their deformation fields: insights from FEAR experiments.*
- **Massin, F.**, Edme, P., Clinton, J., Scarabello, L., Tian, L., Rinaldi, A. P., and Meier, M.-A. and the FEAR team | *Integrating DAS into Seismic Monitoring Systems: Insights from SED and the BedrettoLab.*
- **Meier, M.A.**, Gischig, V., Rinaldi, A., Jalali, M., Supino, M., Mosconi, F., Villiger, L., Selvadurai, P., Spagnuolo, E., Tinti, E., Dal Zilio, L., Zappone, A., Pozzi, G., Mesimeri, M., Scarabello, L., Hertrich, M., Amann, F., Cocco, M., Wiemer, S., and Giardini, D. and the FEAR Team | *An Induced Mw -0.4 Earthquake Under a Microscope at the BedrettoLab.*
- **Pizzati, M.**, Aretusini, S., Spagnuolo, E., Aldega, L., Torabi, A., Storti, F., Balsamo, F. | *Near-surface earthquake rupturing in high-porosity sandstone documented by a combined meso-microstructural, mineralogical, and experimental approach.*
- **Pozzi, G.**, Ceccato, A., Aretusini, S., Spagnuolo, E., Cocco, M. and the FEAR Team | *Shattering and structural inheritance at the onset of faulting in the Rotondo granite.*
- **Schaber, T.**, Jalali, M., Ceccato, A., Zappone, A. S., Pozzi, G., Selvadurai, P., Spagnuolo, E., Gischig, V., Meier, M.-A., Hertrich, M., and Amann, F. and the FEAR Team | *Multidisciplinary characterization of a complex fault zone in crystalline basement rock.*
- **Sciarra, A.**, Falanga, M., Mancini, S., Guida, M., Grassa, F., Misiti, V., Pinzi, S., Venuti, A., Cascella, A. | *A multidisciplinary monitoring approach involving radioactivity, greenhouse gas emissions, stratigraphy and rock magnetism.*
- **Taddeucci, J.**, Pontesilli, A., Di Fiore, F., Scarlato, P. | *Scanning Transmission Electron Microscope (STEM) features of glass in crystal fractures.*

IAVCEI Scientific Assembly, Geneva (Switzerland), 29 June-4 July

- **Arzilli, F.**, Polacci, M., La Spina, G., Di Genova, D., Bamber, E. C., Brooker, R. A.,

- Torres-Orozco, R., Bonechi, B., Mollo, S., Llewellyn, E. W., Neave, D. A., Hartley, M. E., Le Gall, N., Atwood, R., Lee, P. D., Burton, M. R. | *4D crystallization and dissolution kinetics in hydrous basaltic magmas: implications for dynamics of volcanic processes.*
- **Bagnato, E.**, Andronico, D., Cinti, D., Del Bello, E., Scarlato, P., Taddeucci, J. | *Ash-leachates chemistry as a tool for monitoring volcanic activity: An application to Stromboli volcano from 2019 to 2024.*
 - **Biensan, C.**, Taddeucci, J., Alatorre-Ibarguengoitia, M., Scarlato, P., Andronico, D., Ricci, T., Del Bello, E., D'Auria, L., Asensio-Ramos, M., Palladino, D. M. | *In-flight fragmentation dynamics in explosive eruptions of low-viscosity magmas.*
 - **Buono, G.**, Maccaferri, F., Pappalardo, L., Tramelli, A., Caliro, S., Chiodini, G., Pinel, V., Rivalta, E., Spagnuolo, E., Trasatti, E., Di Vito, M. A. | *Weak crustal layer beneath Campi Flegrei identified: is this the engine for bradyseismic movements?*
 - **Califano, E.**, Mollo, S., Brenna, M., Pontesilli, A., Marks, P., Eul, D., Nowak, M., Cronin, S., Scarlato, P. | *Experimental constraints on the magmatic parameters controlling the 2022 eruption of Hunga Tonga-Hunga Ha'apai Volcano, Tonga.*
 - **Caricchi, L.**, Muruzábal, M. M., Jost, C., Agreda-Lopez, M., Mollo, S., Ubide Garralda, T., Petrelli, M. | *Combining thermodynamic- and machine learning-based thermobarometry.*
 - **Davoli, R.**, Engels, K., Montanaro, C., Ricci, T., Sciarra, A., Scheu, B. | *Influence of subsurface soil and lithology alteration on degassing at Krafla Caldera, Iceland.*
 - **Del Bello, E.**, Bagnato, E., Spina, L., Tamburello, G., Ricci, T., Taddeucci, J., Andronico, D., Pennacchia, F., Scarlato, P. | *Integrated High-Frequency Monitoring of Strombolian Explosions: Insights from Multi-Parameter Time Series Data.*
 - **Di Fiore, F.**, Pontesilli, A., Calabrò, L., Civico, R., Ricci, T., Taddeucci, J., Andronico, D., Scarlato, P. | *Monitoring and Modeling Lava Flow Dynamics of the July 2024 Stromboli (Italy) eruptive activity: Insights from UAS Surveys and Petrological Analysis.*
 - **Kim, K.**, Spina, L., Taddeucci, J., Pennacchia, F., Cornelio, C., Spagnuolo, E., Girona, T. | *Investigating volcanic tremor and long-period seismic events through experiments on porous media gas flow.*
 - **Özsoy, R.**, Sunyé-Puchol, I., Bolós, X., Akkas, E., Costa, A., Tavazzani, L., Miggins, D.P., Nazzari, M., Bachmann, O., Scarlato, P., Mollo, S. | *Reconstructing the volcanic history of Ulukışla Caldera to improve the hazard assessment around the Hasandağ Volcanic Complex (Central Anatolia).*
 - **Pontesilli, A.**, Di Fiore, F., Mollo, S., Ellis, B., Andronico, D., Taddeucci, J., Bachmann, O., Scarlato, P. | *Multi-elemental assessment of plagioclase-melt equilibria unravel episodes of crystal growth and provides clues on magma evolution.*
 - **Scarlato, P.**, Andronico, D., Bisson, M., Del Bello, E., Ricci, t., Taddeucci, J., and the UNO Team | *Understanding the ordinary to forecast the extraordinary: four years of integrated insights into Stromboli's explosive activity and hazard mitigation.*
 - **Schiavon, B.**, Petrone, C.M., Forni, F., Pontesilli, A., Hu, H., Scarlato, P., Andronico, D., Del Bello, E., Nazzari, M., Mollo, S. | *Multiple mush generations provide insight into the longevity of open conduit basaltic volcanoes.*
 - **Sork, A.**, Kennedy, B., Fitzgerald, R., Tsunematsu, K., Bisson, M., Watson, L., Sellier, M., Taddeucci, J., Andronico, D., Scarlato, P., Del Bello, E., Ricci, T., Banerjee, D., Kreit, P. | *Does incorporation of irregular bomb shapes significantly influence the outcome of ballistic hazard models?*
 - **Stumpp, D.**, Cabrera-Pérez, I., Savard, G., Ricci, T., Alparone, S., Ursino, A., Palano, M., Sparacino, F., Muñoz Burbano, F., Barat, C., Reyes Hardy, M.P., Ruch, J., Bonadonna, C., and Lupi, M. | *Imaging volcanoes during unrest: Nodal Ambient Noise Tomography of a transient plumbing system, Vulcano, Italy.*
 - **Sunyé-Puchol, I.**, Bolós, X., Özsoy, R., Akkas, E., Smith, V., Tavazzani, L., Nazzari, M., Mollo,

S. | *Tephrostratigraphy and geochemical correlation of Mount Erciyes parasitic tephra rings with distal Mediterranean S1 Ash Records.*

- **Sunyé-Puchol, I.**, Bolós, X., Smith, V., Özsoy, R., Akkas, E., Tavazzani, L., Costa, A., Nazzari, M., Mollo, S. | *Correlating Black Sea (crypto-)tephras to reconstruct the recent explosive volcanic history of Central Anatolian volcanoes.*
- **Sunyé-Puchol, I.**, Bolós, X., Özsoy, R., Akkaş, E., Tavazzani, L., Nazzari, M., Bachmann, O., Scarlato, P., Mollo, S. | *Small-scale phreatomagmatic eruptions as precursors of larger caldera-forming eruptions: Insights from Acigöl caldera, Central Anatolia (Turkey).*
- **Taddeucci, J.**, Scarlato, P., Del Bello, E., Pennacchia, F., Biensan, C., Spina, L., Guarnieri, G., Sottili, G. | *Multi-parametric recording of multi-vent activity at Stromboli volcano (Italy).*
- **Tournigand, P.-Y.**, Smets, B., Ricci, T., Civico, R., Centeno, R., Kervyn, M. | *Assessing cloud points co-registration methods efficiency based on UAS images acquired in an active volcanic environment (Stromboli volcano, Italy).*
- **Zuccarello, L.**, Gheri, D., De Angelis, S., Civico, R., Ricci, T., Scarlato, P. | *The 11 July 2024 Paroxysm at Stromboli Volcano, Italy: A Multidisciplinary Study of Pre-Eruption Unrest and Dynamics.*

Goldschmidt 2025 Conference, Prague (Czech Republic), 6-11 July

- **Akkaş, E.**, Sunyé-Puchol, I., Bolós, X., Uslular, G., Özsoy, R., Mollo, S. | *Machine Learning Model to Predict Cryptotephra Layers in the Black Sea Core Using Glass Geochemistry of Central Anatolian Volcanic Province Eruption.*
- **Cantucci, B.**, Di Toro, G., Sciarra, A., Gomila, R., Grassa, F., Piochi, M., Barberio, M. D., Brusca, L., Bellomo, S., Ricci, T. | *Understanding the seismic cycle in hydrothermal conditions: from innovative experiments and analysis to geochemical modeling.*

Soufriere Hills Volcano International Conference (SHV30), Montserrat Volcano Observatory (West Indies), 14-18 July

- **Nave, R.**, Miseo, A., Ricci, T. | *Facing with volcanic hazard and risk on Stromboli Island (Italy): community engagement, communication strategies, and multi-risk adaptation.*

15th Field Workshop on Volcanic Gases (CCVG/IAVCEI), Hokkaido (Japan), 1-8 September

- **Bagnato, E.**, Andronico, D., Cinti, D., Del Bello, E., Scarlato, P., Taddeucci, J. | *Chemical Signatures of Ash-Leachates as Indicators of Eruptive Styles at Stromboli Volcano (2019-2024).*
- **Del Bello, E.**, Bagnato, E., Guerrieri, L., Tamburello, G., Corradini, S., Merucci, L., Pennacchia, F., Stelitano, D., Scarlato, P., Taddeucci, J. | *A cross-comparison of thermal infrared vs ultraviolet ground-based retrievals of SO₂ masses during Strombolian explosions.*

7th Historic Mortar Conference, Padova (Italy), 2-4 September

- **Casarin, A.**, Mancini, L., Repič, R., Iezzi, G., Nazzari, M., Pierigè, M. I., Brando, G., Criber, E., Scarlato, P. | *Image processing and analysis in archaeometry: unveiling Roman mortars from*

the thermal baths of Teate Marrucinorum (Chieti, Italy).

Congresso Congiunto SIMP-SGI, Padova (Italy), 16-18 September

- **Baroncini, E.**, Rizzo, R.E., Pozzi, G., Papeschi, S., Spagnuolo, E., Aretusini, S., Vannucchi, P. | *CO₂-rich fluids and fault mechanics: Experimental and rate-and-state modelling of carbonated serpentinite friction in a subduction channel.*
- **Buono, G.**, Maccaferri, F., Pappalardo, L., Tramelli, A., Caliro, S., Chiodini, G., Pinel, V., Rivalta, E., Spagnuolo, E., Trasatti, E., Di Vito, M.A. | *Exploring architecture and dynamics of caldera systems during volcanic unrest: The example of the Campi Flegrei caldera (Italy).*
- **Chinello, M.**, Aretusini, S., Spagnuolo, E., Nava, J., Tesei, T., Fondriest, M., Di Toro, G. | *Seismic and subseismic experimental Mirror-like Surfaces in bituminous dolostones.*
- **Colombelli, S.**, Spagnuolo, E., Aretusini, S., Cornelio, C., Kiss, A., Longobardi, V., Scala, A. | *From rupture process to earthquake early warning: ideas, methods & preliminary results of the FORESEEING project.*
- **Di Fiore, F.**, Vona, A., Di Genova, D., Caracciolo, A., Pontesilli, A., Calabrò, L., Giuliani, G., Mollo, S., Bondar, D., Nazzari, M., Romano, C., Scarlato, P. | *Impact of cooling rate on rheology and emplacement dynamics of basaltic lavas: insights from the January 2024 Sundhnúksgrígar eruption (Iceland).*
- **Mollo, S.** | *Crystallization dynamics in magmas recorded by clinopyroxene: a multifaceted perspective.*
- **Pizzati, M.**, Aretusini, S., Spagnuolo, E., Aldega, L., Torabi, A., Storti, F., Balsamo, F. | *Shallow depth fault hosting evidence for past earthquake ruptures propagating through sediments: example from the Croton Basin, South Italy.*
- **Pontesilli, A.**, Di Fiore, F., Mollo, S., Ellis, B., Andronico, D., Taddeucci, J., Bachmann, O., Scarlato, P. | *Multi-elemental assessment of plagioclase-melt equilibria unravels episodic crystal growth.*
- **Rizzo, R.E.**, Baroncini, E., Papeschi, S., Pozzi, G., Aretusini, S., Spagnuolo, E., Vannucchi, P. | *Coupled metasomatic and mechanical evolution of carbonated serpentinite at the subduction interface.*
- **Stabile, P.**, Vetere, F., Giuliani, L., Siligardi, C., Mugoni, C., Nazzari, M., Iezzi, G. | *The influence of cooling rate on the production of glass-ceramic materials from slag and glass waste.*
- **Spagnuolo, E.**, Cornelio, C., Aretusini, S., Cocco, M., Selvadurai, P., Taddeucci, J., Di Stefano, G. | *From stick to slip. Novel opportunities in experimental earthquake mechanics for imaging the earthquake preparation stage.*

European Geothermal Congress, Zurich (Switzerland), 6-10 October

- **Procesi, M.** and IRGIE Team | *Advancing Geothermal Energy in Small Islands: An Overview on the Aeolian Islands (Italy) and IRGIE Project.*

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- **Del Bello, E.**, Zanella, G., Civico, R., Ricci, T., Taddeucci, J., Andronico, D., Scarlato, P. | *From Spattering to Crater Collapse: High-frequency monitoring of explosion parameters and morphological changes during Stromboli May 2021 activity.*
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EGU General Assembly 2025, Vienna (Austria), 27 April - 2 May

- **Session TS1.3 | Fault deformation across scales: from laboratory to geophysical observations via numerical simulations.** *Convener: Carolina Giorgetti. Co-conveners: Nathalie Casas, Chiara Cornelio, Pierre Romanet, Federica Paglialonga.*

1.9 Publications

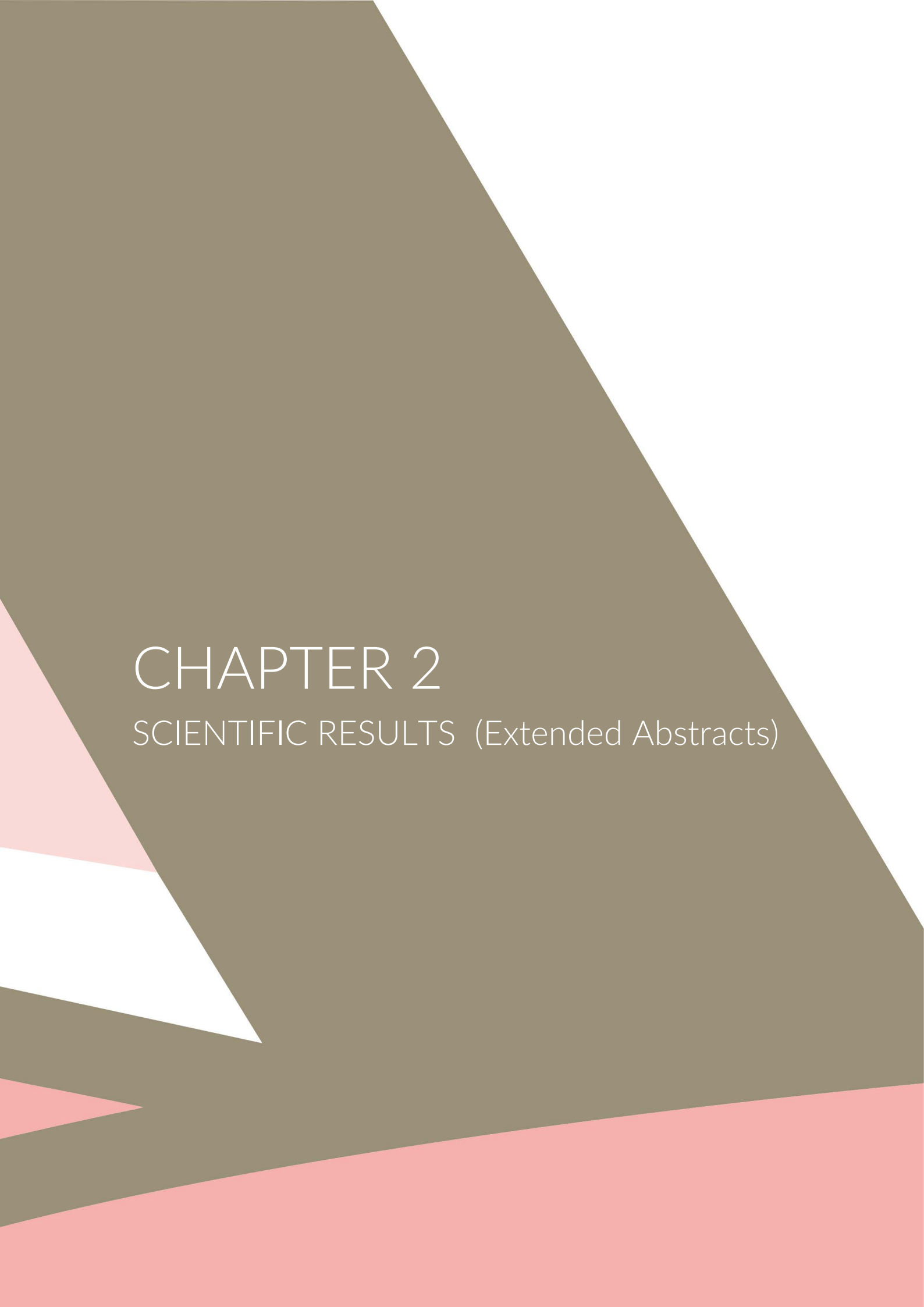
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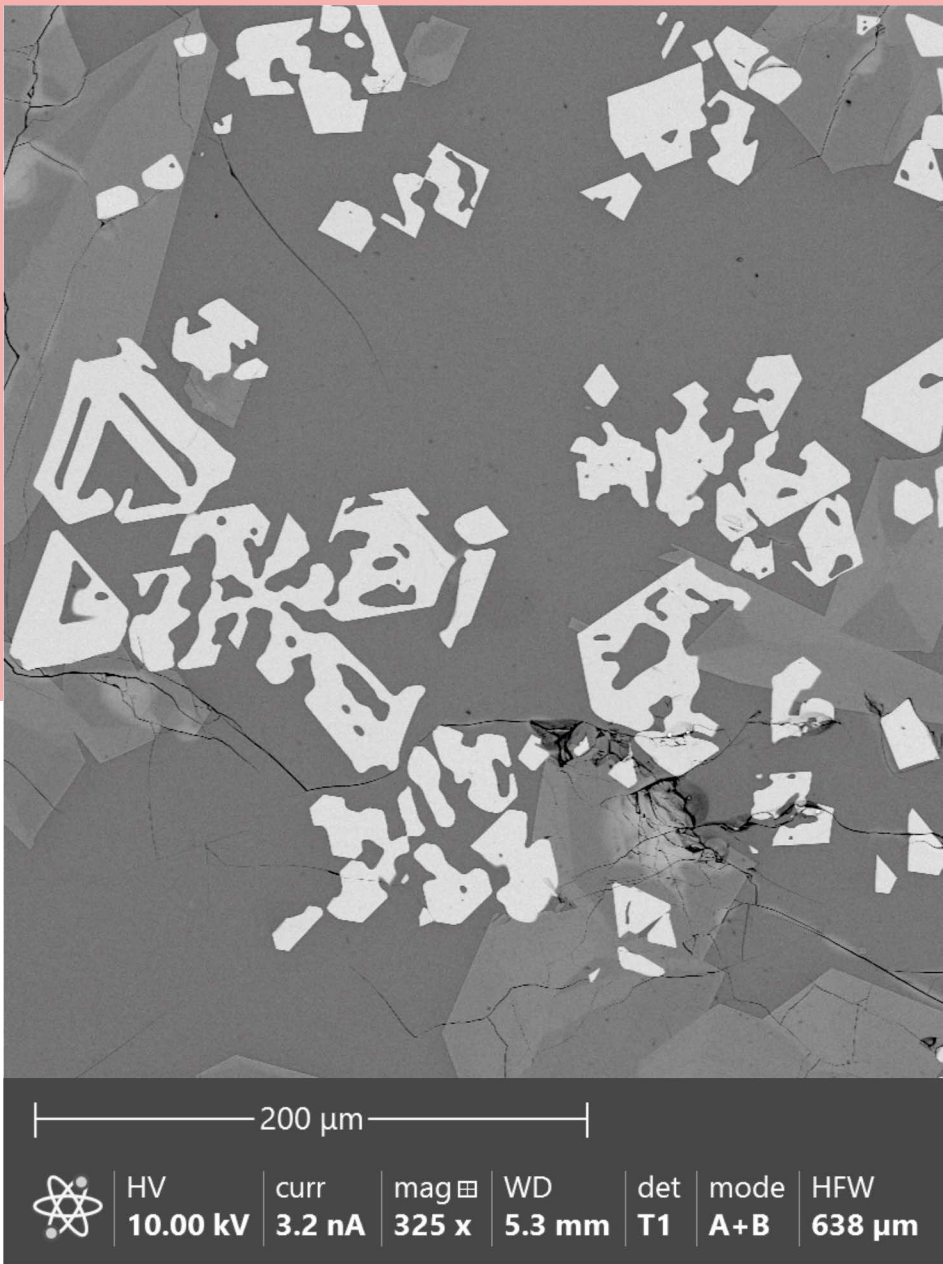
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CHAPTER 2

SCIENTIFIC RESULTS (Extended Abstracts)

2.1 Petrology, Mineralogy, Volcanology



Chemical Signatures of Ash-Leachates as Indicators of Eruptive Styles at Stromboli Volcano (2019-2024)

Bagnato E., Andronico D., Cinti D., Del Bello E., Nazzari M., Scarlato P., Taddeucci J.

Presented at the 15th CCVG Workshop, Hokkaido, Japan, 31th August-8th September, 2025 (<https://ccvg.iavceivolcano.org/field-workshops/14th-workshop-japan-2025/>).

During volcanic eruptions, complex gas-ash interactions lead to the deposition of magmatic volatiles as water-soluble salts on ash surfaces, a process resulting in what are known as ‘ash-leachates’ (Figures 1a, b). Characterizing these leachates yields critical insights into volcanic gas compositions and eruptive dynamics. Their chemical signatures are primarily shaped by the synergistic interplay between magmatic degassing, fragmentation mechanisms, and eruptive style. Specifically, the molar ratios of sulfur (S), chlorine (Cl) and fluorine (F) serve as sensitive indicators of eruptive intensity, reflecting fluctuations in the gas plume. These chemical signals are further supported by SEM-EDS validation, which confirms an unequivocal link between bulk chemistry and surface mineral assemblages such as halite and anhydrite (Figure 1b).

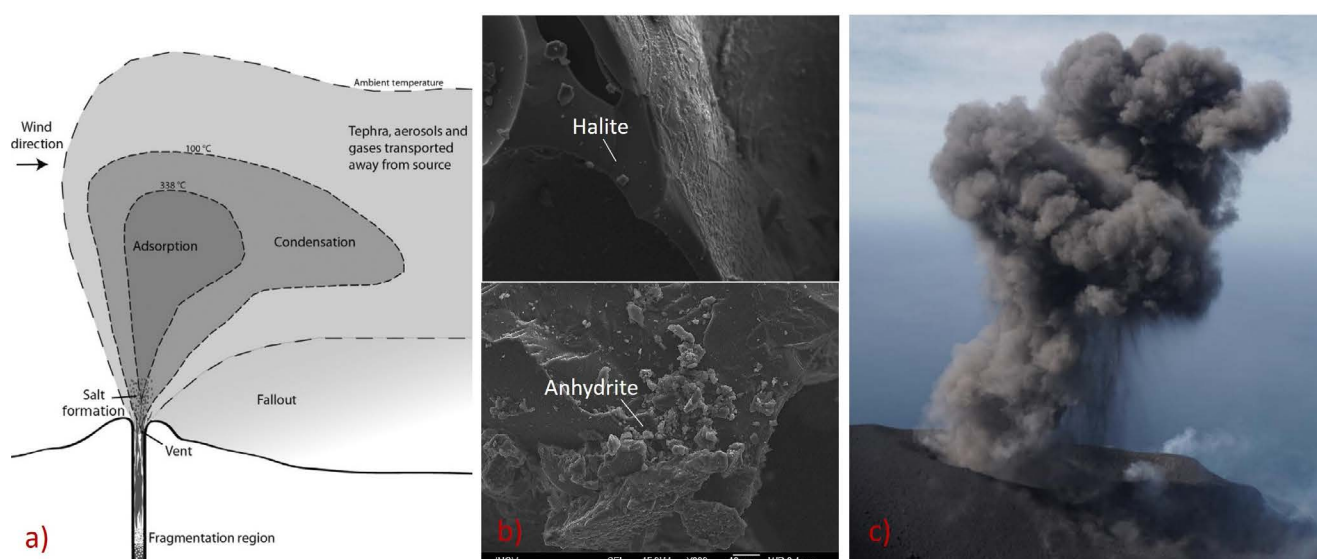


Figure 1 a) Schematic representation of the volcanic plume structure illustrating key temperature dependent processes affecting ash-gas interactions (Oskarsson, 1980). Near the vent (600-1200 °C), salt formation occurs; at intermediate distances and temperatures (190-800 °C), volatile species adsorb onto ash particles; and at temperatures below 190 °C, condensation processes dominate. Tephra, aerosols, and volcanic gases are progressively transported away from the source and undergo fallout. b) SEM analysis illustrates the presence of soluble salts coatings (CaSO_4 frequently accompanied by distinctive cubic NaCl crystals) on ash surface at Stromboli. c) Dense ash plume captured during a typical explosive event at Stromboli volcano (photo credit: D. Andronico, INGV-OE).

This study introduces a comprehensive dataset based on 119 freshly erupted ash samples collected at Stromboli between 2019 and 2024. Due to its persistent explosive activity, Stromboli serves as a unique natural laboratory (Figure 1c) for examining how leachates compositions vary across diverse eruptive scenarios, including ordinary activity, effusive flows, paroxysmal explosions and pyroclastic flows.

Samples were processed at the HPHT lab using a standardized shaking and centrifugation

protocol for ash-leachates analysis, with major element concentrations subsequently determined via ion chromatography. Despite the inherent chemical heterogeneity of ash-leachates, elevated S/Cl and S/F ratios consistently correspond to high-energy events. Notable examples include the paroxysms of July 2019 and 2024, the explosive-effusive phases and associated pyroclastic flows of 2021-2023, and the littoral explosions following the 2024 paroxysm. Interestingly, data associated with similar eruptive styles exhibit a strong year-to-year correlation; following these high-energy episodes, S/Cl and S/F ratios systematically return to the baseline levels characteristic of Stromboli's persistent ordinary activity.

Exploring volcanic rock textures: Integrating 2D and 3D analyses

Buono G., Di Fiore F., Pappalardo L.

Original contribution prepared for the HPHT Lab Annual Report 2025

Volcanic rock textures offer critical insights into magma ascent dynamics. In particular, pores and microcrystals formed during magma ascent, contain crucial information on magma transfer processes in volcanic systems. They are routinely analyzed using scanning electron microscopy (SEM), which enables examinations with exceptional contrast and resolution, despite being a 2D and destructive technique. Recently, X-ray microtomography has enabled non-destructive, high-resolution investigations in 3D. However, 3D studies of volcanic rocks still face significant challenges. This study aims to integrate 2D and 3D analyses to prepare the framework for a detailed characterization of volcanic rocks, starting from different samples from Neapolitan volcanoes. Reference eruptions for the eruptive history of Neapolitan volcanoes with different magnitude, age and vent location were chosen. For each eruption, our sampling focused on specific eruptive phases. For each eruptive phase, density analyses were performed to select representative samples for 2D backscattered electron imaging through SEM at the HPHT Laboratory of the INGV-Roma 1. Similarly selected rocks have been examined through X-ray microtomography at the micro-CT laboratory of the INGV-Osservatorio Vesuviano. Our objective is to develop an innovative approach for thoroughly analyzing the microstructure of volcanic rocks, aimed at optimizing the systematic collection of data on magma migration processes and timescales and improving the interpretation of monitoring data (Figure 2).

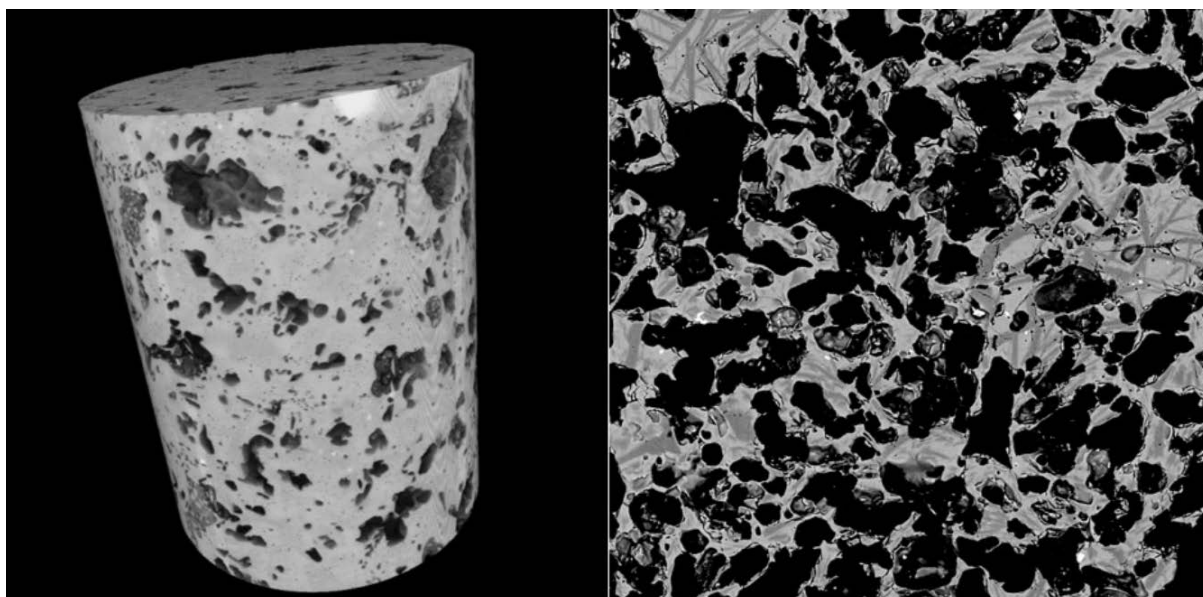


Figure 2 High resolution 3D micro-CT (left) and 2D SEM-BSE (right) images of Neapolitan volcanic rocks.

Volatilities and diffusivities of Tl, Ag, Cu, Pb, Cd, Zn, Ga, and As from a Cl-bearing shoshonitic basalt and their application to volcanic degassing

Califano E., Mollo S., Sossi P. A., Tavazzani L., Moschini P., Pontesilli A., Scarlato P.

Based on: Califano, E., Mollo, S., Sossi, P.A., Tavazzani, L., Moschini, P., Pontesilli, A., Scarlato, P. (2025). Volatilities and diffusivities of Tl, Ag, Cu, Pb, Cd, Zn, Ga, and As from a Cl-bearing shoshonitic basalt and their application to volcanic degassing. *Chemical Geology*, 693, 122947, <https://doi.org/10.1016/j.chemgeo.2025.122947>

The emission of trace metals during volcanic eruptions is modulated by their diffusion rates through the silicate melt and their affinity for the gas phase. However, due to the multicomponent nature of natural magmas, the prevailing controls on emission rates remain poorly understood. To constrain how the presence of Cl affects the diffusivities and volatilities of trace metals (Cl, Tl, Ag, Cu, Cd, Zn, Pb, Ga and As) in a nominally anhydrous shoshonitic basalt, a series of degassing experiments was conducted at 1 atm and 1200, 1300 and 1400 °C, with initial Cl contents of ~0.6 and ~1.2 wt. % Cl for durations of 1 and 4 hours.

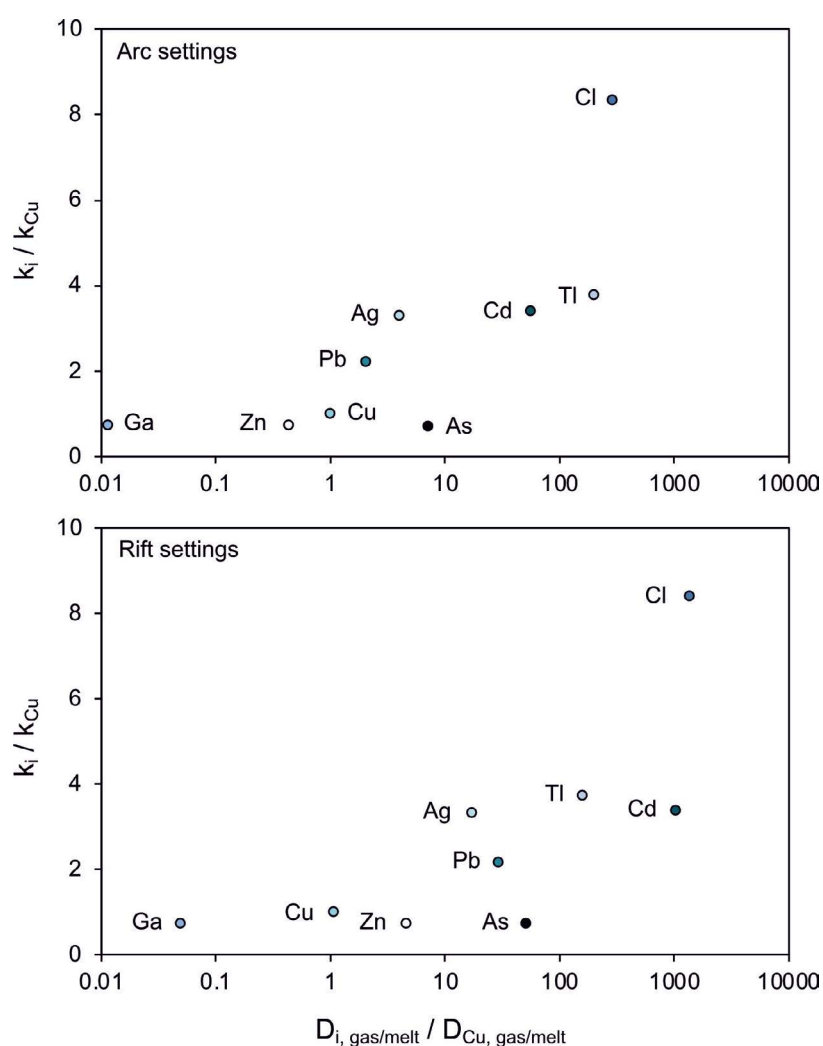


Figure 3 The mean volatilities of the elements relative to that of Cu (k_i / k_{Cu}) for the 1 wt.% $\text{NaCl}_{\text{added}}$ experiments plotted against the apparent partition coefficients (D) between volcanic gas and melt determined empirically, normalized to that of Cu, for **a)** arc settings and **b)** rift settings.

The resulting concentration gradients perpendicular to the gas-melt interface attest to the diffusive transport of trace metals within the silicate framework in response to their evaporative loss. Diffusivities scale inversely with the ionic field strength, with monovalent cations diffusing at rates ($\sim 10^{-10} \text{ m}^2 \text{ s}^{-1}$) two orders of magnitude faster than trivalent cations ($\sim 10^{-12} \text{ m}^2 \text{ s}^{-1}$). The presence of Cl causes a near-uniform increase in diffusivity of roughly 0.5 logarithmic units across all trace metals. Evaporation rates (k), defined as the rates at which volatile elements are lost from the melt surface to the coexisting vapor phase, are found to be fastest for Tl, Ag and Cd ($\sim 10^{-9}$ - 10^{-8} m s^{-1}), whereas Ga and As ($\sim 10^{-10}$ - 10^{-9} m s^{-1}) are the least volatile trace metals. Thermodynamic calculations indicate that all evaporating metal-bearing species are present as chlorides in the gas phase, except for As. A positive correlation is observed between evaporation mass transfer coefficients from this study and the gas-melt partition coefficients determined for volcanic gases, with Ga becoming relatively more volatile, while As, Cd and Tl becoming less volatile in the experiments than observed in natural volcanic settings (Figure 3).

Weakening processes in carbonate-hosted faults: phyllosilicate microlayers and injections along the Mattinata fault (Southern Italy)

Calvanelli R., Aldega L., Billi A., Cavallo A., Curzi M., Mercuri M., Morsilli M., Pontesilli A., Viti C., Carminati E.

Currently under review on AGU - Solid Earth

Micrometric phyllosilicate films along fault slip surfaces can drastically reduce friction, yet they are unexpected in clay-poor carbonate platforms. We enquire how a major carbonate-hosted, seismogenic strike-slip fault can develop weak slip interfaces and undergo dynamic weakening despite an intrinsically strong protolith.

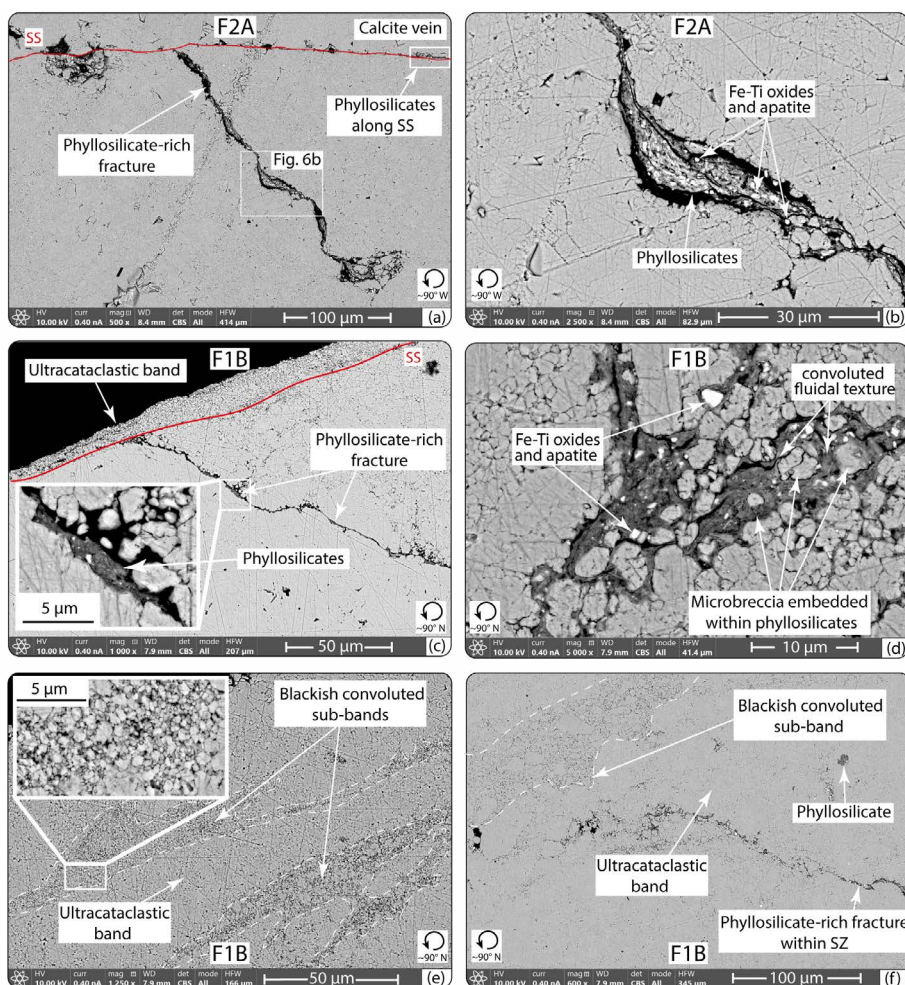


Figure 4. SEM images of the sampled slip surfaces (SSs). **a)** Phyllosilicates along the SS and phyllosilicate-rich fractures departing from the SS into the host rock (Fault 2). **b)** High-magnification view of phyllosilicates within phyllosilicate-rich fracture (Fault 2). **c)** Ultracataclastic band on one side of the SS in sample F1B, featuring a phyllosilicate-rich fracture (Fault 1). **d)** Microbreccia composed of host rock limestone isolated clasts embedded within phyllosilicates along a phyllosilicate-rich fracture in sample F1B (Fault 1). **e)** Ultracataclastic band and blackish convoluted sub-bands occurring within the slip zone (SZ) (Fault 1). **f)** Ultracataclastic band and blackish convoluted sub-band with phyllosilicates occurring within the SZ with phyllosilicates and a phyllosilicate-rich fracture. (Fault 1). Note that the photographed (FESEM images) samples in this figure have been tilted from their natural attitude (see rotation symbols).

Along the Mattinata Fault (Gargano Promontory, southern Italy), we integrate structural mapping and drone-based virtual outcrops with microstructural, mineralogical, and geochemical analyses (optical microscopy, SEM/FESEM-EDS, EPMA, and XRD). We document micrometric illite- and kaolinite-rich layers (locally up to ~15 μm thick) localized on some slip surfaces, together with ultracataclasites and phyllosilicate-filled injection veins that emanate from these surfaces into otherwise nearly pure calcite host rocks, where clay minerals are not detected even at trace levels. Microtextures, vein geometries, and mineral assemblages suggest that clays were derived from outside the carbonate host rock and introduced by transient fluid pressurization during coseismic slip, implying open-system behavior of the fault zone. Because high-velocity experiments show that even minimal amounts of phyllosilicates concentrated in thin films can promote strong dynamic weakening, our observations provide a field-based mechanism for rapid weakening and slip localization in carbonate-hosted foreland faults. More broadly, we show that carbonate seismogenic faults may be cryptically clay-bearing, with important consequences for rupture propagation and for laboratory and numerical models that commonly assume closed, clay-free systems.

FESEM-EDS analyses were carried out at the High Pressure and High Temperature Laboratory (INGV, Rome), using a Thermo Scientific Scios 2 DualBeam focused ion beam scanning electron microscope (FIB-SEM; Figure 4). Graphite-coated samples were investigated to document microstructures and phase distributions within the studied fault-related materials. The INGV facility was used to acquire high-resolution secondary electron (SE) and backscattered electron (BSE) images, and to perform energy-dispersive spectroscopy (EDS) for elemental mapping and quantitative chemical analyses on selected areas.

Chemical composition of clinopyroxene-hosted melt inclusions from Campi Flegrei eruptions

Cariddi B., Maingault L., De Hoog J., Pelullo C., Arienzo I.

Dataset from: Cariddi, B., Maingault, L., De Hoog, J., Pelullo, C., Arienzo, I. (2026). Major and volatile elements contents in clinopyroxene-hosted melt inclusions from Campi Flegrei eruptions. *Mendeley Data*, 1. doi: 10.17632/s692t8yvt6.1

Clinopyroxene-hosted melt inclusions from products of the Campanian Ignimbrite, Agnano Monte Spina and Nisida eruptions were studied to investigate the magma composition and evolution of the Campi Flegrei (Italy) volcanic field, currently experiencing an unrest phase threatening several hundred thousand people, and to shed light on the processes interplaying during magma evolution and transfer to the surface.

The major elements, together with Cl and SO₃, chemical composition of the melt inclusions was acquired, at the HPHT Laboratory of the INGV in Rome, by a Jeol JXA-iSP-100 electron microprobe (EMP) equipped with five wavelength dispersive spectrometers.

All the analysed melt inclusions are trachytic to phonolitic in composition (Figure 5), with less evolved tephriphonolitic inclusions in the Agnano Monte Spina products. These compositions are comparable to the products erupted in the last 15 ky in the Campi Flegrei caldera and are representative of the evolving magma(s) in which clinopyroxenes were crystallizing. The melt inclusions follow the typical trends, such as CaO content decrease at MgO content decrease, of magma evolution mainly driven by feldspar and pyroxene crystallization. In the most evolved melt inclusions from Agnano Monte Spina and Nisida, Cl contents-behaving as an incompatible element-increase slightly from 0.5 to 0.9 wt%, whereas evolved melt inclusions from the Campanian Ignimbrite display lower Cl contents (~0.4 wt%).

Additional work will be carried out on volcanic eruptions from the same volcanic system to better constrain the magma evolution conditions and to reconstruct plumbing system architecture and processes.

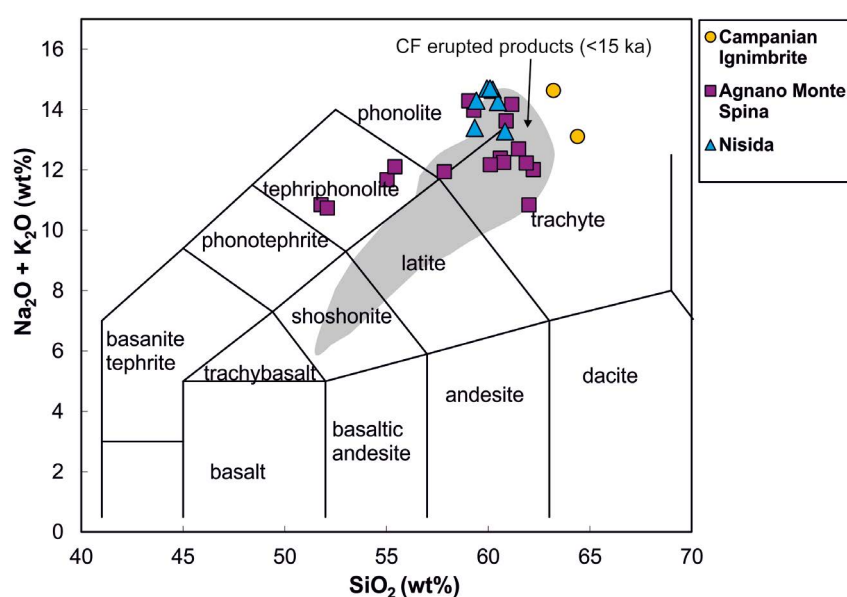


Figure 5 Total Alkali vs. Silica (T.A.S.; Le Bas et al., 1986) classification diagram with the analysed clinopyroxene-hosted melt inclusions from the Campanian Ignimbrite, Agnano Monte Spina and Nisida eruptions and the field of the Campi Flegrei volcanic rocks erupted within the last 15 ka.

Zoning pattern investigation of clinopyroxene crystals from the 1906 CE eruption of Mt. Vesuvius (Italy)

Cariddi B., Pelullo C., Sparice D., Marfè B., Arienzo I.

Original contribution prepared for the HPHT Lab Annual Report 2025

The recent activity of Mt. Vesuvius volcano was investigated in the framework of the SMEEGOL project (historical Sources, Mineral microanalysis, Experimental pEtrology and numerical modellinG to unravel the precursor phenomena Of volcanic eruptions: the case of the neapolitan volcanoes) aimed at constraining the timescale and type of magmatic processes that proceed selected volcanic events. As part of this project, a detailed study of the compositional zoning of clinopyroxenes from the 1906 CE eruption is in progress and aims at reconstructing the evolutionary history of the magmatic feeding system and at identifying the pre-eruptive events and their associated timescales.

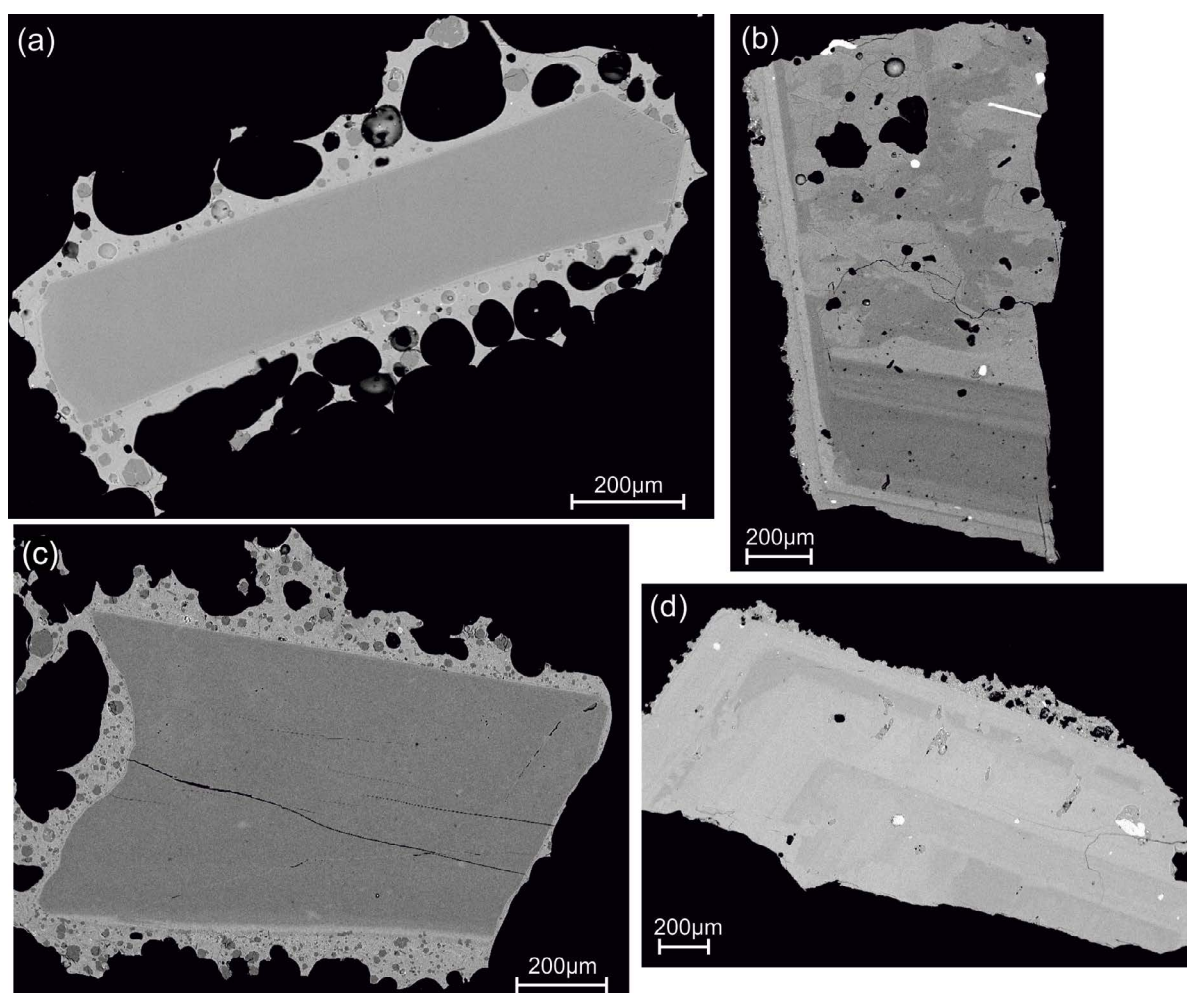


Figure 6 Examples of zoning patterns observed in clinopyroxene crystals from the 1906 CE eruption of Mt. Vesuvius: **a)** unzoned crystal, **b)** patchy core with oscillatory zoning in the outer portion of crystal, **c)** crystal with normal zoning, **d)** crystal with oscillatory zoning.

Clinopyroxene crystals with euhedral habit were selected and separated from the 0Φ, 1Φ and 2Φ fractions from volcanic products belonging to the four erupted units. About 150 crystals

of each eruptive unit were embedded in epoxy resin, ground, and polished. Crystals were observed through a Jeol JXA-iSP-100 electron microprobe (EMP) at the High Pressures-High Temperatures Laboratory of Experimental Volcanology and Geophysics (HPHT Lab) of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome (Italy) and back-scattered images were acquired.

Preliminary observations provide information on the type and amount of zoning patterns. Almost all the crystals result to be zoned (96.7%), whereas unzoned crystals are quite rare (3.3%; Figure 6a). Most of the zoned crystals show patchy zoned cores (86.7%); among these, ~30% of the crystals exhibit complex zoning in the outer bands near the rim (Figure 6b). The other crystals show regular concentric zoning in the form of simple normal (3.3%; Figure 6c) or complex zoning (e.g., oscillatory zoning; 6.7%; Figure 6d).

This preliminary investigation of the zoning patterns indicates a highly complex evolutionary history. Ongoing high-spatial resolution analyses of the chemical composition of the identified different zoning types will allow detailed characterization of the zoning patterns. Together with petrologic modelling, this approach allows reconstructing the set of magmatic variables (e.g. P, T, fO_2 , fH_2O) in which crystals grew, providing insights into the architecture of the plumbing system. Lastly, diffusion models applied to the crystal zoning will provide constraints on the timescales of residence at different magmatic conditions. Future investigations of clinopyroxene zoning, melt and fluid inclusions, experimental petrology, numerical modelling, and historical data on different eruptions (79 CE, 1631 CE) will constrain the plumbing system evolution in terms of multi-scale magmatic processes, providing key insights for volcanic hazard assessment and risk mitigation.

From Spattering to crater collapse: high-frequency monitoring of explosion parameters and morphological changes during Stromboli May 2021 activity

Del Bello E., Zanella G., Civico R., Ricci T., Taddeucci J., Andronico D., Scarlato P.

Based on: Del Bello, E., Zanella, G., Civico, R., Ricci, T., Taddeucci, J., Andronico, D., Cristaldi, A., & Scarlato, P. (2026). High-Frequency Monitoring of Explosion Parameters and Vent Morphology During Stromboli's May 2021 Crater-Collapse Activity Using UAS and Thermal Imagery. *Remote Sensing*, 18(2), 264. <https://doi.org/10.3390/rs18020264>

This research provides an in-depth analysis of the eruptive and structural transformations associated with the north crater-rim collapse at Stromboli volcano on May 19, 2021. By combining high-frequency thermal monitoring with high-resolution Unmanned Aerial System (UAS) photogrammetry, the study quantifies the transition from ordinary activity to a state of structural instability. The findings demonstrate that rapid shifts in explosion styles and vent configurations serve as critical indicators of impending vent failure.

The pre-collapse phase was marked by a significant intensification of activity, including increased explosion frequencies, multi-vent activity, and high-velocity gas-rich “Type 0” explosions. These signals suggest near-surface pressurization by volatile-rich magma within the shallow conduit system. Morphological analysis showed that the specific geometry of the northern craters made the area particularly vulnerable to collapse under these pressurized conditions.

Post-collapse activity shifted toward ash-rich “Type 2b” explosions, which reflects the presence of cooler, stagnant magma near the vent resulting from conduit obstruction and a drop in the magma level. The study also documented the adaptation of the vent system to the new stress fields, with the eventual resumption of original vent configurations once stability was recovered. These results underscore the necessity of moving beyond simple explosion counts in volcano monitoring. By integrating parameters such as ejection speed, duration, and explosion type with topographic surveys, monitoring systems can significantly improve hazard assessments for basaltic open-vent volcanoes (Figure 7).

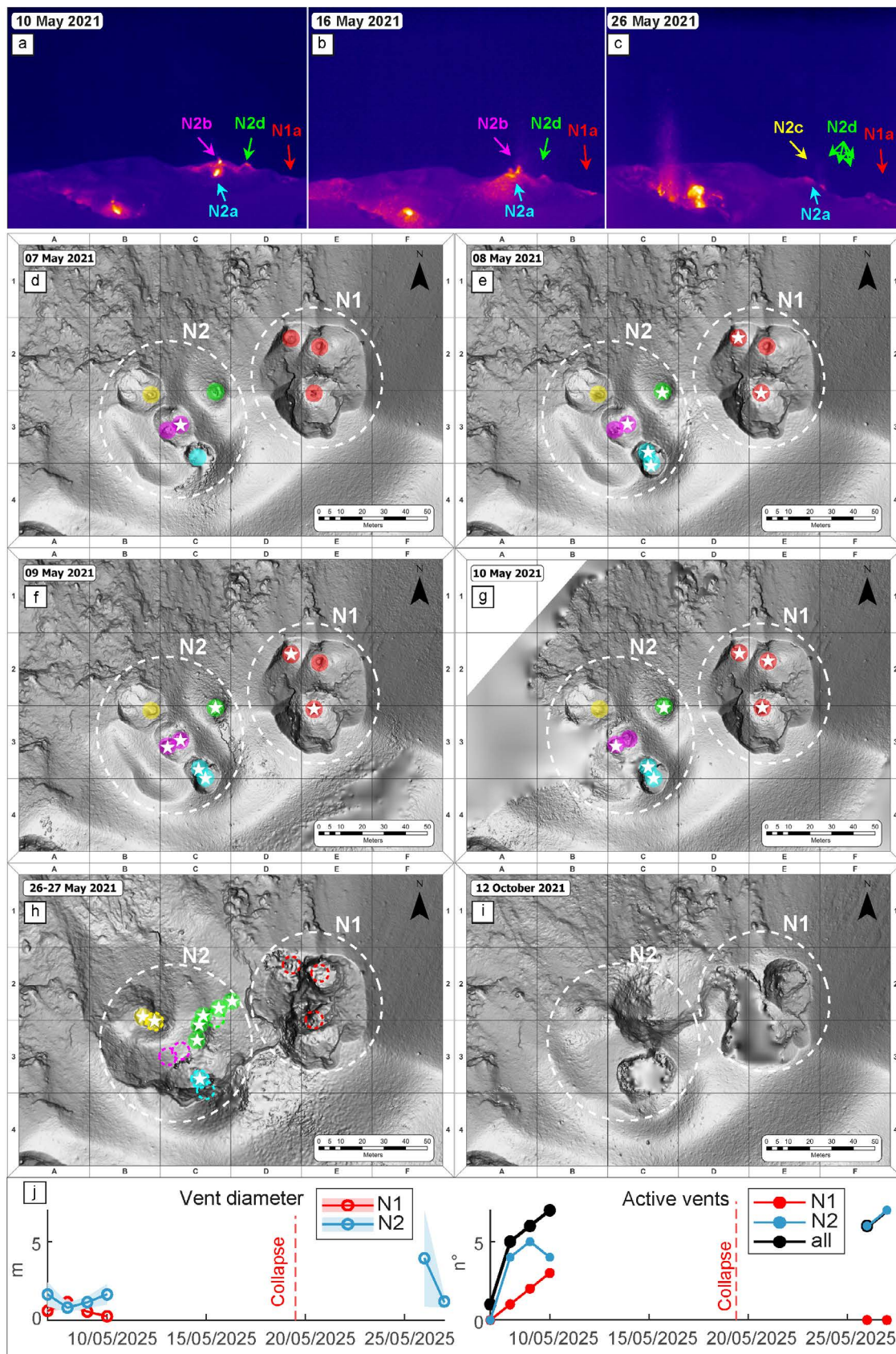


Figure 7 Topographic evolution and structural failure of the North Crater area. This figure integrates high-resolution Digital Elevation Models (DEMs) and Orthomosaics to map the morphological impact of the May 2021 event. The analysis quantifies the volume of the collapsed crater rim and documents the rapid reconfiguration of the vent floor, illustrating the dynamic link between shallow conduit processes and large-scale surface instability.

A cross-comparison of thermal infrared versus ultraviolet ground-based retrieval of SO₂ masses during Strombolian explosions

Del Bello E., Bagnato E., Guerrieri L., Tamburello G., Corradini S., Merucci L., Pennacchia F., Scarlato P., Stelitano D., Taddeucci J.

Based on: Del Bello, E., Bagnato, E., Guerrieri, L., Tamburello, G., Corradini, S., Merucci, L., Pennacchia, F., Scarlato, P., Stelitano, D., & Taddeucci, J. (2025). A cross-comparison of thermal infrared versus ultraviolet ground-based retrievals of SO₂ masses during Strombolian explosions. *Volcanica*, 8(2), 583-599. <https://doi.org/10.30909/VOL/SGIC1814>

This study presents a systematic cross-comparison between ground-based ultraviolet (UV) and thermal infrared (TIR) camera systems for the quantification of sulfur dioxide (SO₂) mass during both passive degassing and explosive activity at Stromboli volcano. Using a synchronized multi-sensor setup, the research evaluates the performance of a novel, low-cost TIR system (VIRSO₂) against established UV camera methodologies. The dataset includes 49 Strombolian explosions categorized by their ash and ballistic content (Type 0, 1, 2a, and 2b), providing a robust framework for assessing instrumental response under varying eruptive conditions.

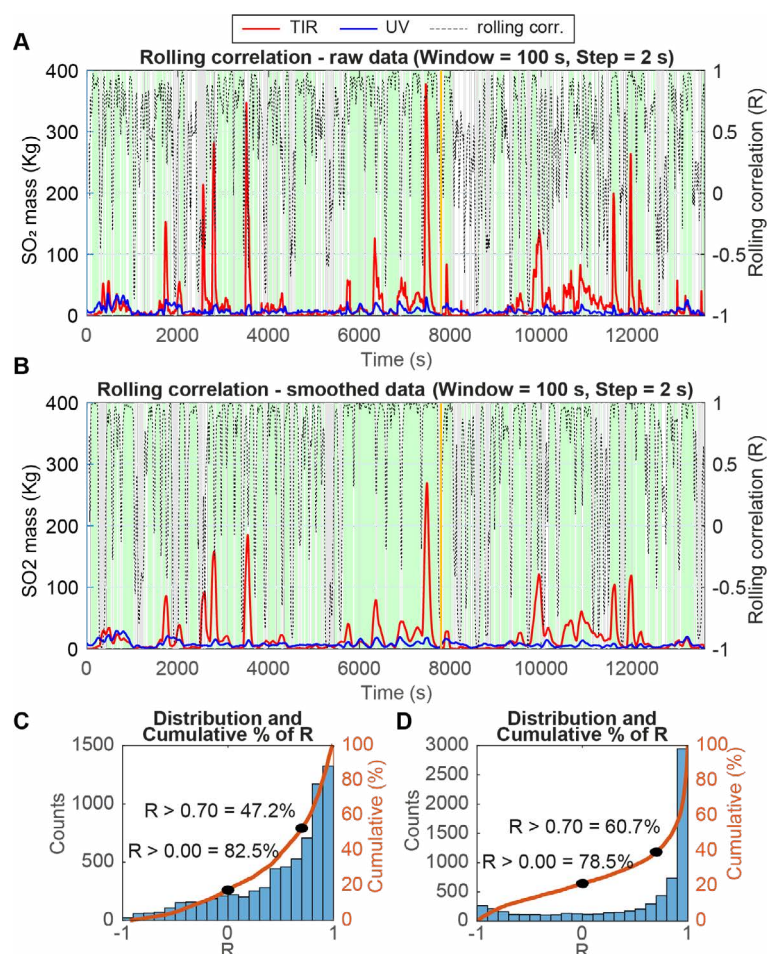


Figure 8 Signal coherence and temporal correlation between UV and TIR sensors. This figure illustrates the time-series comparison of SO₂ mass retrievals and their rolling Pearson correlation. The high degree of coherence during stable degassing phases validates the consistency of both methods, while the fluctuations during explosive intervals highlight the divergent sensitivities of the two sensors to plume temperature and particulate matter.

The results indicate that while UV and TIR retrievals are highly comparable during periods of quiescent, passive degassing, significant discrepancies emerge during explosive events. Specifically, the TIR technique exhibits a systematic overestimation of SO₂ mass (up to an order of magnitude) during ash-rich and high-temperature explosions. This bias is primarily attributed to spectral interference from volcanic ash and thermal radiation from incandescent blocks, which the current TIR retrieval algorithms interpret as additional gas. Conversely, UV retrievals remain temperature-independent but can suffer from signal attenuation in optically thick, ash-laden plumes, though this study demonstrates that such effects can be mitigated through high-frequency temporal picking.

The study concludes that integrated multi-sensor monitoring is essential for accurate volcanic gas assessments. While UV cameras remain the most reliable tool for capturing high-frequency explosive pulses during daylight, the TIR system offers unique potential for continuous 24/7 monitoring. However, the findings emphasize that further development of TIR retrieval models-incorporating temperature and ash corrections-is required to achieve reliable quantification during the intense phases of basaltic eruptions (Figure 8).

The oxidation of Fe in riebeckite at 0.7 GPa

Della Ventura G., Oberti R., Misiti V., Radica F., Redhammer G.J., Bernardini S., Boiocchi M., Mihailova B.

Based on: Della Ventura, G., Oberti, R., Misiti, V., Radica, F., Redhammer, G.J., Bernardini, S., Boiocchi, M., Mihailova, B. (2025). The oxidation of Fe in riebeckite at 0.7 GPa. *European Journal of Mineralogy* 37, 535-547. <https://doi.org/10.5194/ejm-37-535-2025>.

At high temperatures riebeckite, ideally $\text{Na}_2(\text{Fe}^{2+}_3\text{Fe}^{3+}_2)\text{Si}_8\text{O}_{22}(\text{OH})_2$, undergoes significant crystal-chemical rearrangement in response to the reaction: $\text{Fe}^{2+} + \text{OH}^- \rightarrow \text{Fe}^{3+} + \text{O}^{2-} + \text{e}^- + \text{H}^+$, leading to the development of charge carriers (hopping electrons and delocalized H^+ ions) and to the release of H_2O . The process of oxidation of Fe and dehydrogenation has thus important implications for planetary-scale phenomena, including electrical conductivity, water cycling, seismicity, volcanism, and ore generation, particularly in subduction zones.

In this work, we addressed the effect of pressure on the oxidation of Fe in riebeckite, a process that is irreversible for temperatures above $\sim 377^\circ\text{C}$ at 1 atm pressure, under oxidizing conditions. Single crystals of riebeckite were annealed using a piston-cylinder apparatus (at INGV, Rome) at temperatures in the $600\text{--}750^\circ\text{C}$ range under a constant pressure of 0.7 GPa and f_{O_2} close to NNO. The crystal-chemical response of the amphibole to these P-T- f_{O_2} conditions was analyzed using a combination of X-ray diffraction and spectroscopic methods, including Mössbauer, Raman, and Fourier Transform Infrared (FTIR) spectroscopy.

We found that at 0.7 GPa there is no oxidation of Fe in riebeckite (Figure 9). The stability of the amphibole structure extends at least up to 750°C , without any transition to oxo-riebeckite and hence without any release of H^+ . Since the conditions of our experiments replicate those of rocks at pressures corresponding to ~ 25 km depth, our findings further support the concept that thermally activated electron hopping significantly contributes to the electrical conductivity of lithospheric rocks, and suggest that both conductivity and water cycling in the Earth interior may be active over a broader P-T range (and thus at greater depths) than previously considered.

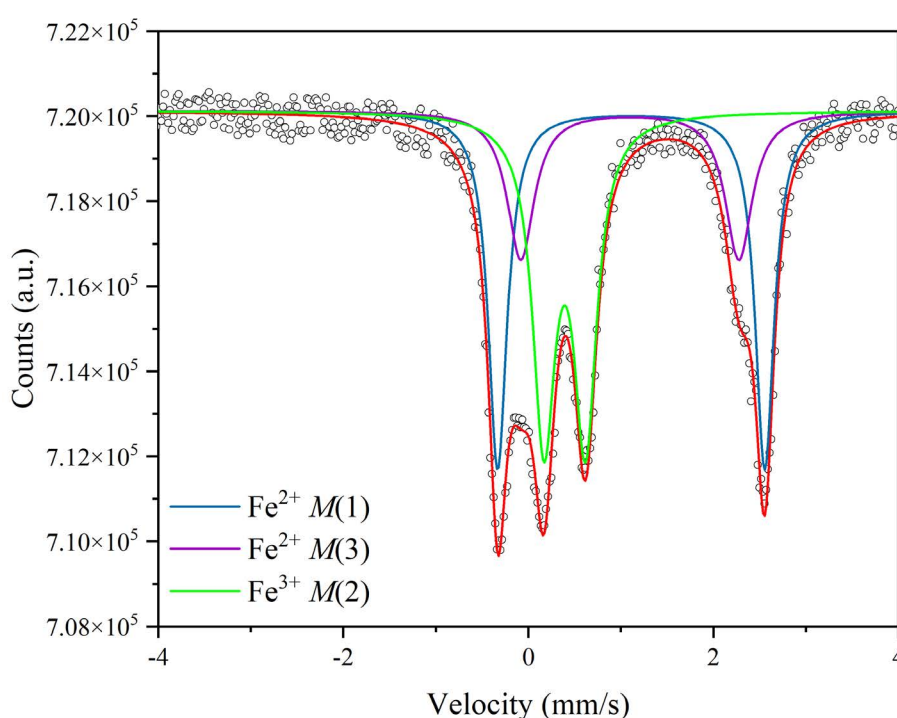


Figure 9 Fitted ^{57}Fe Mössbauer spectrum of riebeckite RHP7 annealed at 750°C and 0.7 GPa.

Impact of Cooling Rate on Rheology and Emplacement Dynamics of Basaltic Lavas: Insights from the January 2024 Sundhnúksíggar Eruption (Iceland)

Di Fiore F., Vona A., Di Genova D., Caracciolo A., Pontesilli A., Calabrò L., Giuliani G., Mollo S., Bondar D., Nazzari M., Romano C., Scarlato P.

Based on: Di Fiore, F., Vona, A., di Genova, D., Caracciolo, A., Pontesilli, A., Calabrò, L., Giuliani, G., Mollo, S., Bondar, D., Nazzari, M., Romano, C., & Scarlato, P. (2025). Impact of cooling rate on rheology and emplacement dynamics of basaltic lavas: Insights from the January 2024 Sundhnúksíggar eruption (Iceland). *Journal of Volcanology and Geothermal Research*, 466, 108400. <https://doi.org/10.1016/j.jvolgeores.2025.108400>

The 2023-2024 eruptions at Sundhnúksíggar in Iceland produced tholeiitic basaltic lavas that traveled at high velocities, affecting vast areas. In this context, disequilibrium crystallization can play a fundamental role in modulating the lava flow dynamic and inundation capacity.

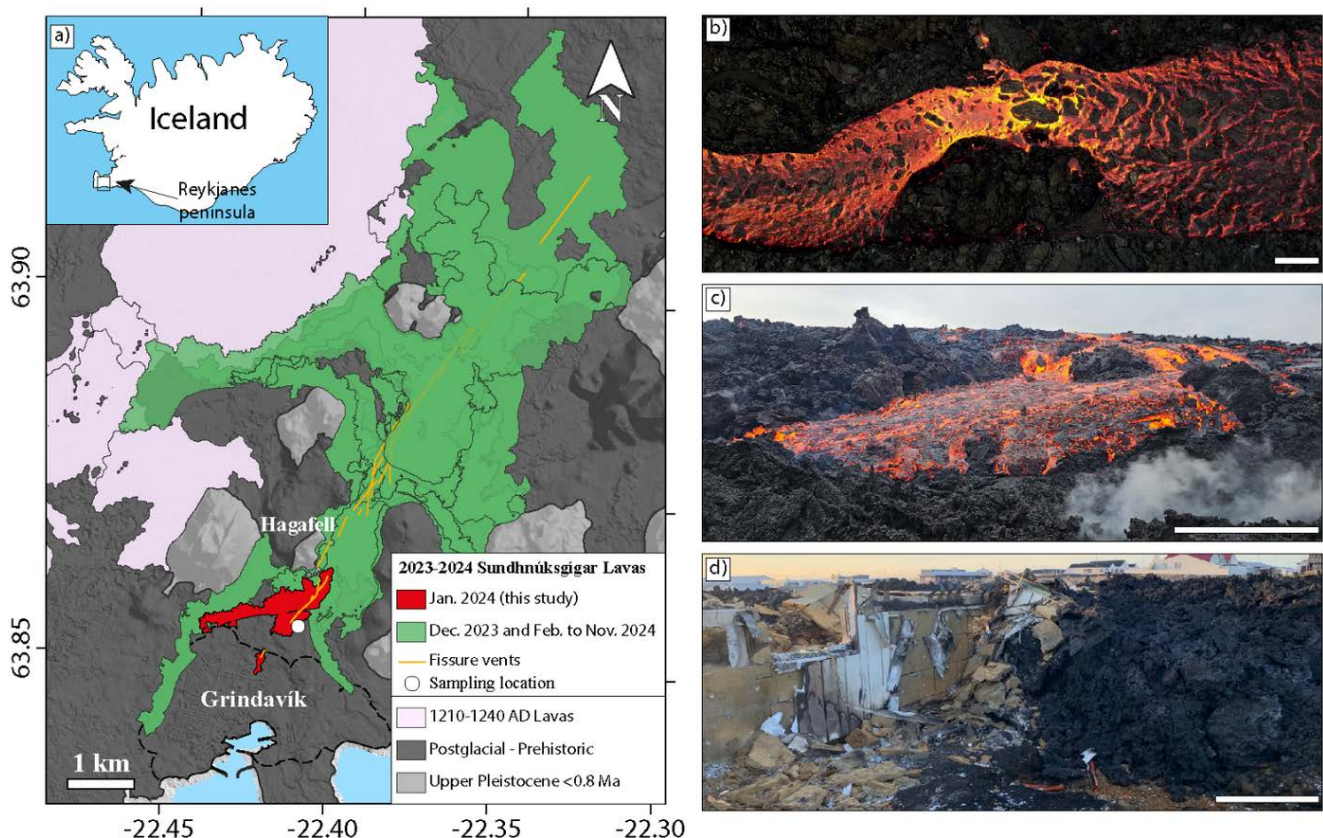


Figure 10 a) Geological features of the area affected by the 2023-2024 eruptions at Sundhnúksíggar, near the town of Grindavík (black dashed outline). The inset map shows the location of the Reykjanes Peninsula within Iceland. Geological data are from Landmælingar Íslands geoserver (gis.lmi.is/geoserver). b) and c) Photos of pahoehoe lava outbreaks, where the formation of the external crust during flow can be observed. In particular, in c), both slabby/shelly and roofoxy external crusts on the lava flow surface can be seen, which are typical features of the transition from pahoehoe to 'a'ā flow (photos by A. Caracciolo). d) Photo of a solidified lava flow reaching a house in Grindavík town. In this case, the surface is characterized by a roofoxy crust and the formation of cauliflower structures, typical of 'a'ā flow (photo by S. A. Halldórsson). All scale bars correspond to 1 meter.

To investigate this phenomenon, we performed a comprehensive rheological characterization of the Sundhnúksgígar basalt, analyzing both the liquid phase and crystal-bearing suspensions under disequilibrium conditions (cooling rates ranging from 0.1 to 10 °C/min) and near-equilibrium conditions (at fixed temperatures between 1242 and 1180 °C). Our results show that the cooling rate critically influences the extent and timescale of disequilibrium crystallization, thereby shaping the rheological evolution of the melt, leading to distinct deformation response of the crystal-bearing magmatic suspension. Compared to other basalts erupted worldwide, the Sundhnúksgígar melt exhibits two main features: i) an exceptionally low rate of viscosity increase induced by crystallization and ii) the ability to crystallize even at the highest cooling rates applied during the experiments. These characteristics may contribute to enhancing the efficiency of external crust formation, limiting heat loss from the inner portion of the lava flow, which consequently cools more slowly. This thermal insulation effect reduces the rate of viscosity increase during lava emplacement, a key factor in determining lava flow inundation potential. Our findings underscore the critical role of disequilibrium crystallization in governing the rheological evolution and emplacement dynamics of basaltic lavas, offering new insights into lava flow behavior (Figure 10).

The importance of 4.3-ka Accademia explosive-effusive eruption in the ongoing volcanic unrest at Campi Flegrei, southern Italy

Ebrahimi P., Morgavi D., Natale J., Arzilli F., Di Fiore F., Laumonier M., Petrosino P.

Presented at the RETURN Final Meeting, Napoli, 3-5 December 2025

Assessing Campi Flegrei volcanic hazard is critical for emergency planning, but difficult due to the limited understanding of the uncertain link between the ongoing unrest and magma ascent through the crust, as well as the conditions and processes controlling the explosive-effusive phase transition. Studying the shift from explosive to effusive eruption in the 4.3-ka Accademia activity helps fill this knowledge gap, as the onset of a local geodetic anomaly around Accademia since 2021 may be a signal of volcanic reawakening in this area. We collected field data and representative scoria and lava samples. Bulk composition was determined via ICP-OES while texture, minerals and glass were characterized by investigating thin sections using optical microscopy, SEM-EDS and EMPA. Field observations revealed that porous light brownish, dark grayish and reddish (units A to C, respectively) scoria layers are covered with dense light grayish lava (unit D). The deposits are trachytic (3 wt.% H₂O) with a glassy matrix in units A and C and a crystalline matrix in units B and D. Mafic magma recharge events are characterized by the following petrological evidence: (1) the presence of Ca-bearing plagioclase and Mg-bearing clinopyroxene phases that could not be in equilibrium with trachyte; and (2) the decreasing orthoclase content in K-feldspar and increasing/oscillating Mg# in clinopyroxene from core to rim. The estimated pre-eruptive pressures show that mafic magma batches from a deep reservoir at a depth of 8-10 km (200-250 MPa) intruded into a trachytic magma reservoir at 6-8 km depth (150-200 MPa) and triggered a relatively fast magma ascent (regarding the observed euhedral to subhedral micas) with pre-eruptive temperatures of 950-980°C. In unit A, the glassy groundmass and bomb-sized lithics in the scoria layer highlight magma-water interactions and conduit opening in a phreatomagmatic activity. A slower ascent rate then resulted in stalling magma at a shallow depth, crystallization of unit B groundmass and a shift from a phreatomagmatic to a purely magmatic eruption. The above-mentioned phreatomagmatic and magmatic events repeated several times and emplaced units A to C.

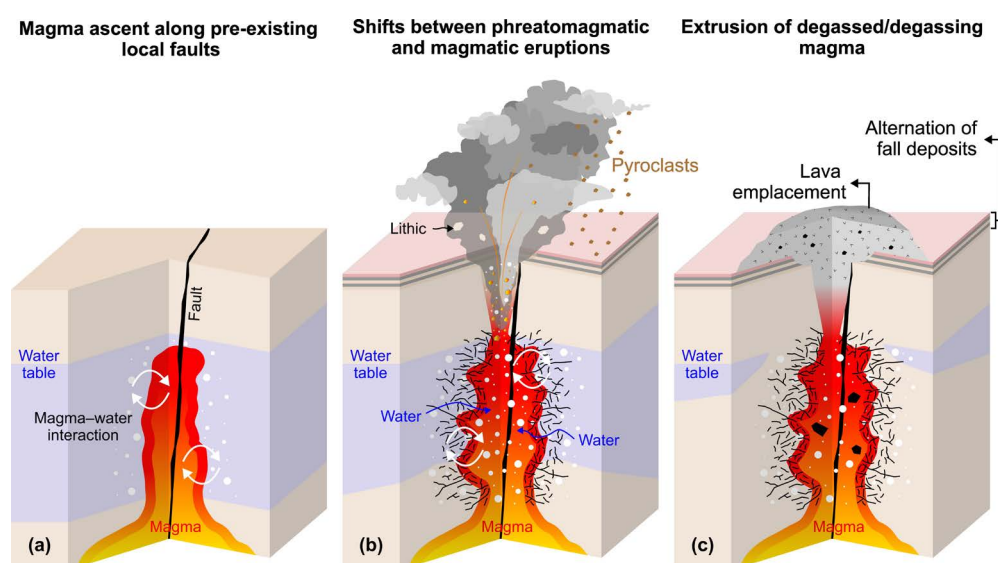


Figure 11 Conceptual model of Accademia eruption.

The viscous trachytic lava (unit D) with pre-eruptive temperatures above 980°C finally extruded and emplaced on the explosive deposits. The estimations indicated emplacement of $\geq 14 \text{ Mm}^3$ (bulk volume) of lava during the effusive phase of eruption. However, the available data do not allow a representative estimation of the magma volume erupted explosively. Comparing the estimated thickness of lava (up to ~150 m) with the observed thickness of scoria layers (up to ~15 m) highlights that the non-explosive phase of activity poses the main hazard to the locals, which needs to be taken into account for emergency planning (Figure 11).

Earth degassing in seismic and volcanic regions: How do mantle fluids move to the atmosphere?

Italiano L., Caracausi A., Nazzari M., Rotolo S.G.

Currently under review on Scientific Reports /Original contribution prepared for the HPHT Lab Annual Report 2025

The study of the petrological and geochemical heterogeneity of the continental and oceanic mantle remains a central topic in Earth Sciences, as it is fundamental to understanding the evolution of our planet over geological time. Mantle products preserve geochemical traces of the Earth's primordial state, as well as imprints of geodynamic cycles. Processes such as subduction enrich the mantle with fluids of crustal and atmospheric origin, creating a continuous recycling cycle that has fundamentally influenced the evolution of the atmosphere and the conditions necessary for life.

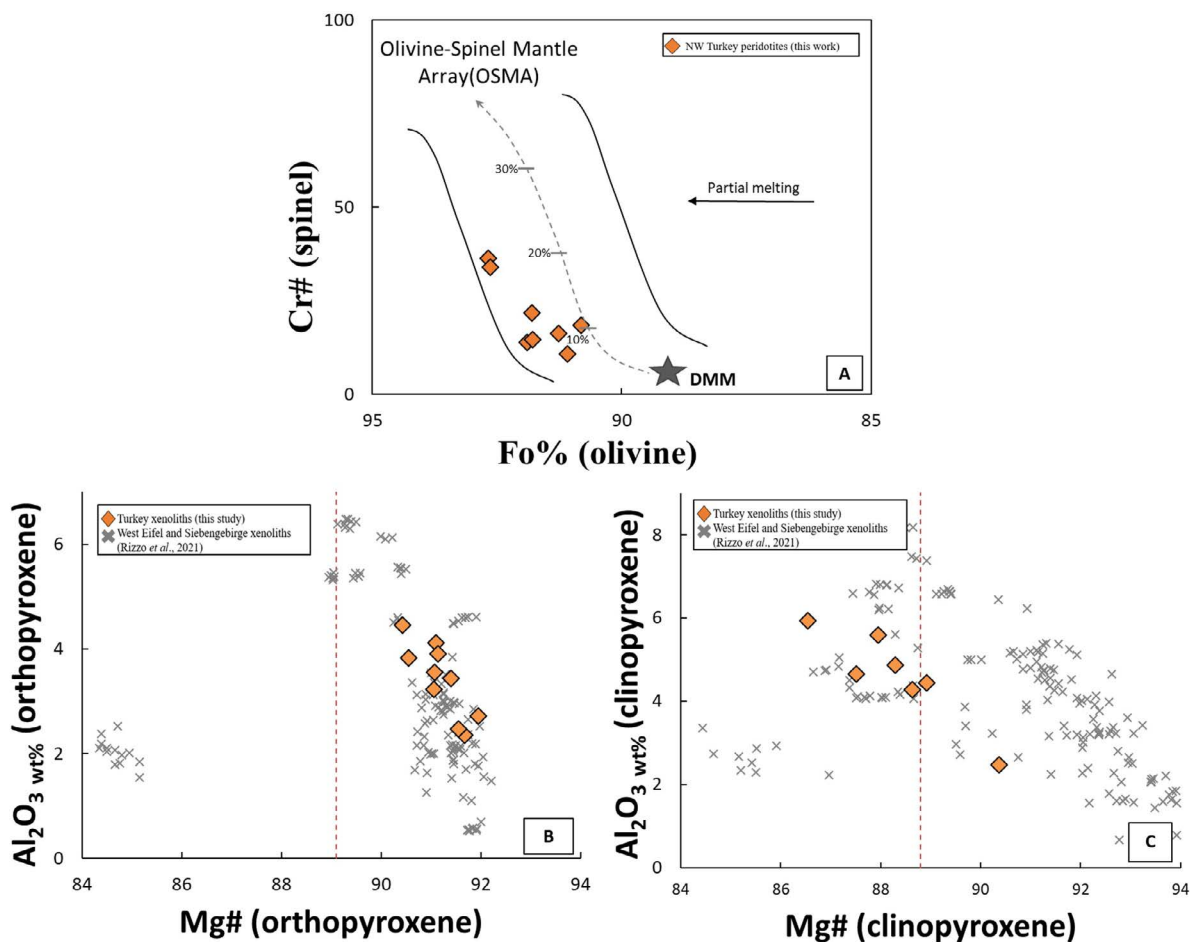


Figure 12 Chemical composition of olivine, clinopyroxene and spinel from lherzolites and harzburgites from Turkey. **a)** Samples showed medium-high partial melting, as evidenced by Fo_{91-93} . **b)** Mg# versus Al₂O₃ wt% in orthopyroxene and **c)** in clinopyroxene. Dashed vertical line represents the Mg# thresholds used to discriminate between cumulates and mantle minerals.

This project aims to explore the origins of such heterogeneity by analysing Mid-Ocean Ridge Basalt (MORB) products, such as oceanic glasses, together with continental mantle xenoliths. These materials serve as primary indicators of mantle sources and the complex processes,

including subduction and deep mantle plume dynamics, that drive differentiation on a global and temporal scale. Since mantle-derived melts allow the transfer of volatiles from the mantle to the crust and finally to the atmosphere, studying their original composition is essential for understanding the mechanisms that control the Earth's volatile budget across different geospheres.

The research focuses in particular on ten samples of mantle xenoliths from Turkey, including lherzolites and harzburgites, and on five samples of glass from the Mid-Atlantic Ridge, the Indian Ocean and the East Pacific Ridge. A complete microanalytical study using Electron Probe Micro-Analysis (EMPA) was necessary to accurately characterize the Turkey xenoliths and the various MORB glasses. The mineral major element chemical composition of olivine, orthopyroxene, clinopyroxene and spinel from mantle xenoliths was determined. For each sample, two grains from each phase were analysed, at rim and at core. For the MORB glass samples, compositional transects were carried out, for a total of about 200 data points analysed for this research. The results of the analyses on the xenoliths from Turkey, shown in Figure 12, reveal the presence of Mg-rich olivine (Fo_{91-92}), high MgO values in orthopyroxene ($\text{Mg\#} = 0.90-0.92$) and clinopyroxene ($\text{Mg\#} = 0.86-0.91$). No compositional differences were observed within the minerals from the rim and core analyses, making it possible to treat the data as compositionally homogeneous minerals.

In addition, the results obtained from these chemical analyses will be compared and integrated with the data from noble gas isotopes, trace element concentrations, and oxygen fugacity measurements. These comprehensive results (as well as those from MORB glasses) are currently in the processing and elaboration stage, and they will provide the necessary data to understand how mantle fluids migrate to the surface and how natural events, such as volcanic eruptions and earthquakes, regulate the chemical exchange between the Earth's deep interior and its atmosphere (Figure 12).

Switch on tunnel vision: portable wind tunnels to understand and quantify Aeolian processes

Marzen M.B., Akshalov K., Asensio Grima C., Avecilla F., Buschiazzi D.E., Colazo, J.C., Del Bello E., Engelmann L., Etyemezian V., Fischella M.R., Fister W., Funk R., Iserloh T., Katra I., Koza M., Merrison J., Okin G., Rezaei M., Ries J.B., Schmid, G., Taddeucci J., Tan L., Van Pelt R. S.

Based on: Marzen, M.B., Akshalov, K., Grima, C.M.A., Avecilla, F., Buschiazzi, D., Colazo, J.C., del Bello, E., Engelmann, L., Etyemezian, V., Fischella, M.R., Fister, W., Funk, R., Iserloh, T., Katra, I., Koza, M., Merrison, J., Okin, G., Rezaei, M., Ries, J.B., ... van Pelt, R.S. (2026). Switch on tunnel vision: Portable wind tunnels to understand and quantify aeolian processes. *Earth-Science Reviews*, 105396. <https://doi.org/10.1016/J.EARSCIREV.2026.105396>

This comprehensive review explores the evolution, design, and scientific impact of Portable Wind Tunnels (PWTs) in aeolian research. Aeolian processes—the transport and redistribution of sediment by wind—are fundamental geomorphological agents that shape landscapes and influence global biogeochemical cycles. While stationary laboratory tunnels provide controlled environments, PWTs allow researchers to conduct experiments directly *in situ*, preserving the delicate and complex structures of natural soil surfaces, such as physical and biological crusts, which are nearly impossible to replicate in a laboratory setting.



Figure 13 Aerodynamic configurations and velocity profiles in portable tunnels. This figure illustrates the technical differences between the suction and blowing systems used in *in situ* experiments. The plots highlight the development of the boundary layer within the tunnel, which is crucial for ensuring that wind simulations accurately reflect natural conditions and for precisely determining the sediment detachment threshold across different soil types.

The study categorizes PWTs into two main design philosophies: “push-type” (blowing) and “suction-type” (suction) tunnels, evaluating their respective aerodynamic properties and boundary layer similarities. A significant portion of the work is dedicated to the integration of advanced sensors and devices, such as the PI-SWERL® (Portable In Situ Wind Erosion Laboratory), which has revolutionized the ability to quantify dust emissions and erodibility on supply-limited surfaces. By synthesizing decades of field experiments across diverse environments—from the semi-arid steppes of Kazakhstan to the agricultural lands of the Mediterranean—the authors demonstrate how PWT data is essential for determining threshold wind velocities and validating global dust emission models.

Ultimately, the research advocates for “tunnel vision” as a necessary perspective for Earth science. By providing a bridge between plot-scale observations and regional-scale modeling, portable wind tunnels remain an indispensable tool for understanding how land management, climate change, and surface characteristics dictate the intensity of wind erosion and its subsequent environmental and socio-economic impacts (Figure 13).

Structural and thermobarometric evolution of the Ligurian Accretionary Complex in Cilento (southern Apennines, Italy)

Mehmood M., Vitale S., Cavalcante F., Di Fiore F., Ciarcia S., Cucinello C.

Original contribution prepared for the HPHT Lab Annual Report 2025

This study examines the tectonic, deformational, and metamorphic evolution of oceanic orogenic prism of the Ligurian Accretionary Complex (LAC) in the southern Apennines. The LAC exhibits a complex polyphase deformation history, marked by the superposition of three-fold sets, associated with thrust faults and ductile shear zones. Thermal analyses based on the Kübler Index (KI) and Raman spectroscopy reveal peak conditions of approximately 250-280 °C. Chlorite and white mica petrology analysis indicates same temperature range and pressures of 0.3-0.4 GPa, corresponding to burial depths of 11-15 km and resulting geothermal gradient of 17-25 °C/km. Kinematic Vorticity and strain analyses indicate a dominant simple shear with an oblate strain. The integration of structural, petrographic, and geothermometric data provides new insights into the thermobaric evolution and deformation mechanisms operating within the LAC. These results contribute to a refined understanding of accretionary wedge formation and tectono-metamorphic processes along active plate margins. Moreover, the findings offer a valuable framework for interpreting the interplay among fluid migration and shear zone dynamics during orogenesis, and they can serve as a comparative model for reconstructing regional tectonic histories in other convergent settings (Figure 14).

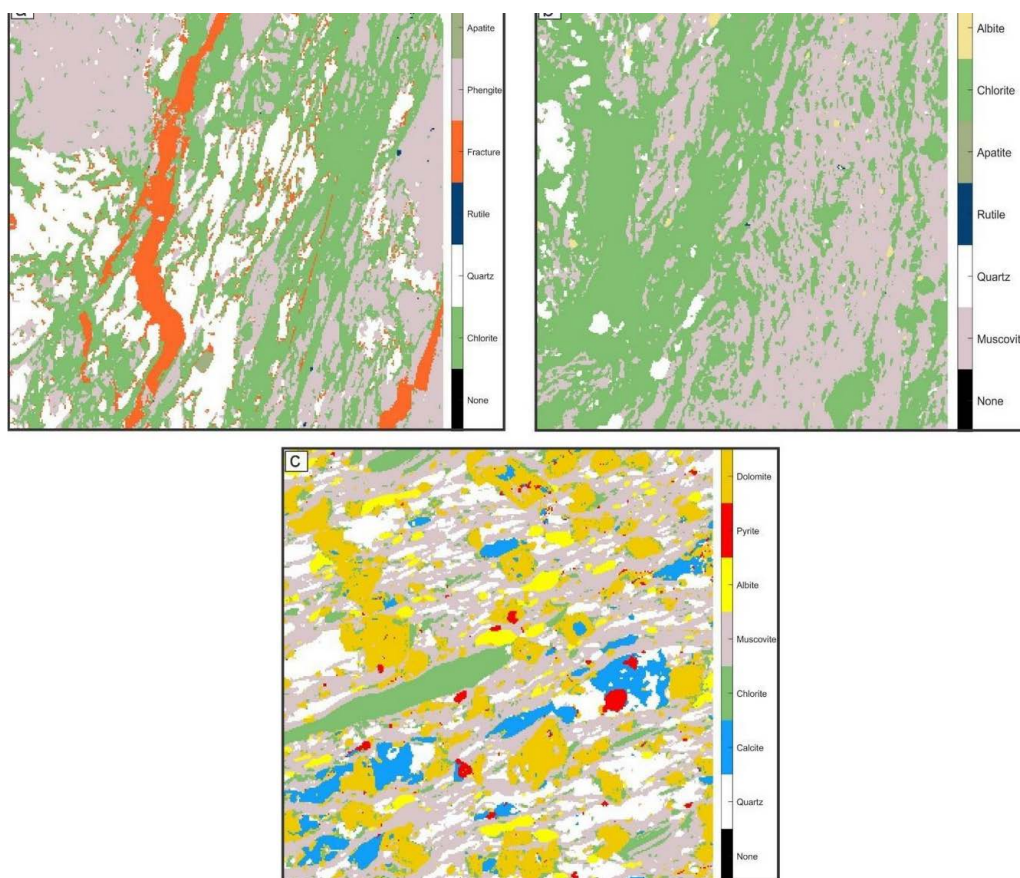


Figure 14 EPMA-mineral chemistry based mineral phase maps for three locations **a)** Pioppi; **b)** Punta Telegrafo; **c)** Caprioli. The dominant mineral phases include phengite, muscovite and chlorite. The white mica-chlorite thermobarometer indicator shows temperature and pressure range approximately 250-280°C and 0.3-0.4 GPa.

Are large effusive eruptions produced by magma accumulation within shallow crustal reservoirs or fed from deeper reservoirs close to the mantle? Insights from Sabatini volcanic system

Morganti L., Arzilli F., Morgavi D., Masotta M., Di Fiore F., Bamber E.C., Frontoni A., Pontesilli A., Polacci M., Conticelli S., Carroll M.R., Giordano G.

Original contribution prepared for the HPHT Lab Annual Report 2025

The current paradigm of trans-crustal magmatic systems describes volcanic complexes as open, vertically extensive structures in which *crystal mush* dynamics regulate the accumulation of eruptible magma over variable timescales, ranging from millennia to decades. Within this framework, the Sabatini Volcanic District (SVD) represents a key case study for investigating the evolution of ultrapotassic magmas in open systems operating at low pressure ($P < 0.5$ GPa) and high temperature ($T > 1100$ °C), affected by magma recharge and assimilation-fractional crystallization processes. However, uncertainties regarding the present configuration of these reservoirs limit the ability to forecast reliable eruptive scenarios, constituting a major challenge for volcanic hazard assessment in densely populated regions.

The recent geological history of the SVD (ca. 600-70 ka) is characterized by the alternation of highly explosive caldera-forming events and less energetic effusive phases. This study focuses on the analysis of the products of a voluminous lava flow (estimated volume of ~ 1 km³) emplaced in the southern sector of Bracciano Lake between 341 ka and 320 ka. This unit reflects an effusive phase that impacted an area of 90-100 km² with thicknesses of several tens of meters, preceding the final caldera collapse in the region.

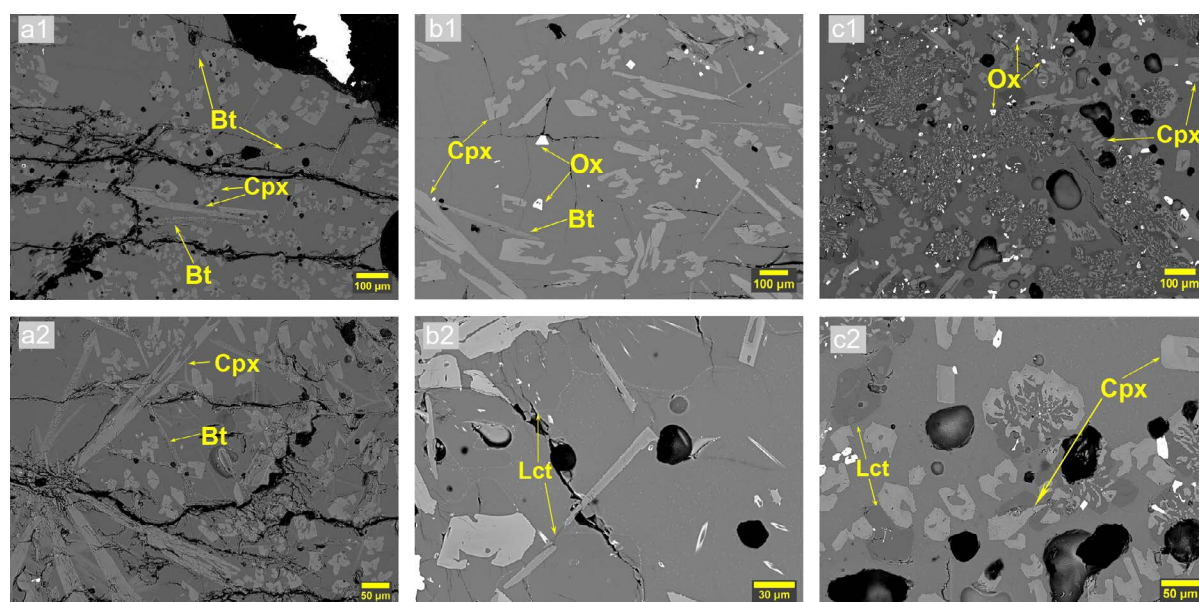


Figure 15 Comparison of EMPA images obtained on experimental samples at 600 MPa (a1, a2), 300 MPa (b1, b2), and 150 MPa (c1, c2). The absence of biotite in the sample produced at 150 MPa provides constraints on the depth of the reservoir that fed the eruption.

Petrological investigations, including chemical and textural analyses, were used to constrain pre-eruptive and syn-eruptive thermodynamic conditions. Micro-analytical characterization was carried out using scanning electron microscopy (SEM) and electron microprobe analysis

(EMPA). Concurrently, experimental petrology runs were conducted at different pressures (600 MPa, 300 MPa, and 150 MPa) at a constant temperature of 1150 °C in the laboratories of the University of Pisa. Comparison between experimental and natural mineral assemblages allowed a robust estimate of the magma reservoir storage depth.

This work aims to contribute to the understanding of magma feeding and transfer processes within trans-crustal systems by proposing a petrogenetic model capable of discriminating mantle-derived signatures from modifications acquired during crustal transit (Figure 15).

Reconstructing the volcanic history of the Ulukışla Caldera: A collapse structure within the Hasandağ Volcanic Complex, Central Anatolia (Turkey)

Özsoy R., Sunyé-Puchol I., Bolós X., Akkaş E., Costa A., Tavazzani L., Miggins D.P., Nazzari M., Bachmann O., Scarlato P., Mollo S.

Based on: Özsoy, R., Sunyé-Puchol, I., Bolos, X., Akkaş, E., Costa, A., Tavazzani, L., Miggins, D.P., Nazzari, M., Bachmann, O., Scarlato, P., Kaya, S., Mollo, S. (2025). Reconstructing the volcanic history of the Ulukışla Caldera: A collapse structure within the Hasandag Volcanic Complex, Central Anatolia (Turkey). *Journal of Volcanology and Geothermal Research*, 463, 108345. <https://doi.org/10.1016/j.jvolgeores.2025.108345>.

The Ulukışla Caldera is a collapse structure within the active Hasandağ Volcanic Complex (Central Anatolia), situated along the southern branch of the Tuz Gölü Fault Zone (TGFZ). This study aims to reconstruct the volcanic history of the Ulukışla Caldera by characterising its associated pyroclastic deposits using tephrostratigraphy, glass chemistry (major and trace elements), and geochronological data ($^{40}\text{Ar}/^{39}\text{Ar}$ and U-(Th)-Pb). Our findings reveal that the Ulukışla Caldera has undergone at least three major explosive rhyolitic eruptions, which formed the pyroclastic deposits of the Yenipınar Eruption (~442 ka), the Belbaşhanı Eruption (~400 ka), and the Ulukışla Eruption (~326 ka). The Yenipınar units were produced by an unsteady eruption column originating from paleo-Ulukışla volcanic structure, that deposited pumice fallout layers and interbedded pyroclastic density current (PDC) deposits. The Belbaşhanı Eruption began with a Plinian column that deposited the Belbaşhanı Pumice fallout. This phase was followed by the emplacement of thick PDC deposits and co-ignimbrite lithic lag breccias during the collapse, which ultimately led to the formation of the Ulukışla Caldera. The volume of this eruption, including the caldera-forming ignimbrite, could reach up to 10 km³ DRE, corresponding to a magnitude of ~6. The Ulukışla Pumice resulted from a post-caldera eruption, which did not generate PDCs. The Ulukışla Caldera exhibits an elongated morphology, which is strongly influenced by the NW-SE alignment of the TGFZ. Based on this morphology and the regional tectonic setting, we conclude that the Ulukışla Caldera is a strike-slip/graben caldera. Reconstructing the volcanic history of this newly identified caldera is essential for enhancing our understanding of the Hasandağ Volcanic Complex. Our findings offer valuable context for future eruptive behaviour, improving the hazards assessment for potential caldera collapses, and contributing to mitigating associated risks (Figure 16).

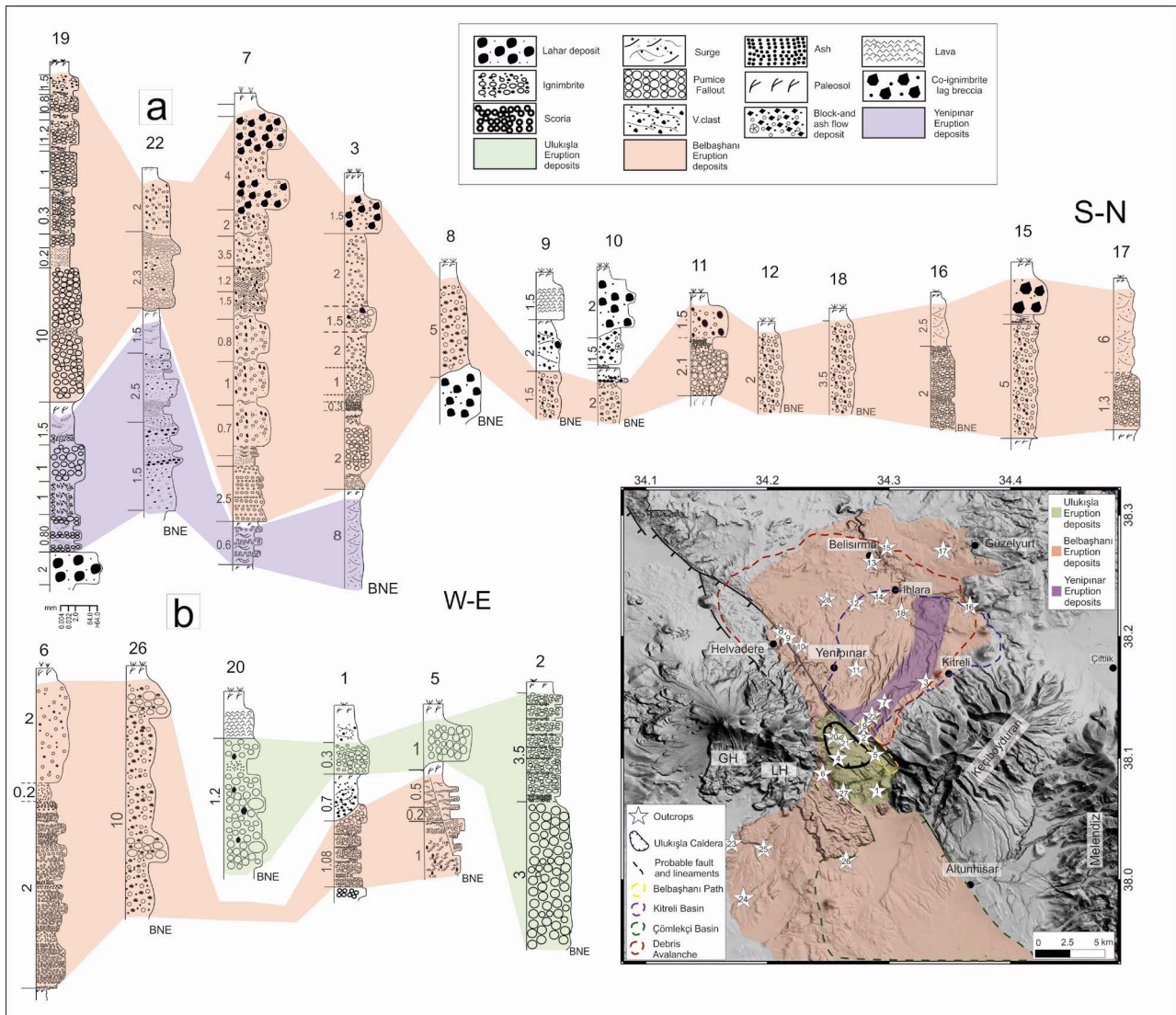


Figure 16 Stratigraphic correlations of the three Ulukışla Caldera eruption deposits: the 1) Yenipinar, 2) Belbaşhani, and 3) Ulukışla Eruptions. **a)** Representative logs from the Belbaşhani Quarry (location 19) along the Kitreli Basin (~S-N profile). **b)** Representative logs from the Shepherd Trench (location 6) to the old Belbaşhani Quarry (~W-E profile). The inset map shows the geographic locations of the stratigraphic logs. BNE, base not exposed.

Pre-eruptive magmatic processes of the Pomici Principali Plinian eruption (Campi Flegrei caldera, Italy): constraints from mineral chemistry

Pelullo C., Arienzo I., Sparice D., Nazzari M., D'Antonio M.

Original contribution prepared for the HPHT Lab Annual Report 2025

In the framework of the INGV-SMEEGOL project, new stratigraphic, geochemical and petrological investigations allowed us to investigate pre-eruptive magmatic processes of the Pomici Principali eruption (11,915-12,158 cal. yrs BP), one of the highest-magnitude eruptions of the Campi Flegrei caldera (South Italy) over the past 15 ka. The eruption deposit comprises five members, ranging from a basal phreatomagmatic ash (Member A) to Plinian fallouts (Members B-D), and phreatomagmatic ash surges (Member E).

The products from the whole sequence were investigated through chemical (major and trace elements) and isotopic (Sr and Nd) analyses. Mineral chemistry was carried out at the HPHT Laboratory of Experimental Volcanology and Geophysics of the Istituto Nazionale di Geofisica e Vulcanologia in Rome (Italy), using a Jeol-JXA-iSP100 electron microprobe.

A key feature of the main mineral phases is the systematic occurrence of two distinct groups, reflected by the clinopyroxenes and plagioclases chemical and isotopic compositions (Figure 17a,b). Notably, clinopyroxenes with high Mg# Plagioclases with high Sr-Ba contents, the latter belonging only to the last erupted members (layers D5 to E3; Figure 17a,b), also show chemical and isotopic disequilibrium with their whole rocks and glasses.

Overall, the bimodal mineral chemistry and the detected mineral-melt disequilibria suggest that crystals with high An, Ba, Sr and Mg contents and low $^{87}\text{Sr}/^{86}\text{Sr}$, not in equilibrium with their melt, have been inherited (e.g., they are antecrysts) from magmas feeding the volcanic activity before the Pomici Principali event and/or reflect the interaction of mafic magma(s) with an evolved magma or a crystal mush before the eruption.

Together with petrologic modelling, the acquired data allow us to shed light on the pre-eruptive processes operating in the plumbing system including fractional crystallization, entrapment of crystals from previous eruptions and partial melting of cumulate mush induced by mafic recharge. A combination of these processes was possibly able to make the magma eruptible and trigger such a complex Plinian eruption.

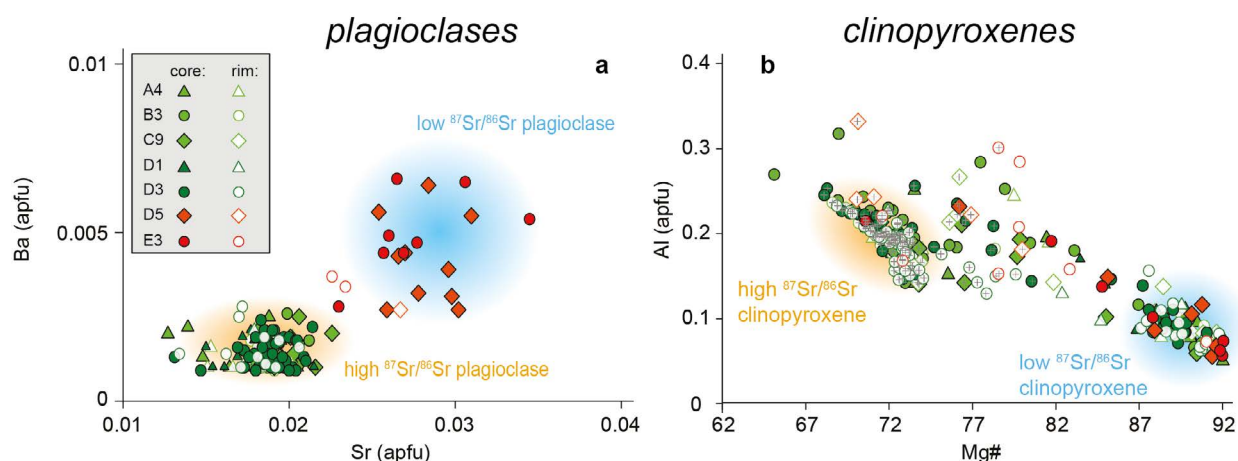


Figure 17 a) Sr vs Ba (apfu) diagram of Pomici Principali plagioclase highlighting two compositional groups; b) Mg# vs Al (apfu) diagram of Pomici Principali clinopyroxene highlighting two dominant compositional groups; the grey crosses indicate the clinopyroxenes that resulted in equilibrium.

Multi-elemental plagioclase-melt modeling unravels episodic crystal growth and magma dynamics

Pontesilli A., Di Fiore F., Mollo S., Andronico D., Taddeucci J., Nazzari M., Ellis B., Bachmann O., Scarlato P.

Presented at IAVCEI 2025 - Geneva (29th June - 4th July 2025. <https://e5k.github.io/IAVCEI-SA2025/abstracts/1-7-31/>), and currently under review in Chemical Geology

Assessing magma storage conditions relies heavily on crystal-melt equilibrium models. However, natural rocks are replete with disequilibrium features that testify to open-system processes and episodic crystal growth. This presents a critical challenge, as traditional petrological modeling faces a circularity problem, represented by the interdependence between intensive parameters and the coexisting melt compositions.

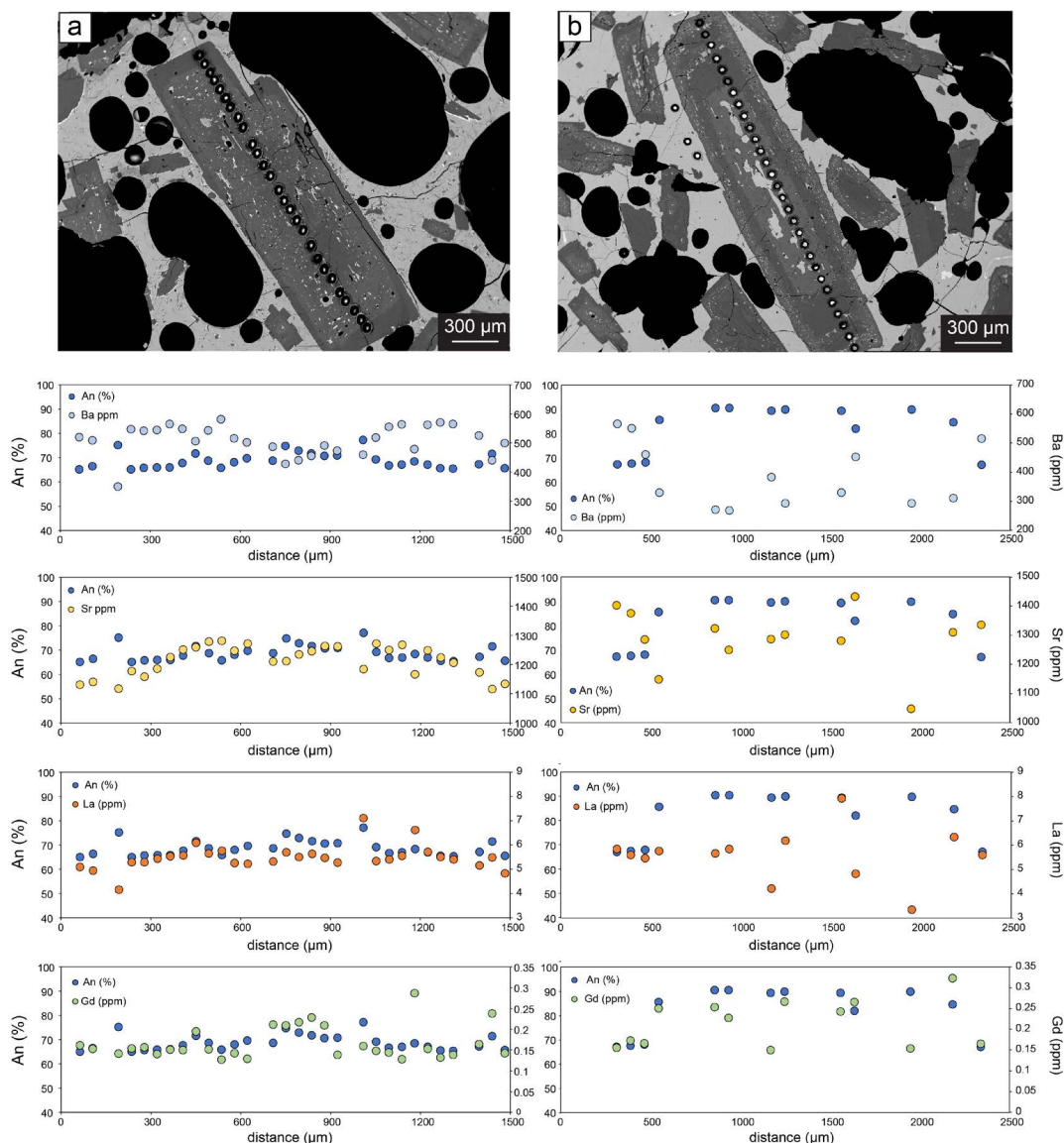


Figure 18 Chemical profiles of plagioclase crystals (laser hole orientation corresponding to profile orientations) displaying variations in Anorthite as well as selected trace elements. Sample details for each panel: a) Scoriaceous bomb from paroxysm on 3rd July 2019. b) Scoriaceous bomb from major explosion on 6th October 2021.

Adding to these intricacies, kinetics of cation exchange may not keep pace with sudden changes of physicochemical conditions determined by magma dynamics. We present and discuss results of a numerical approach that helps circumvent these difficulties. Our model uses multi-element (major and trace) partitioning between plagioclase and melt to self-consistently solve for the best-fit intensive parameters and liquid compositions simultaneously. This scheme was applied to an extensive new dataset of plagioclase crystals from Stromboli volcano, paired with a comprehensive database of matrix glass compositions. Stromboli's well-constrained plumbing system, characterized by frequent mixing between a shallow, degassed magma and a deeper, volatile-rich magma, provides an ideal natural laboratory to test the model. This approach is designed to not only reproduce known equilibrium conditions but also to reconstruct the transient melt compositions generated during dynamic processes like magma mixing and crystal resorption. By deconstructing the chemical record of individual crystal zones (Figure 18), this study provides new quantitative constraints on Stromboli's magma dynamics and offers a powerful, flexible tool for interpreting magma evolution in open-conduit systems.

Double-Schlieren investigation of the effect of particle loading on seismo-acoustic signals

Posati A., Spina L., Taddeucci J., Pennacchia F., La Spina G., Perugini D.

Presented at the 7th Conferenza Rittmann 2026, 7-9 July 2026 Catania (<https://www.conferenzarittmann.it/>) and at the INGV-BSL Workshop, 10-14 May 2026 (<https://istituto.ingv.it/it/attivita-di-ricerca/workshop/third-ingv-bsl-workshop-on-solid-earth-geophysics-roma-10-14-maggio-2026.html>)

The role of particles within volcanic jets in controlling jet dynamics, and consequently the seismic and acoustic signals recorded at the surface, has long been recognized. Nevertheless, this relationship remains largely unexplored from a quantitative point of view, owing to the difficulty of linking geophysical observations to the physical properties of the plume associated with individual explosive events, as well as to the broad range of variability of these properties, even within the same volcanic system.

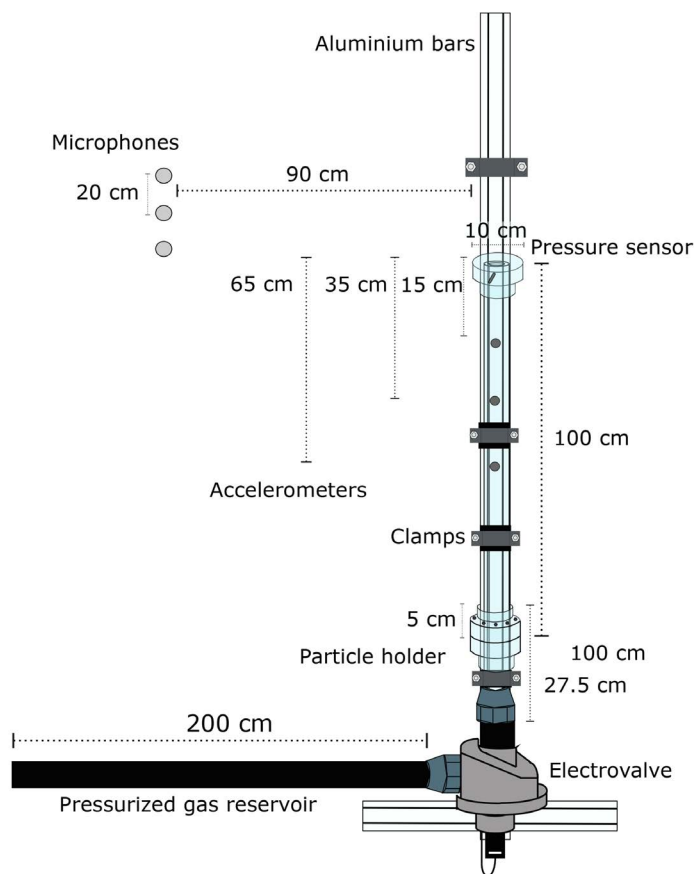


Figure 19 Schematic diagram of the experimental and sensor systems (not to scale).

To fill this knowledge gap and provide a valuable parametrization of the correlation between observed seismo-acoustic signals and particle-bearing plume dynamics, we adapted the Shock-Tube System at HPHT laboratory to enable the addition of controlled solid-loading in the jet (Figure 19). For our experiments we used micro-spherical glass beads of 0.5-1 mm diameter as analogues for volcanic particles, which were poured in a 60-mesh net fixed at the base of the tube. A set of 60 experiments were performed by varying the starting pressure (0, 2, 4, 6, 6.5 and 8 bar) and particle content (weights of 0, 2, 4, 6, 8 and 10 g). The seismo-acoustic signals associated

with each run were monitored with a 3-microphone array, 3 accelerometric sensors along the conduit and one pressure sensor located at the vent. The experiments were then repeated after the addition of two high-speed cameras, joined with double-mirror Schlieren technique to visualize the dynamic evolution of the jet structure along the dataset. The two independent datasets allowed us to test the possible effects on the array of microphones of reflections caused by the proximity of several instruments required for double-Schlieren technique.

Preliminary analysis of the geophysical data includes parametrization of the transients collected through temporal and spectral features. A window of 0.35 seconds of signals was selected by identifying the maximum value on the microphone closest to the vent and selecting a temporal window starting 0.1 before on all the channels. Subsequently, peak-to-peak amplitude and root mean square RMS value were evaluated. We also estimated peak and mean frequencies (i.e. centre of mass of the spectrum) from power spectrum and maximum and mean frequencies among values of wavelet transform with highest spectral energies at each time. Preliminary results show that acoustic data in the supersonic regime are affected by particle content in a non-linear behaviour. Peak-to-peak amplitude, RMS and peak frequency decrease with the addition of particles at 8 bar, whereas the mean frequency and mean value of cwt maxima follow the opposite trend.

Image analysis from double-Schlieren high-speed videos is still in progress, but this will allow us to determine the dynamic evolution of the jet structure by measuring the temporal evolution of shock-cells geometry along with the profile of the volumetric distribution of particles. Preliminary observations highlight the influence of particle ejection on shock-cells lengths and hence on Mach number itself.

SOMBRERO - StrOMBoli moRphology changEs and dRones

Ricci T., Civico R., Scarlato P., Cecili A.

Original contribution prepared for the HPHT Lab Annual Report 2025

Active volcanoes undergo rapid geomorphological changes that directly reflect eruptive activity, making high-resolution topographic monitoring essential for understanding volcanic processes, quantifying erupted volumes, and supporting multi-hazard 3-D numerical models. The SOMBRERO project aims to investigate the dynamics that predispose and generate hazardous mass-wasting processes affecting both the crater area and the Sciara del Fuoco at Stromboli volcano through the acquisition of high-resolution UAS-derived datasets (Figure 20).

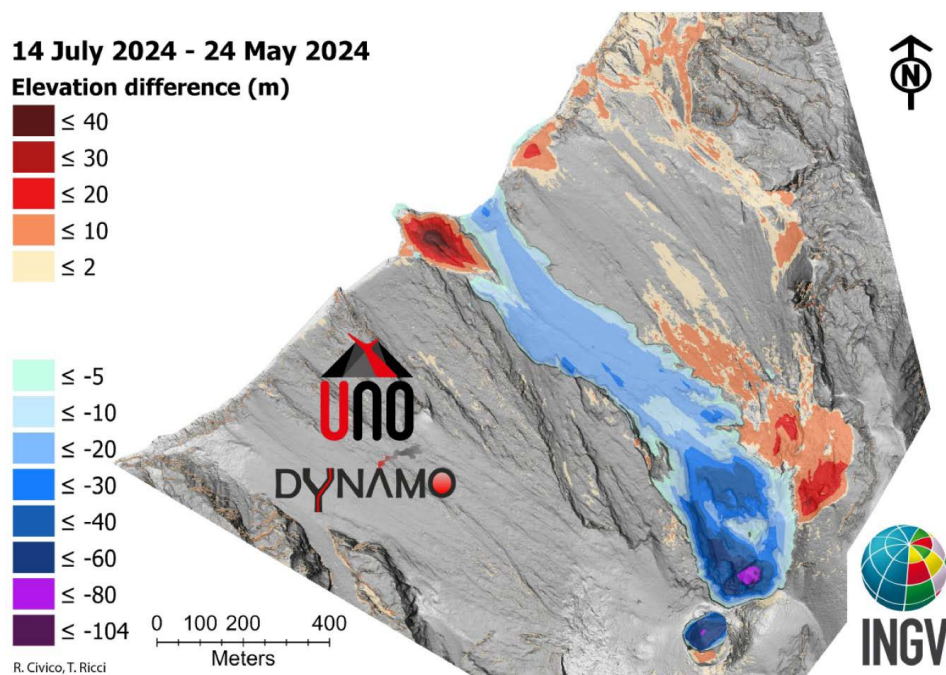


Figure 20 Example of products consistent with the expected results of the SOMBRERO project, based on outputs obtained within the UNO and DYNAMO projects. The figure shows an elevation difference map for the period 24 May 2024 to 14 July 2024, representing pre- and post-July 2024 eruption topographic changes at Stromboli (Taken from: Civico R., T. Ricci, A. Cecili, P. Scarlato (2024). High-resolution topography reveals morphological changes of Stromboli volcano following the July 2024 eruption. Scientific Data, doi:10.1038/s41597-024-04098-y).

Special attention is devoted to the major morphological changes that occurred in the crater area on 4 July 2024, the reconstruction of a weakened crater terrace, and the significant modifications of the Sciara del Fuoco, including the development and widening of a deep canyon with possible implications for tsunami generation. To address the challenges of data acquisition in an active open-conduit volcanic environment, the project will employ multi-sensor UAS platforms equipped with visible and thermal cameras, capable of operating in difficult conditions such as plume obstruction, degassing, and explosive activity. Two field campaigns per year are planned to detect morphological changes related to both primary processes, including lava flows, fallout deposits, and pyroclastic flows, and secondary processes such as gravitational instability and subsidence. UAS imagery will be processed using Structure-from-Motion photogrammetry to

generate high-resolution digital elevation models, including thermal-based DEMs when visible imagery is limited. Expected results include the identification and quantification of topographic changes in the crater area and Sciara del Fuoco, the estimation of erosion and deposition volumes, and hazard assessment through the geometrical characterisation of active vents and the recognition of fractures, cracks, and other relevant morphological features.

Multiple mush generations provide insight into the longevity of open-conduit basaltic volcanoes

Schiavon B., Petrone C.M., Forni F., Pontesilli A., Hu H., Scarlato P., Andronico D., Del Bello E., Nazzari M., Mollo S.

Based on: Schiavon, B., Petrone, C.M., Forni, F., Pontesilli, A., Hu, H., Scarlato, P., Andronico, D., Del Bello, E., Nazzari, M., Mollo, S. (2025). Multiple mush generations provide insight into the longevity of open-conduit basaltic volcanoes. *Scientific Reports*, 15, 21393. <https://doi.org/10.1038/s41598-025-07005-6>

Investigating the dynamics and timescales of magmatic processes in open-conduit basaltic volcanoes is crucial for improving our understanding of explosive eruptions and better assessing volcanic hazards. Among these processes, the role of mush disaggregation and remobilisation within the plumbing system remains rather underexplored. This study examines the longevity and dynamics of the mush system beneath Stromboli volcano (Aeolian Islands, Southern Italy), whose persistent activity results from variable degrees of interaction between different magmatic components. The complex zoning patterns of plagioclase phenocrysts from 2003-2021 eruptions have been interrogated by combining *in-situ* Sr isotope compositions, thermometric modelling, and Mg diffusion chronometry.

Our findings shed new light on the physicochemical changes within the plumbing system, the timescales of crystal residence in the shallow reservoir, and the timing of magma recharge events. Timescales of mafic recharges and mush remobilisations recorded by plagioclase suggest rapid magma-mush dynamics during violent explosions but more sluggish during normal activity. Sr isotope heterogeneities in plagioclase reveal that multiple mush generations at Stromboli have been active over millennia, with remobilisation events and crystal recycling driven by mafic magma recharges from depth. This is further supported by a complementary *in-situ* investigation of clinopyroxene phenocryst cores. A previously unseen, prehistoric, highly radiogenic mush has been actively remobilised in recent years, pointing out that older components of open-conduit basaltic systems may persist longer than previously hypothesised (Figure 21).

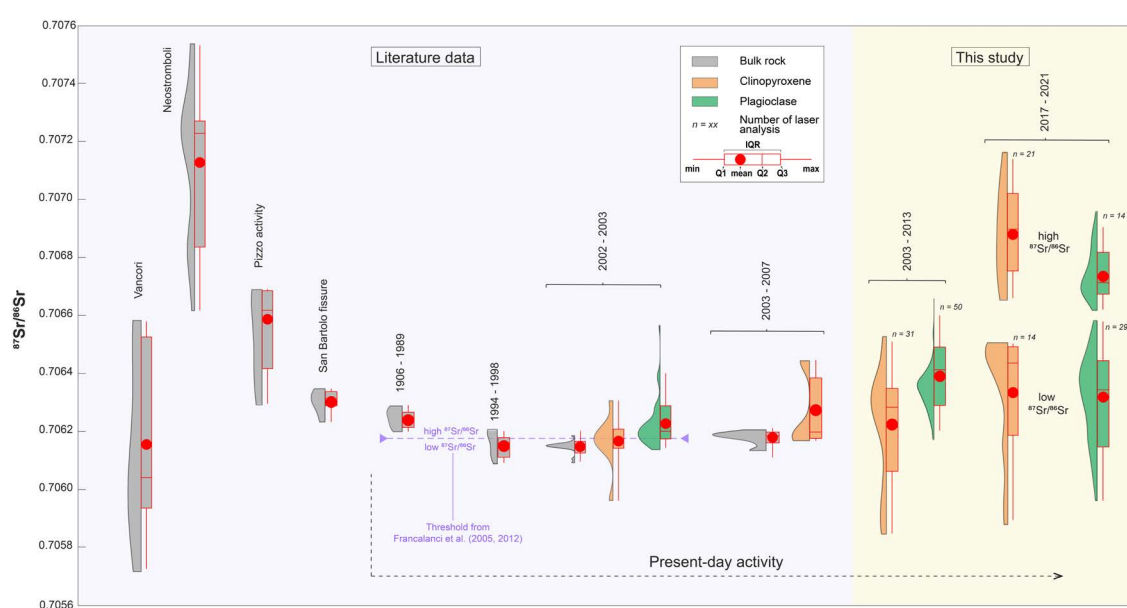


Figure 21 Violin plots and box plots for $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of bulk rocks, and plagioclase and clinopyroxene phenocrysts from historical time to present-day activity at Stromboli. The number of analysed crystals from this study is indicated by n .

Genesis of Natural Hydrogen by Hydrothermal Alteration of Tuscan Peralkaline Granites

Schirripa Spagnolo G., Marchesini B., Aldega L., Ruggieri G., Novella D., Caracausi A., Billi A., Boschi C., Carminati E.

Presented at Genesis of Natural Hydrogen by Hydrothermal Alteration of Tuscan Peralkaline Granites: Schirripa Spagnolo, G., Marchesini, B., Aldega, L., Ruggieri, G., Novella, D., Caracausi, A., Billi, A., Boschi, C., Carminati, E. (2025). *Società geologica Italiana*, Padova.

Natural hydrogen can be generated through fluid-rock interactions, particularly via the reduction of water by oxidation of Fe^{2+} -bearing minerals. Among these reactions, the serpentinization of Fe-rich olivine in ultramafic rocks is the most extensively studied. However, a less explored but potentially significant source of natural H_2 is the hydrothermal alteration of peralkaline granites. In such systems, H_2 may form through the oxidation of Fe^{2+} -rich biotite, accompanied by the neoformation of Fe^{3+} -bearing minerals such as chlorite or magnetite. Additionally, at lower temperatures, the hydrothermal alteration of magnetite within peralkaline granites may produce H_2 via oxidation of H_2S under acidic conditions, leading to magnetite pyritization, or through direct oxidation of magnetite to hematite.

This study, which is part of NHEAT (Natural Hydrogen for Energy trAnsiTion) project, funded by the Italian Ministry of University and Research (MIUR) under the PRIN PNRR 2022 program, investigates the potential for natural H_2 generation from peralkaline granites in Tuscany, where hydrothermal alteration is active. Tuscany is characterized by a high heat-flow anomaly linked to Late Miocene-Pliocene granite intrusion associated with the opening of the Tyrrhenian back-arc basin, which is currently exploited in the Larderello geothermal field.

Combining field work, micro-structural, mineralogical, and geochemical analyses, we examine the hydrothermal alteration of peralkaline granites exposed in the Gavorrano and Botro ai Marmi areas. Microstructural analyses reveal that both hydrothermal alteration of biotite in magnetite and pyrite precipitation are governed by secondary fractures that allow the mixing between high-temperature hydrothermal and low-temperature meteoric-derived fluids. Micro-Raman spectroscopy of fluid inclusions within quartz grains that healed these secondary fractures in both fault-related metasomatic lodes and in altered granites-reveals the trapping of molecular hydrogen (H_2).

These findings demonstrate that hydrothermal alteration of peralkaline granites can generate natural hydrogen. Future perspectives required to quantify the rate and volume of hydrogen production will be discussed with the final goal of assessing the potential for economic exploitation of H_2 in this region (Figure 22).

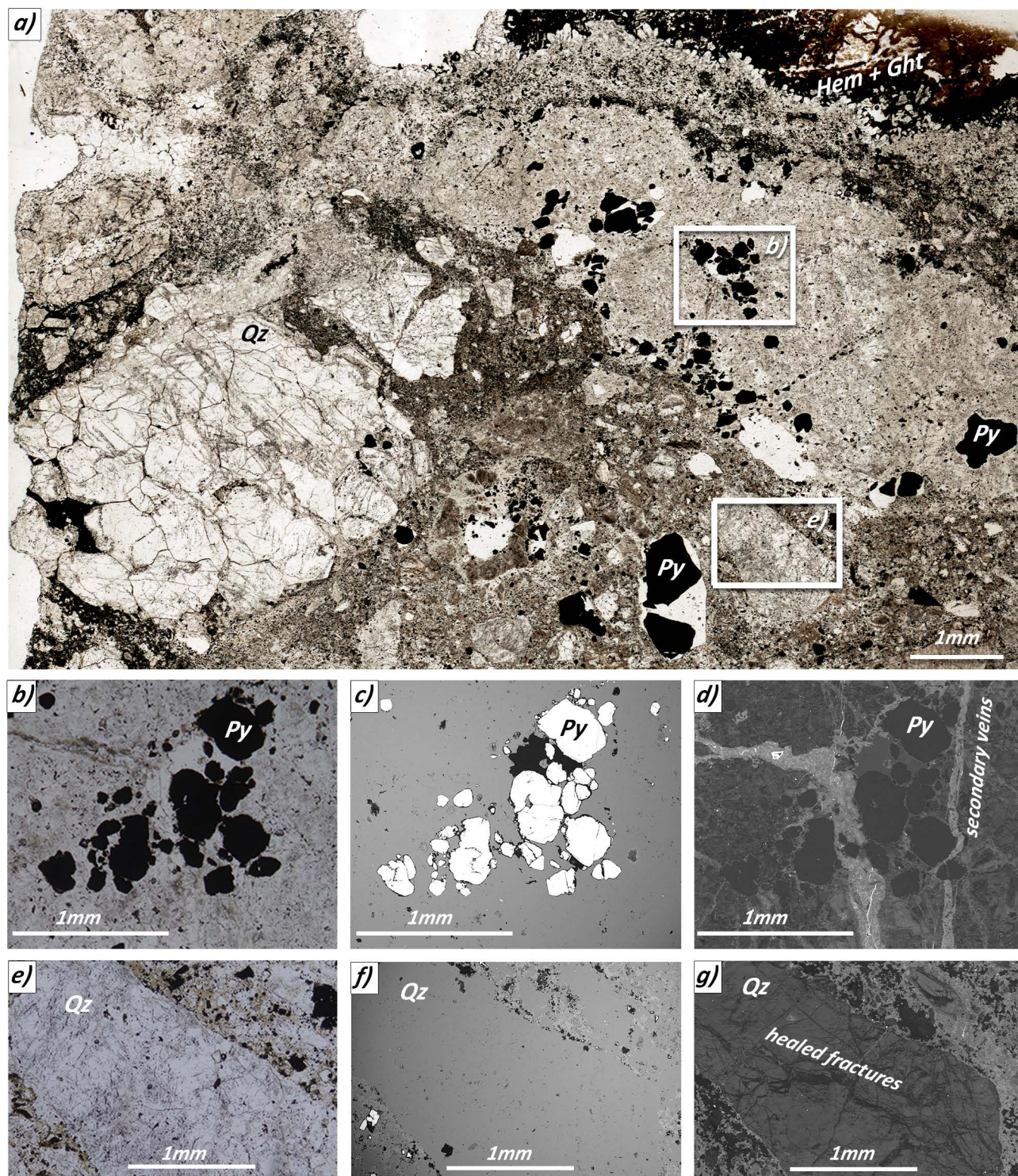


Figure 22 a) Optical (parallel light) image of the fault-related metasomatic lode that is a breccia composed of an iron oxides and hydroxides wall (Hem: hematite, Ght: goethite), fractured grains of quartz (Qz), and pyrites (Py) along secondary veins. b), c), and d) Optical (parallel light), SEM, and cathodoluminescence images of secondary veins that led to pyrite precipitation. e), f), and g) Optical (parallel light), SEM, and cathodoluminescence images of fractured quartz grains.

The structure of high-Mg alkali-bearing aluminosilicate glasses investigated in situ at ambient and high pressure by multi-angle energy dispersive X-ray diffraction and infrared microspectroscopy

Stopponi V., Piccirilli F., Hrubak R., Misiti V., Lupi S., Stagno V.

Based on: Stopponi, V., Piccirilli, F., Hrubak, R., Misiti, V., Lupi, S., Stagno, V. (2025). The structure of high-Mg alkali-bearing aluminosilicate glasses investigated in situ at ambient and high pressure by multi-angle energy dispersive X-ray diffraction and infrared microspectroscopy. *Chemical Geology*, 692, 122970. <https://doi.org/10.1016/j.chemgeo.2025.122970>

The structural properties of synthetic high-Mg alkali-bearing aluminosilicate glasses analogues of natural picriticto-komatiitic magmas were investigated in situ by multi-angle energy dispersive X-ray diffraction at ambient pressure and 2.1 GPa and by Fourier Transform infrared spectroscopy up to 5.4 GPa upon compression and decompression. Our results reveal that the intermediate range ordering of the glass structure at 2.1 GPa is 3.14 Å, increasing to 3.19 Å when decompressed to ambient pressure. The local structure at 2.1 GPa shows T-O lengths of 1.66 Å and T-T distances of 3.19 Å, resulting in a T-O-T angle of 147°. Upon decompression, T-O lengths shorten to 1.65 Å and T-T distances increase to 3.21 Å, widening the T-O-T angle to 154°. The deconvoluted infrared spectra result in the presence of Q1, Q2, Q3 populations in the aluminosilicate spectral region, whose proportions remain relatively unchanged up to 5.4 GPa. The structural response of the investigated glasses to cold compression does not involve changes in polymerization, but rather a shrinking and compaction of the structure as evidenced by the Q_n species shifting to higher wavenumbers as a function of pressure. The structural properties determined by X-ray diffraction for this glass composition are discussed along with those of glasses from previous studies to highlight a compositional dependence dictated by the amount of SiO₂ and Al₂O₃.

2.2 Rock Physics and Earthquakes Mechanics



Frictional and hydromechanical properties of the Utah FORGE enhanced geothermal site lithologies

Affinito R., Eijsink A., Volpe G., Kroll K., Elsworth D., Marone C.

Original contribution prepared for the HPHT Lab Annual Report 2025

Enhanced geothermal systems (EGS) are a rapidly developing technology for delivering firm, low-carbon energy, but reservoir stimulation can generate induced seismicity that threatens well integrity and nearby infrastructure. The Utah FORGE project-funded by the U.S. Department of Energy-provides a unique field laboratory to test stimulation strategies while constraining the mechanisms that control slip stability. Here we report frictional and ultrasonic measurements on core recovered from the FORGE 16A characterization well (2100-2400 m depth), targeting the two dominant lithologies in the reservoir: granite and gneiss. Samples were tested both as intact rock and as comminuted fault wear material (gouge) in a custom true-triaxial shear configuration, using single-direction and double-direct shear geometries. Experiments span effective normal stresses of 5-100 MPa, pore-fluid pressures of 0-40 MPa, and temperatures of 25-150 °C, representative of stimulation-relevant conditions.

Velocity-step tests were used to estimate rate-and-state friction parameters (a-b, critical slip distance D_c , and evolution-law terms (epsilon)), complemented by slide-hold-slide tests to quantify time-dependent restrengthening (healing). Additional pressure-stepping experiments constrained the Linker-Dieterich α parameter, enabling frictional stability models that explicitly incorporate pore-pressure transients. Concurrent ultrasonic monitoring from transducers embedded in the side blocks tracked wave-speed and amplitude evolution as functions of stress and accumulated strain, providing a proxy for damage and contact evolution during shear (Figure 23).

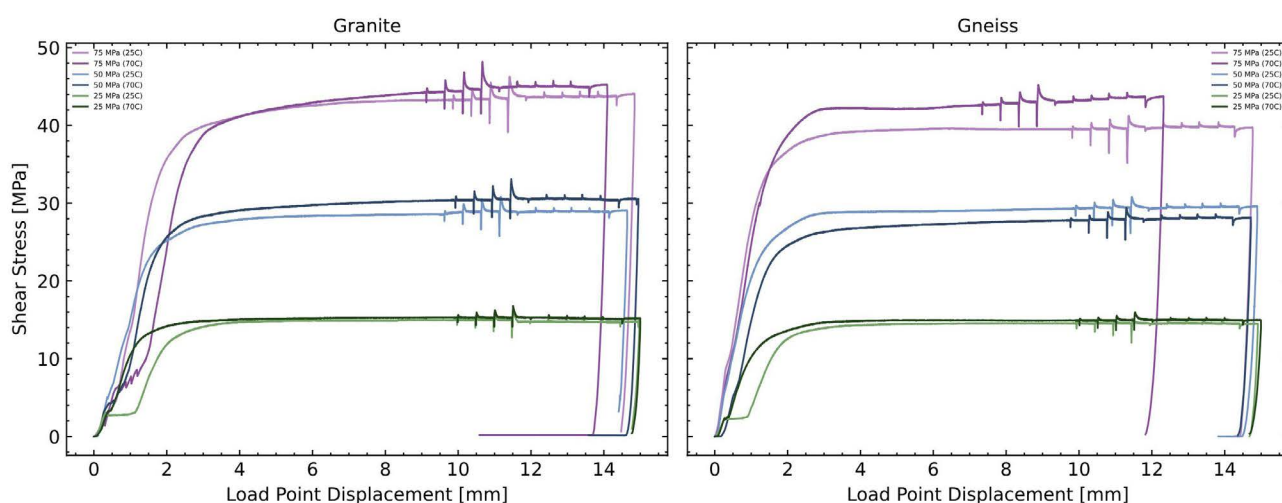


Figure 23 Shear stress - shear displacement evolution of the gouges of the rocks interested by the EGS activity within the FORGE project.

Across tested conditions, granite exhibits velocity-neutral to velocity-weakening behavior, whereas gneiss is predominantly velocity-strengthening, implying that instability and event

nucleation are more likely to localize within granite-rich shear zones. Granite also displays stronger healing, indicating a greater propensity for stress re-accumulation between slip episodes. Together, these results suggest that lithologic heterogeneity and the coupled effects of temperature and pore-pressure transients govern both the likelihood and style of induced slip at FORGE, with direct implications for stimulation design aimed at maximizing permeability enhancement while minimizing seismic hazard.

Fault core structure and the fault slip behavior during fluid injection: insights from laboratory friction experiments

Aretusini S., Cornelio C., Spagnuolo E., Volpe G., Pozzi G., Dal Zilio L., Selvadurai P., Cocco M.

Presented at EGU 2025. <https://doi.org/10.5194/egusphere-egu24-8226>

Fluid pressure plays a crucial role in controlling fault reactivation in both natural and induced seismicity. The effective normal stress is linearly reduced by an increase in fluid pressure (P_f) with $\sigma_{eff} = \sigma_n - S \cdot P_f$, which lowers the frictional strength of the fault, $\tau = \mu \cdot \sigma_{eff}$, increasing the potential for fault reactivation and seismic slip. Upon reactivation, slip can occur quasi-statically or dynamically depending on the interplay between σ_n and P_f and mediated by the S parameter, (the hydromechanical coupling) and by the rate-and-state properties of the fault materials. In this context, the fault zone structure dictates the frictional properties as well as the fault hydro-mechanical coupling, particularly when $S \neq 1$ and reactivation might occur at effective stresses different than predicted.

In Bedretto Underground Laboratory for Geosciences and Geoenergies (BULGG, Switzerland), a target fault zone chosen for fluid-induced fault stimulation is characterized by a fractured host rock surrounding a sub-centimetric fault core with fault gouge and bare-rock asperities. Therefore, to define slip mode of the target fault it is important to characterize the frictional properties of both fault gouge and bare-rock asperities taking advantage of a laboratory controlled experimental environment.

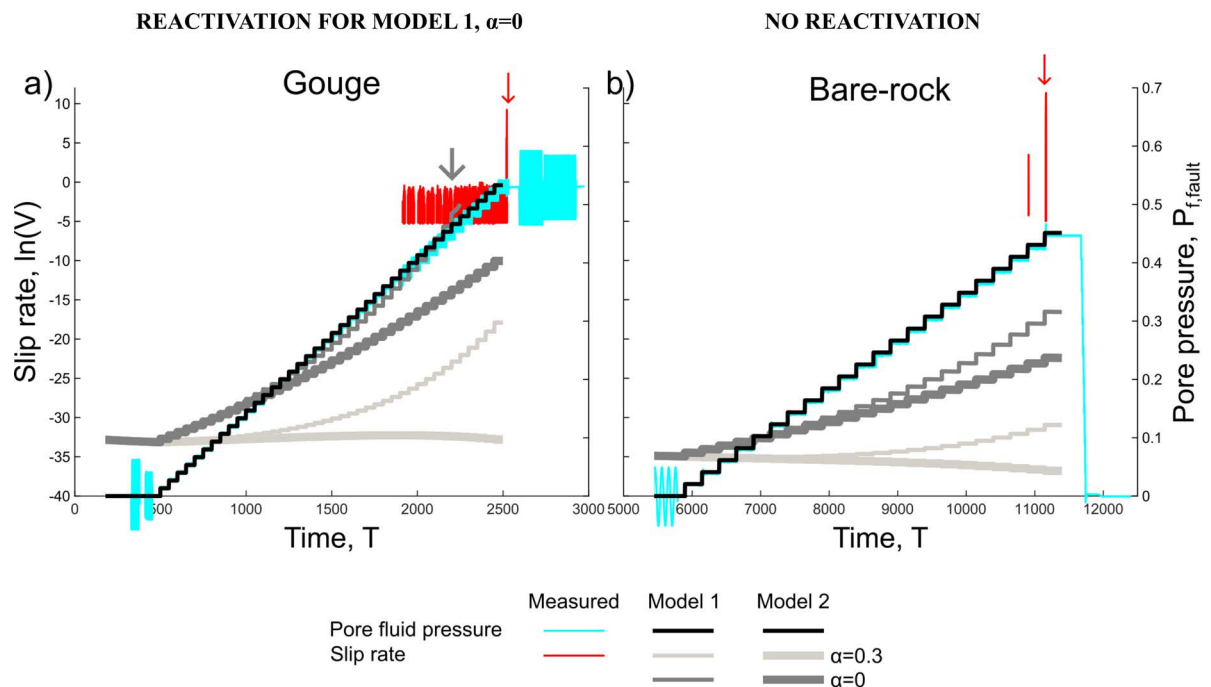


Figure 24 Results of fault reactivation models in the framework of rate and state friction (Rudnicki, 2023). Tested materials are: **a)** MC fault gouge **b)** granite bare rocks. Blue curves are the measured pore pressures, red curves are the measured slip rates, whereas the several grey curves represent the modeled slip rates. Two types of models are compared, a simpler (thin lines) and a more complex (thick lines). Light grey curves are calculated with Linker and Dieterich, (1992) α parameter set to 0.3, whereas the darker grey curves with α set to 0. Fault reactivation (the measured one from the experiments occurred as indicated by vertical red arrows) was predicted limitedly to gouge simpler models, with α set to 0 (vertical grey arrow).

Fault stimulation by fluid injection was simulated in the laboratory by increasing the P_f following an injection protocol suitable for the BULGG fluid stimulation. Experiments were performed on both the fault gouge sampled from the target fault and on bare rock surfaces sampled in the surrounding host rock. We employed a rotary shear apparatus (SHIVA) to perform fluid injection experiments. First, we imposed the stress conditions measured at depth in the underground laboratory, halved due to apparatus limitations: 7.5 MPa σ_{eff} , 7.5 MPa confining pressure and 2.5 MPa P_f . Second, we imposed a slip rate of 10^{-5} m/s for 0.01 m to develop a stable fault core structure. Third, we applied a constant shear stress of 2.7 MPa, considering the slip tendency measured on the target fault (0.35). We then increased stepwise the P_f by 0.1 MPa every 150 s. After fault slip initiation, the maximum allowed slip velocity was 0.1-1 m/s. Between each of the experimental stages, permeability and transmissivity were measured with the gradient (Darcy) or P_f oscillations methods.

We show that fault reactivation and slip behavior are different between gouge and bare rocks: in gouge creep and dilatancy precede reactivation, whereas in bare rock surfaces reactivation is sudden and not preceded by neither tertiary creep nor dilatancy indicating that dynamic reactivation is promoted in smooth bare-rock surfaces. Moreover, gouge displays a higher friction (0.58 vs 0.49) and a lower hydraulic transmissivity (i.e., 10^{-19} vs 10^{-17} m³) than bare rocks.

Here we proceed to test a suite of constitutive models against our data: rate and state friction, (Figure 24), and a fully coupled poromechanical model, to understand what are the physical processes controlling the onset and style of fault activation in the two fault core structures.

ChatGPT and the acceleration of development and deployment of a metadata manager

Aretusini S., Sbarra M., Cocco M.

Presented at Giornata AI 2025 9/7/2025

Over the past two years, we interacted with an AI assistant (ChatGPT, GPT 4.0) to develop and deploy an application for metadata management combining Python and OpenBIS. Here, we highlight advantages and limitations we found in the use of AI. ChatGPT accelerated the deployment, such as in the Docker configuration of OpenBIS with other applications (authentication system, proxy, etc.). In automated file classification, it offered effective suggestions on the logical and organisational structure of the Python script, and regex for data recognition. Also, in the development of a Streamlit application as front-end for OpenBIS, the AI assistant facilitated both code writing and deployment. However, AI showed limitations in the understanding of the specific operational context. The user often had to adapt and test separately the received indications, especially in the advanced definition of regex or Docker and LDAP configurations. In some occasions, ChatGPT's implemented Python libraries (in our case, pybis), with non-existent methods or misleading suggestions that required manual verification, correction and debugging. In conclusion, ChatGPT proves to be a valuable tool for speeding up and simplifying our tasks, provided that it is supported by direct and competent user intervention. The combination of AI and human intervention proved to be crucial in developing and deploying our application (Figure 25).

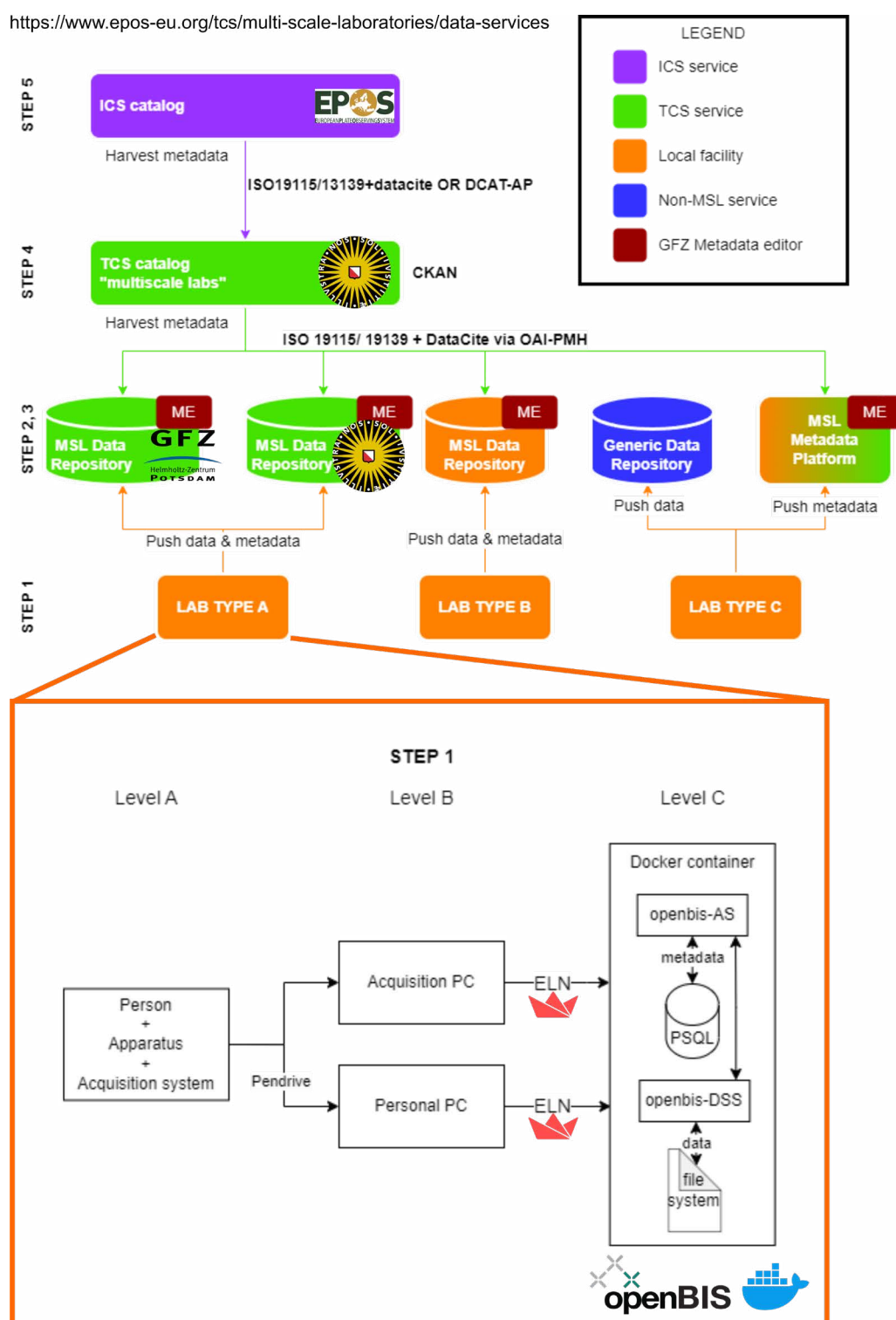


Figure 25 Our IT architecture in the framework of EPOS MSL. a) EPOS MSL IT architecture diagram. Step 1: individual laboratories producing data; step 2 metadata and data are annotated (e.g. in the GFZ metadata editor); step 3: metadata and data are published in Data Repositories with attribution of DOI (i.e., DOI minting); step 4: the Thematic Core Services (TCS) repository harvests metadata and data from the Data Repositories; step 5: the Integrated Core Services (ICS) Data Portal harvests data and metadata from the TCS repository. b) A detail within step 1, with our application, highlighting the data and metadata path from the source, where data is produced by people using apparatuses and acquisition systems (level A), to where data is temporarily stored, in a PC attached to an apparatus or personal (level B), to our Openbis repository (level C). Interface B to C can occur with either the Electronic Lab Notebook natively installed with Openbis or with the modified Streamlit app, tailored to our metadata model.

Digital image correlation technique applied to visualization of the displacement field in laboratory experiments on seismic rupture

Cavaliere N., Cornelio C., Spagnuolo E., Taddeucci J., Di Toro G.

Modified from: Cavaliere, N. (2025). *Tecnica di correlazione delle immagini digitali applicata alla visualizzazione del campo di spostamento negli esperimenti di laboratorio sulla rottura sismica*. Master's Thesis, University of Padova, Academic Year 2024/2025. <https://hdl.handle.net/20.500.12608/92674>

Earthquakes are natural phenomena that cause ground shaking and significant damage to both people and infrastructure. Despite substantial progress in understanding earthquake initiation, propagation, and arrest, many aspects of their underlying physics and mechanics remain incompletely understood due to their intrinsic complexity.

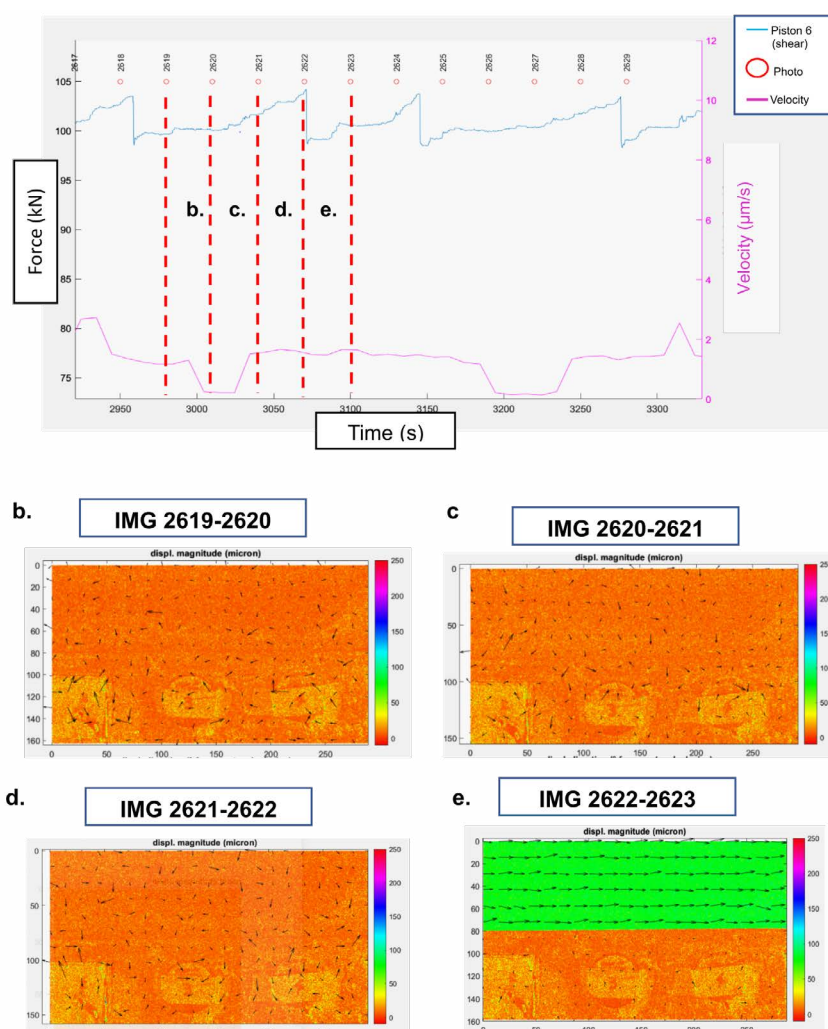


Figure 26 DIC data of experiment M0013 during step 4 (load point velocity of about 1 $\mu\text{m/s}$) Panel a) displays the stick-slip behaviour observed for experiment M0013. The red dashed lines mark the time points at which the selected images (IMG 2619, 2620, 2621, 2622, 2623) were acquired. Panels b) through e) arranged in chronological order present the corresponding displacement magnitude maps derived for the image pairs IMG 2619-2620, IMG 2620-2621, IMG 2621-2622, and IMG 2622-2623, respectively. Panels b), c), and d- represent different moments within the loading phase of a single cycle, while panel e. refers to the early stage of the subsequent cycle.

This thesis adopts an experimental approach to investigate the initial tests conducted with the Mechanics of Earthquakes and Extended Ruptures Apparatus (MEERA), located at the National Institute of Geophysics and Volcanology (INGV) in Rome. The aim of these experiments is to better understand how MEERA operates and to explore its potential for studying the full seismic cycle, including the nucleation, propagation, and arrest of a seismic rupture. To support this analysis, Digital Image Correlation (DIC) method and a 3D static stress-strain numerical model were used. The Digital Image Correlation (DIC) method was used to track surface displacements and measure the deformation of the sample surface during the simulation of the seismic cycle. Furthermore, a new three-dimensional numerical model allowed us to observe: (1) the mechanical response of the sample when subjected to a normal load; and (2) the spatial distribution of the deformation on the surface of the sample (= in the vicinity of the fault). Clearly, further work is required to deepen our understanding of earthquake nucleation and mechanics, as well as to better characterize the response and capabilities of the MEERA apparatus. However, the results presented in this thesis provide a solid foundation for future experiments and demonstrate the potential of MEERA as a powerful tool to investigate fault behaviour, the preparatory phase of earthquakes and the nucleation, propagation and arrest of seismic ruptures under controlled laboratory conditions (Figure 26).

Seismic and sub-seismic experimental mirror-like surfaces in Bituminous Dolostones

Chinello M., Aretusini S., Spagnuolo E., Nava J., Tesei T., Fondriest M., Di Toro G.

Dataset from www.doi.org/10.25430/researchdata.cab.unipd.it.00001707

Mirror-like Surfaces (MSs) are ultra-polished fault surfaces widespread in carbonate-built, exhumed seismogenic fault zones. Field and experimental investigations indicate that MSs form under a variety of pressure-temperature conditions and slip rates, ranging from “seismic” (≈ 1 m/s) to “sub-seismic” (≈ 0.1 - 100 $\mu\text{m/s}$) and possibly corresponding to different phases of the seismic cycle (co-seismic vs. post- and inter-seismic). Motivated by the abundance of MSs cutting through bituminous dolostones in the Central Apennines (Italy), we deformed Bituminous Dolostones gouges using a rotary-shear apparatus at seismic (1 m/s) and sub-seismic (10 and 100 $\mu\text{m/s}$) slip rates under 20 MPa of normal stress for 1 m of slip displacement (Figure 27). Experiments were conducted under both water-dampened and room-humidity conditions. The experimentally-produced fault surfaces were then analysed using a FEG-FIB-SEM. The main goals were (1) to determine under which loading and ambient conditions MSs form and (2) whether the micro- and nano-structures reveal if the MS formed under “sub-seismic” or “seismic” conditions.

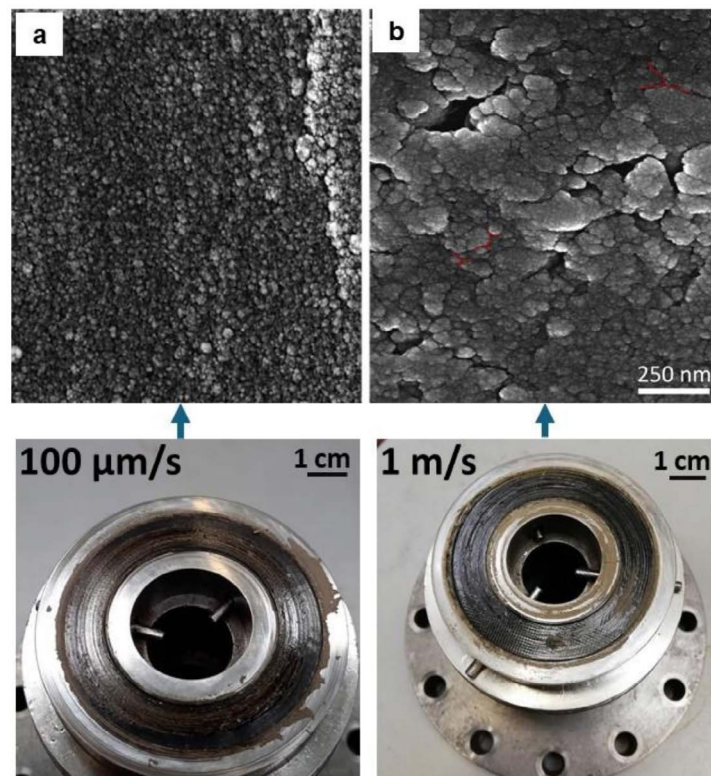


Figure 27 Fault mirrors produced in experiments performed on gouges of bituminous dolostones. The experiments were performed at sub-seismic (100 $\mu\text{m/s}$) and seismic (1 m/s) loading conditions with SHIVA (INGV HT-HP Laboratories in Rome). Top: SE-FESEM image of the slip surface; Bottom: slip surface after the experiment. a) In the “sub-seismic” mirror-like surface produced at 100 $\mu\text{m/s}$, the nanoparticles are arranged in sub-spherical clusters measuring only a few tens of nanometres. b) In the “seismic” mirror-like surface produced at 1 m/s, the surface nanoparticles are arranged in flat, sub-rounded clusters measuring 15-150 nm in diameter.

Well-developed MSs (i.e., they reflect light) were produced under both “seismic” and “sub-seismic” deformation conditions, independently of the presence of liquid water. Similar to natural samples, under the FEG-SEM, all the experimental MSs consist of a film (tens of nanometre-thick) made of rounded nanoparticles with well-defined sizes (5-15 nm) lying on top of a 10-100 m-thick cataclastic slip zone. Lineation on the MSs is due to mechanical grooves that are recognizable down to the sub-micrometre scale. However, subtle differences are found in the MSs produced at room-humidity conditions: (1) in the “seismic” MSs produced at 1 m/s, the surface is cut by 10-20 m long microcracks and the nanoparticles are arranged in flat, sub-rounded clusters measuring 15-150 nm in diameter; (2) in the “sub-seismic” MSs produced at 100 $\mu\text{m/s}$ and 10 $\mu\text{m/s}$, the nanoparticles are arranged in sub-spherical clusters measuring only few tens of nanometres. FIB cuts perpendicular to the slip surface reveal that in the “sub-seismic” MS produced at 100 m/s, the first 2-3 m of cataclasite beneath the MS is compact and free of porosity while in the “seismic” sample, the cataclasite is porous (10s to 100s nm in size). These different sub-micrometre scale features may affect the surface roughness and the permeability properties.

Given the variety of deformation conditions (strain rates, temperature, presence of fluids, etc.) that lead to the formation of MSs, they result from the morphological convergence down to the sub-micrometre scale of different physical and chemical processes (e.g., grain boundary diffusion and grain growth, diffusive mass transfer). However, few micro- to nano-structural differences related to the spatial arrangement of the nanoparticles and pores, if preserved in nature, may serve as an indicator of the “seismic” vs. “sub-seismic” origin of MSs.

Fluid induced fault slip behavior: frictional healing vs velocity dependence of friction

Coppola L., Volpe G., Giorgetti C., Pozzi G., Collettini C.

Original contribution prepared for the HPHT Lab Annual Report 2025

Fluid-induced fault reactivation and associated seismicity is a critical process in reservoir exploitation and emerging geo-energy activities such as Carbon Capture and Storage (CCS), Enhanced Geothermal Systems (EGS) and wastewater disposal. During fluid injection, the fault stress state progressively approaches the failure criterion, where $\tau = (\sigma_n - Pf)\mu + C$ is shear stress, σ_n normal stress, Pf fluid pressure, μ friction, and C cohesion. Once the stress state reaches the failure envelope, faults may reactivate either seismically or aseismically. However, the mechanisms governing aseismic versus seismic fault reactivation during fluid injection remain debated.

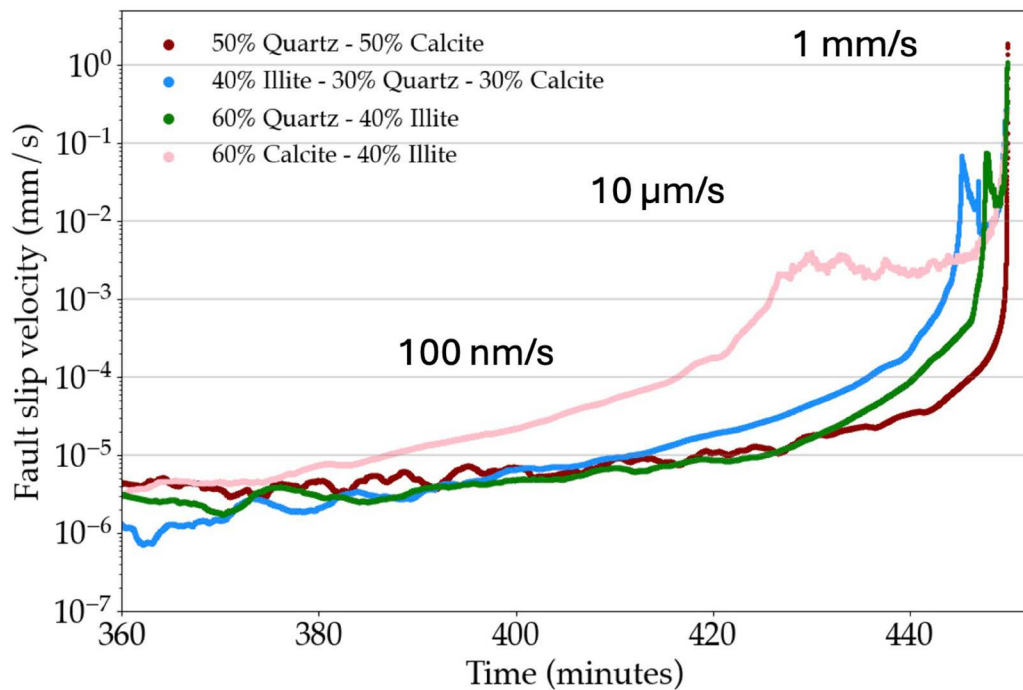


Figure 28 Fault slip velocity vs. time curves. Note that red (50% Qz- 50% Cal) has the highest peak velocity with an exponential reactivation, whereas illite-rich faults show lower velocities and self-decelerations.

Previous laboratory studies suggest that this seismic vs. aseismic deformation may be influenced by fault frictional properties influenced by mineralogy, fault zone structure, stress state, and injection rate, yet the relative contribution of these factors remains unclear. To address this issue, we present an experimental study on binary and ternary fault gouges with variable fractions of quartz, calcite, and illite. These are minerals found along faults zones and within reservoir rocks commonly exploited for geo-energy applications.

For each mineralogical composition, two experimental datasets were acquired. In the first dataset, we performed slide-hold-slide and velocity-step tests to measure friction, frictional healing and the velocity dependence of friction. In the second dataset, we investigated fault

slip behavior during fluid-pressure-induced reactivation at three different stress states. The frictional properties reveal a pronounced contrast between granular and platy phyllosilicate-rich gouges. Granular materials exhibit high friction ($\mu \approx 0.6$), positive frictional healing, and low $a-b$ values, indicating velocity-weakening and potentially seismogenic behavior. In contrast, illite-rich gouges (illite > 40%) display low friction ($0.28 < \mu < 0.4$), low to negative healing, and strongly positive $a-b$ values, indicative of velocity-strengthening and aseismic behavior. During fluid injection induced-reactivation, granular-rich gouges reactivate through an exponential increase in slip velocity, mimicking seismic-like instability. Conversely, illite-rich gouges reactivate through aseismic but accelerated creep that does not evolve into dynamic failure. Notably, reactivation in granular gouges is abrupt and occurs at stress states well above the predicted failure envelope, whereas in illite-rich gouges reactivation is gradual and occurs at or before the predicted failure envelope. In addition, at constant illite content, quartz-rich gouges reactivate faster than calcite-rich fault gouges (Figure 28).

The integration of these results suggests a conceptual framework in which fluid-induced fault reactivation is governed by the interplay between frictional healing and rate dependence, with mineralogy exerting a first-order control. In granular gouges, strong healing dominates the fluid induced reactivation process, leading to delayed but abrupt fault reactivation that can overcome the stabilizing slight rate-strengthening effect, promoting an exponential acceleration under fluid pressurization. In contrast, in phyllosilicate-rich gouges, weak or negative healing combined with a marked rate strengthening behavior stabilizes slip, favoring continuous aseismic creep.

This framework demonstrates that the balance between healing and rate dependence, strongly linked to fault mineralogy, governs whether fluid-induced fault reactivation produces seismic slip or aseismic creep.

Imaging the Nucleation of Laboratory Earthquakes: The Role of Fault Heterogeneity in Stick-Slip Events

Cornelio C., Spagnuolo E., Aretusini S., Kiss A., Taddeucci J., Colombelli S., Cocco M.

Presented at SIMP-SGI 2025 - Geosciences and the Challenges of the 21st Century Padova, 16-18 September 2025. <https://doi.org/10.3301/ABSGI.2025.03>

Understanding the nucleation and localization of earthquake ruptures is a fundamental challenge in seismology. Mapping fault displacement and stress fields throughout the seismic cycle is critical for constraining physical models of the earthquake nucleation and propagation processes with the final aim to improve seismic hazard assessment. Recent large-scale laboratory experiments have provided invaluable insights into rupture propagation, aftershock-like sequences, and the effects of stress heterogeneity. However, resolving the full-field deformation patterns during the earthquake preparatory phase remains a significant challenge, especially on geomaterials.

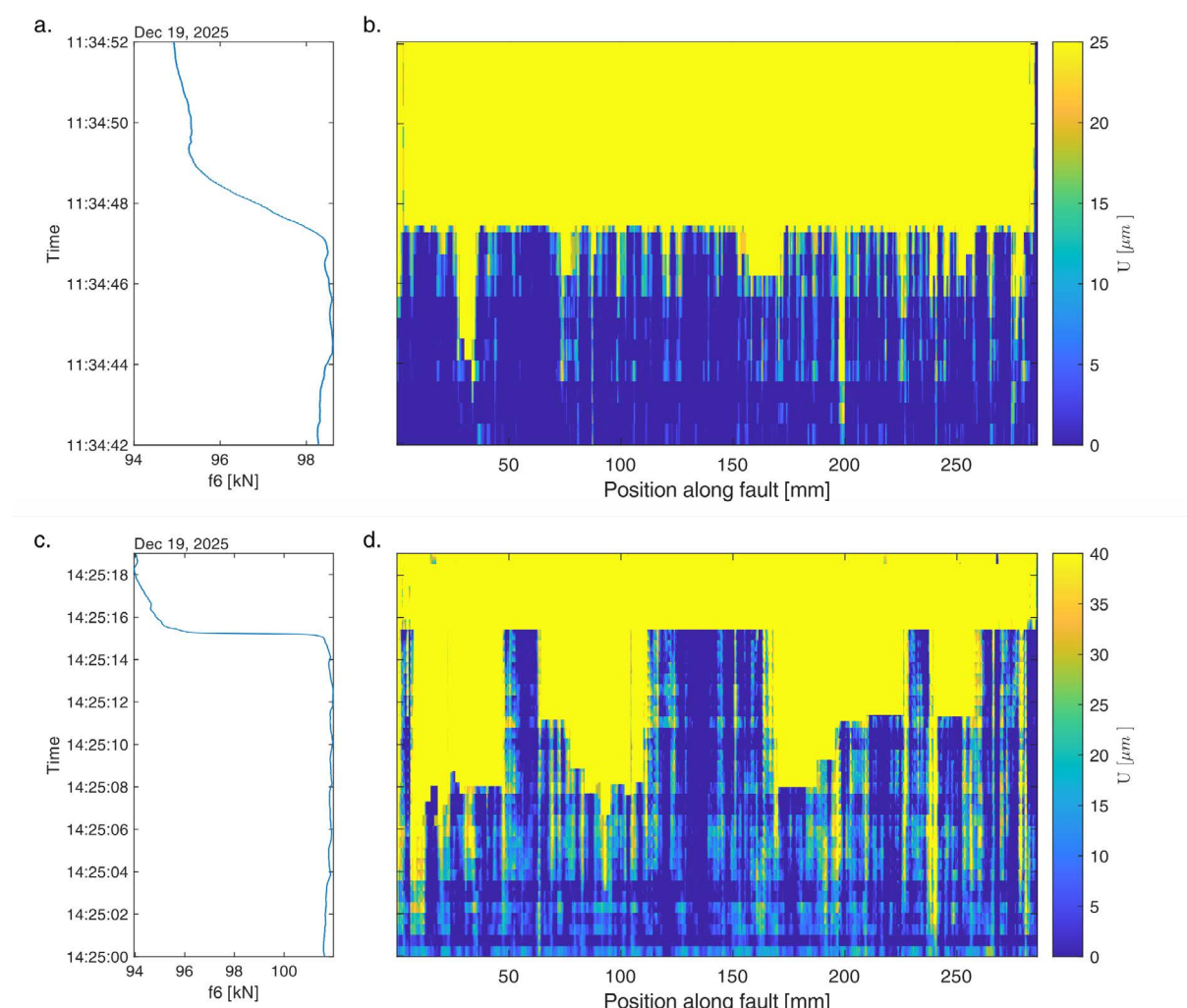


Figure 29 Evolution of shear force (a and c) and field displacement (b and d) during stick slip for experiments m0021 and m0022, respectively. Panels a and c show the zoom of evolution of the shear force with time closer to the slip phase of two stick slip. Panels b and d show the evolution of the displacement along strike captured with the camera through the DIC technique. We can observe the development of different patches for the nucleation of the instabilities. In particular, they are smaller in the experiment m0021 than in the experiment m0022.

To address this gap, we have developed the MEERA apparatus at Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome. MEERA is a novel multi-axial press that applies complex, servo-controlled shear (up to 150 kN) and normal (up to 100 kN, 20 MPa) loading paths on large-scale cement samples ($300 \times 80 \times 45$ mm³), simulating conditions relevant to the upper crust. The mechanical loading and control data (piston force and displacement) is combined with a multi-scale monitoring system that integrates surface deformation mapping via Digital Image Correlation (DIC), fault-parallel strain measurement with embedded fiber-optic Bragg grating sensors, and acoustic emission monitoring via Acoustic Emissions (AEs).

Here, we performed stick-slip experiments at 10 MPa normal stress and a far-field load point velocity of 1 $\mu\text{m/s}$ on cement samples under air humidity conditions. With pressure films we mapped the initial fault zone heterogeneity. For each stick-slip cycle, we obtained: i) from analysis of the mechanical data: stress drop and duration, preseismic and coseismic slip ii) with DIC methods the nucleation patch length during the stick phase, and iii) with AEs we recorded precursory events in the stick phase and the release of energy during the slip phase. We correlate the initial fault heterogeneity with the evolution of the nucleation patch length and, possibly, with the early P-wave signals recorded by AEs during the subsequent stick-slip cycles.

This research is conducted within the framework of the ERC Synergy Grant FEAR and the ERC Starting Grant FORESEEING. By resolving the preparatory phases of fault slip with exceptional detail, we aim to identify robust precursory signals that could distinguish between the nucleation of small and large earthquakes. Ultimately, these laboratory-derived insights are a critical step toward developing more physically constrained and effective earthquake early warning systems (Figure 29).

Experimental Study of Transient Fault Slip and Accelerated Creep in Shallow Subduction Zones (Sunda Megathrust, Indian Ocean)

Spagnuolo E., Aretusini S., Di Toro G., Vannucchi P.

Based on: Spagnuolo, E., Aretusini, S., Di Toro, G., & Vannucchi, P. (2025). Experimental study of transient fault slip and accelerated creep in shallow subduction zones (Sunda megathrust, Indian Ocean). *Journal of Geophysical Research: Solid Earth*, 130, e2024JB029686. <https://doi.org/10.1029/2024JB029686>

Strain accumulation and release in shallow sections of subduction zones results in a broad variety of fault slip behaviors, from slow aseismic creep to abrupt coseismic slip. The variety of slip styles in megathrust environments remains a matter of debate although the role of pressurized fluids is increasingly substantiated.

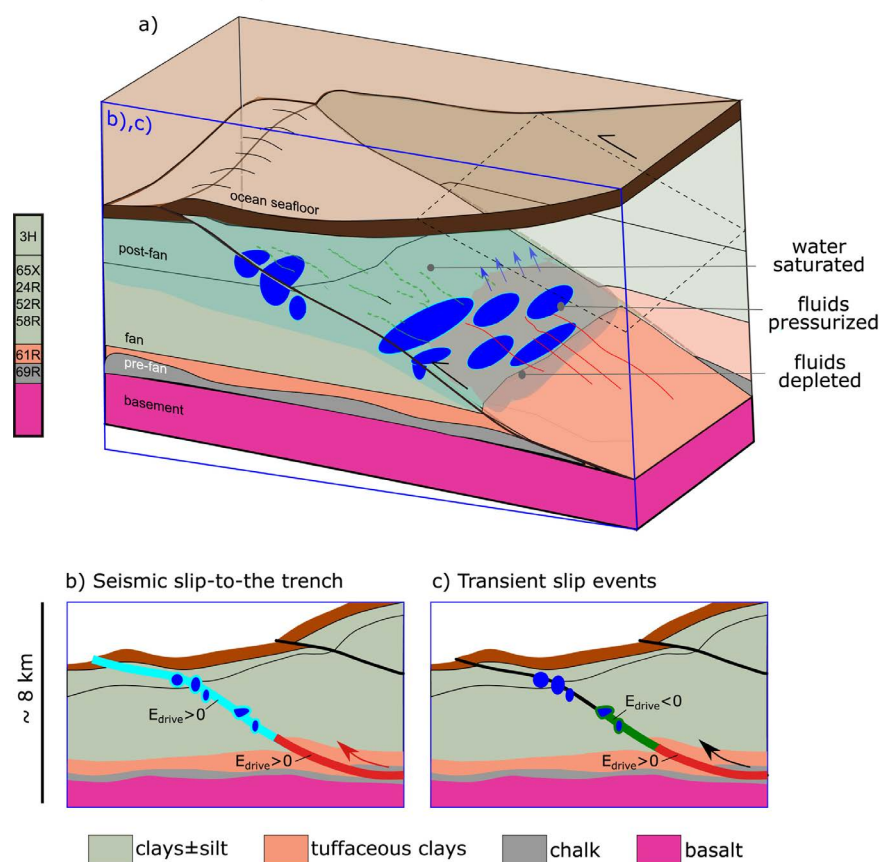


Figure 30 Conceptual model for the fluid- and lithological- dependent mechanical behavior of the shallow Sunda megathrust and associated accretionary wedge. **a)** The block diagram model generates from the geological structure and the experimental results. In cross sections **b)** and **c)**, different slip events are expected because of interacting volumes of sediments with varying lithology and water content. Blue arrows indicate possible pathways for fluid escape. We envision two possible scenarios. **b)** Seismic slip-to-the-trench: a rupture originating from depth (red arrow) propagates at first within the poorly saturated to water depleted tuffaceous clays (red solid line) which can accumulate large elastic strain energy and have large dynamic stress drops ($E_{drive} \gg 0$). Then, rupture propagates easily within either the wet or fluid pressurized clays $\pm$ silt-rich sediments with $E_{drive} > 0$ (cyan solid line). **c)** Transient slip events: the stress redistribution either due to the slow tectonic loading or to a nearby seismic event (black arrow) would produce transient slip events which are fast and seismic in the tuffaceous clays (red solid line) and accrue slip and eventually arrest ($E_{drive} \cong 0$) in the poorly saturated to water depleted clay $\pm$ silt fan sediments (green solid line).

Yet, understanding the lithological characteristics of sediments in the shallow portion of megathrusts significantly contributes to this debate and can be elucidated through a suite of experiments also accounting for the loading history. Compelling evidence originates from 49 newly conceived friction experiments performed under water depleted, dampened, and pressurized conditions on sediments with varying composition sampled during the Oceanic Drilling IODP Exp. 362 ~225 km seaward of the Sunda trench. Experiments were performed under velocity- (imposed slip pulses) and shear stress- (spontaneous slip pulses) control conditions. The experiments documented that sediments are frictionally strong, leading to acceleration of creep, transient slip instabilities and eventually seismic slip. However, depending on the water content and composition, the same sediments are also frictionally weak, enough to store limited elastic strain energy and arrest or decelerate slip instabilities. Our experiments highlight the relevance of compositional-dependent frictional properties on the heterogeneous coseismic slip distribution to the trench, afterslip and transient slip events in the area that hosted the 2004 Mw 9.2 Sumatra-Andaman earthquake (Figure 30).

Healing behavior of Pozzolanic cements at low normal stresses

Volpe G., Pozzi G., Collettini C.

Based on: Volpe, G., Affinito, R., Calzolari, L., Pozzi, G., Marone, C., & Collettini, C. (2025). The influence of cementation on fault stability. *Earth and Planetary Science Letters*, 671(3739), 119674. <https://doi.org/10.1016/j.epsl.2025.119674>

Frictional healing is a fault restrengthening mechanism that leads to an increase in fault resistance with the duration of stationary contact. This process is driven by an increase in both the number and the quality of asperity contacts, promoted by plastic deformation at the asperity scale. In addition to frictional healing, fault restrengthening may also result from chemical processes such as pressure solution, lithification, and cementation.

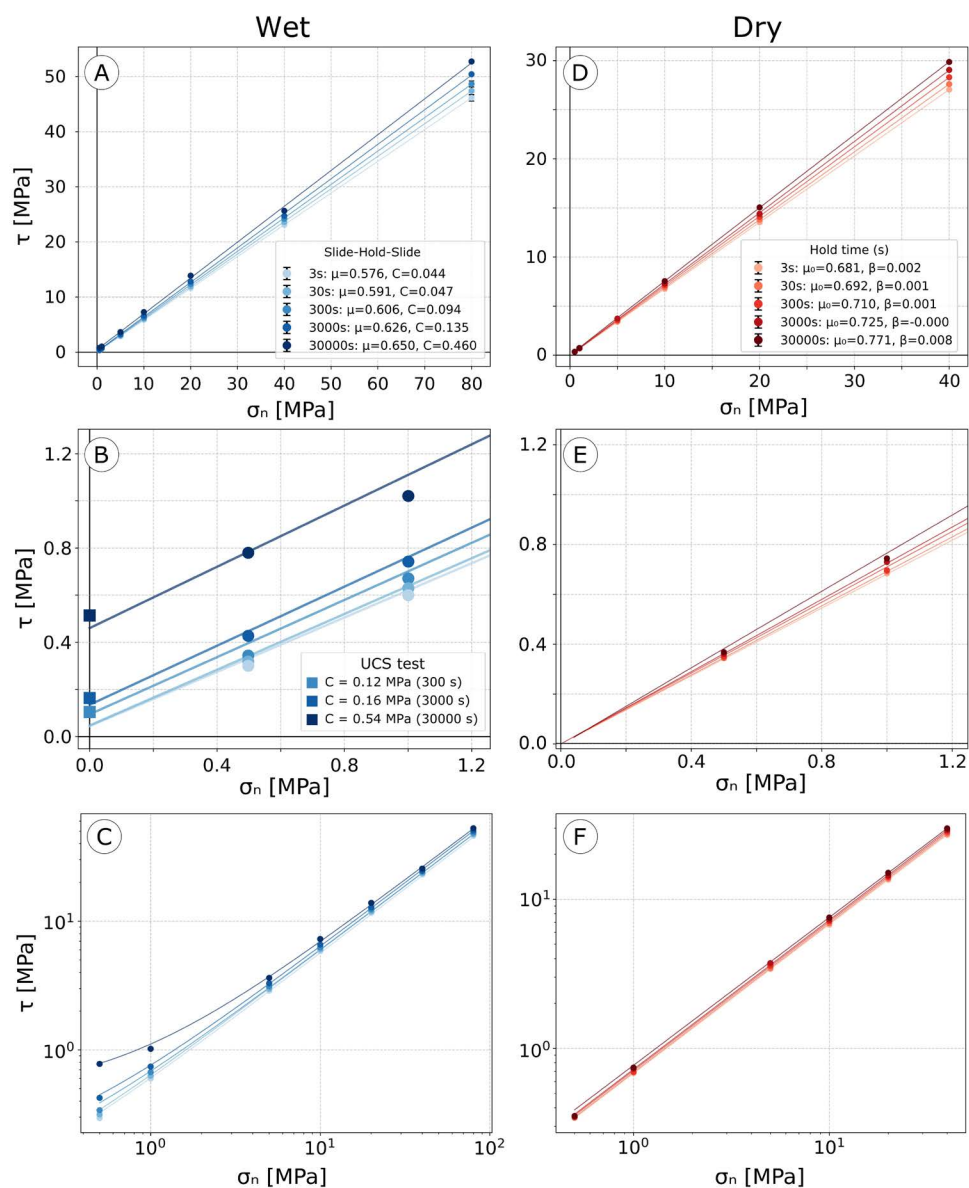


Figure 31. Peak frictional resistance of pozzolanic mortar in wet and dry conditions during slide-hold-slide experiments (circles) conducted at hold times of 3, 30, 300, 3000, and Unconfined Compressive Strength (UCS) tests (squares), conducted at curing times of 300, 3000, and 30000 seconds. The figure illustrates the evolution of peak shear strength as a function of both normal stress and hold time for wet (panels A-C) and dry (panels D-F) respectively.

These mechanisms are particularly relevant in natural settings, where the presence of fluids, elevated temperatures and pressures, and geological timescales favor their activation. Field observations commonly show that fault materials are cohesive, suggesting that chemical healing processes operate in nature and lead to a time-dependent increase in fault cohesion, thereby strongly influencing fault mechanical behavior. If faults develop cohesion, they may become seismogenic even at very low normal stresses. In contrast, cohesionless fault materials (e.g., gouges), in which frictional healing dominates, are expected to exhibit negligible healing at low normal stress due to the strong normal-stress dependence of frictional healing, thus inhibiting seismic slip. However, seismological observations of both natural and induced seismicity indicate that earthquakes can nucleate at very shallow depths, where stress conditions should favor stable sliding according to classical frictional models. This discrepancy suggests that additional healing mechanisms capable of promoting unstable slip may operate at low normal stresses. To address this issue, we investigated the healing behavior of pozzolanic cement over a wide range of low normal stresses (0-80 MPa) under both dry and wet conditions, in order to discriminate between the effects of chemical and frictional healing. Our results show that cementation leads to faster and more pronounced fault restrengthening than frictional healing, even at low normal stresses. Moreover, chemical healing produces a measurable increase in cohesion, whereas frictional healing does not generate cohesion for any of the hold times investigated. We also find that shear stress restrengthening associated with chemical healing scales linearly with normal stress, while frictional healing follows a nonlinear power-law relationship, suggesting a change in contact mechanics with increasing normal stress. Overall, our findings demonstrate that chemical healing processes such as cementation can dominate fault mechanical behavior at low normal stresses, significantly enhancing the seismogenic potential of faults at shallow depths, where classical friction-based frameworks predict stable sliding (Figure 31).

Experimental characterization of the fault stability of the materials from the Pohang EGS Site - South Korea

Woo S., Volpe G., Coppola L., Collettini C.

Original contribution prepared for the HPHT Lab Annual Report 2025

In 2017, a Mw 5.5 earthquake struck the Pohang region, representing the most damaging seismic event in South Korea. This seismic event was triggered by hydraulic stimulation at the Pohang Enhanced Geothermal System site. Despite the paramount importance of this seismic event, the frictional properties of the rock from the Pohang system remain poorly constrained.

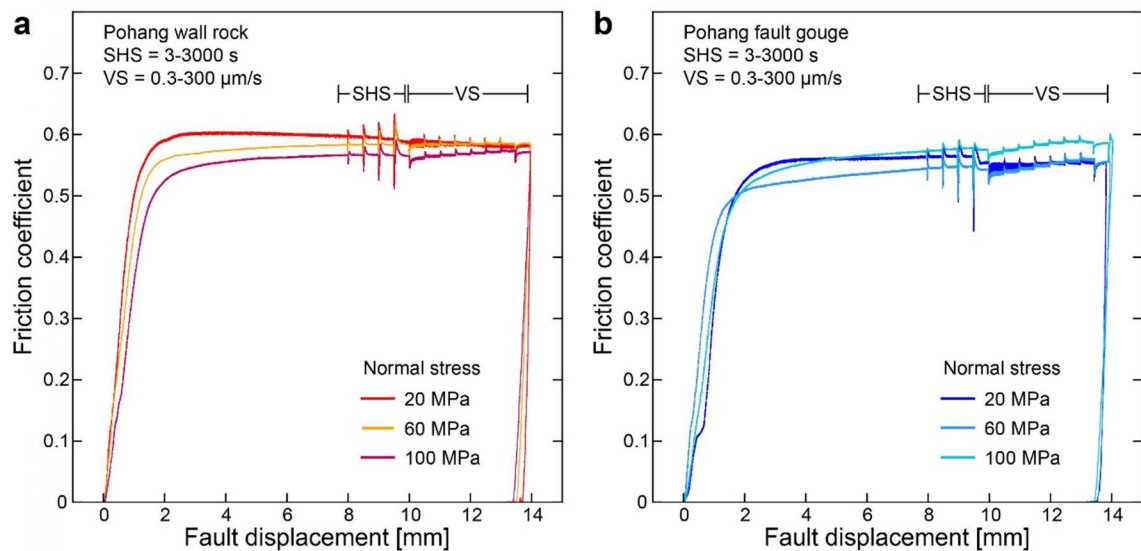
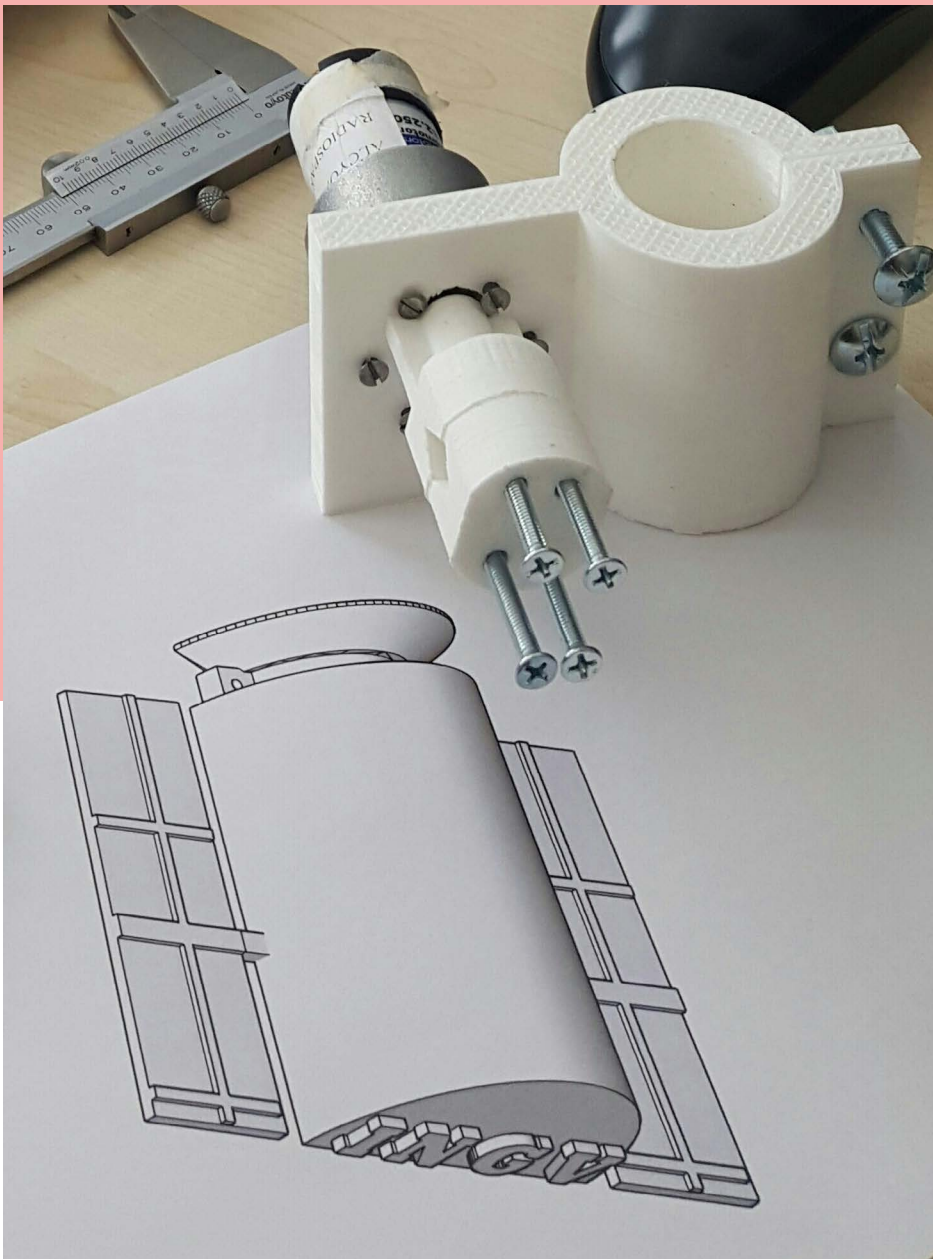


Figure 32. Friction coefficient (μ) versus fault displacement for wet double-direct shear experiments on Pohang PX-2 materials: **a)** granodiorite wall-rock powder and **b)** fault gouge. Tests were conducted at normal stresses of 20, 60, and 100 MPa. The loading history consists of a run-in followed by slide-hold-slide sequences (SHS; hold times 3-3000 s) and subsequent velocity-stepping (VS; 0.3-300 $\mu\text{m/s}$). Steady-state friction is $\mu = 0.59$ for wall-rock powder and $\mu = 0.56$ for fault gouge.

This motivates our experimental study aimed at the characterization of the frictional properties and the slip behavior upon fluid-induced reactivation of the granodiorite wall rock powder and on the fault gouge recovered from the Pohang PX-2 borehole (~3.8 km depth). We firstly assessed the mineralogical assemblage of the two fault materials that consists of a mixture of quartz, feldspars, plagioclase and phyllosilicates (mostly chlorite), these last varying between 15% and 23% for the wall rock and the fault gouge respectively. We then assessed the frictional properties (friction, healing rate and velocity dependence of friction) of the two fault materials under water-saturated conditions at normal stresses of 20-100 MPa using BRAVA (Brittle Rock deformAtion Versatile Apparatus) hosted at the National Institute of Geophysics and Volcanology (INGV). We performed frictional experiments in double direct shear configuration with an experimental procedure consisting of a run-in at 10 $\mu\text{m/s}$, a slide-hold-slide test (SHS; hold time ranging between 3 and 3000 seconds hold) and velocity-steps tests (VS; velocity ranging between 0.3 and 300 $\mu\text{m/s}$). Steady-state friction coefficients for both materials fall close to the Byerlee range ($\mu \approx 0.55$ -0.62). SHS tests reveal a clear contrast in frictional healing; wall rock powder exhibits greater healing rate ($\beta \approx 0.0025$ -0.004) than

fault gouge ($\beta \approx 0.0006-0.0015$; Figure 32). The velocity dependence of friction, represented by the $a-b$ parameter: the wall rock shows a slightly velocity-weakening to neutral behavior ($a-b = -0.0007 - 0.0020$), while fault gouge is predominantly velocity neutral to strengthening ($a-b = 0.005 - 0.0028$) over the tested stress and velocity range. These results, within the rate and state friction framework, suggest that the granodiorite wall rock may have a greater tendency toward unstable slip under elevated pore-pressure conditions than adjacent fault gouges. Overall, our results will help quantify how lithological heterogeneity, rate-and-state parameters, and pore-pressure evolution govern slip stability and the nucleation potential of injection-induced earthquakes in geothermal settings with important implications for induced seismicity hazard assessment.

2.3 Technology and Innovation



Upgrade of a Gas Measurement System for Remote Operated Terrestrial Platform

Acerra C., Spinelli G., Gasparini A., Mari M.

Based on: Acerra, C., Spinelli, G., Gasparini, A., Mari, M. *A gas measurement system for remote operated terrestrial platform*. Annual Report 2024 HPHT - NTS LABS

As part of the FURTHER departmental project, the LNTS laboratory developed a specialized gas measurement system integrated into a terrestrial Remote Operated Vehicle (ROV). Designed for deployment in harsh and inaccessible environments, the system features a multi-level sensing architecture. It utilizes ten sensors including AlphaSense gas sensors (O_2 , H_2S , CO_2) and an E+E Elektronik anemometer-distributed at heights of 1m, 0.5m, and ground level to map gas concentrations and fluxes in relation to wind patterns. Data management is handled by an Arduino-based CPU for A/D conversion, GPS timestamping, and local SD storage, powered by the vehicle's internal battery network.

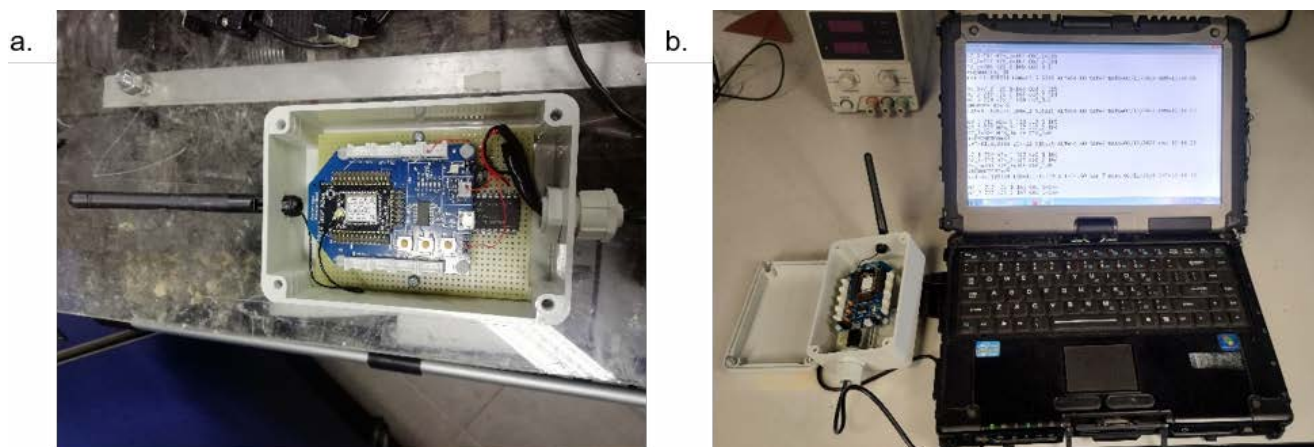


Figure 33 a) Transmitter unit of the telemetry subsystem. b) Fixed Base Station (Receiver unit + laptop).

Wireless Telemetry Integration

To enhance operational monitoring, the system has been upgraded with a specialized wireless telemetry link, allowing for the near real-time observation and recording of data at a fixed base station. This communication layer complements the local SD storage and was implemented using a pair of DIGI XBee 3 Wi-Fi/RS232 modules (Figure 33 a, b). The modules are configured for a unidirectional point-to-point link, transmitting data from the mobile ROV to the remote terminal.

Technical Implementation and Hardware Refinement

The integration of this telemetric upgrade necessitated specific hardware and software adjustments to ensure signal stability and power integrity:

- **Power Supply Management:** A dedicated 12V power supply, isolated from the other subsystems, was implemented for the transmission module on the ROV to prevent

interference.

- Receiver Configuration (Figure 33b): The receiving unit at the fixed station is interfaced directly via a USB/RS232 port on a laptop, which serves as both the monitoring terminal and the power source for the module.
- Signal Optimization: Both units are equipped with Wi-Fi stub antennas, providing a line-of-sight operational range of approximately 200 meters, as specified by the manufacturer.

Experimental Simulation of Volcanic Vortex Rings: Apparatus Design and Analytical Framework

Iezzi F., Taddeucci J., Pennacchia F., Palladino D.M., Scarlato P.

Original contribution prepared for the HPHT & LNTS Lab Annual Report 2025

A new experimental apparatus was designed to perform analog simulations of volcanic vortex rings through a controlled horizontal configuration. The setup consists of a smooth-walled, transparent polycarbonate cylindrical tube coupled with a spring-loaded piston mechanism (Figure 34a). The experimental procedure involves introducing neutral-density white smoke as a flow tracer before manually retracting the piston to compress the spring. Upon rapid release, the piston ejects a specific gas volume from the tube nozzle, generating a coherent toroidal vortex ring that propagates into the ambient air. By systematically varying piston stroke lengths and spring elasticity, the bursting of gas slugs with different volumes and velocities was simulated to investigate vortex ring formation and evolution.

Data acquisition was performed using a synchronized multi-camera system to capture the process with high temporal and spatial resolution. A high-speed camera focused on the initial 30-40 cm from the nozzle to document ejection, pinch-off, and early development phases (Figure 34b), while a 4K visible spectrum camera recorded a broader field of view (up to 2.5 m) to track propagation until the final breakdown phase (Figure 34c). The resulting analytical framework enabled the precise tracking of vortex ring position and radius over time, allowing for the determination of rise velocity and expansion rates. Finally, dimensionless parameters were calculated to ensure a robust comparison between laboratory-reproduced rings and those naturally emitted during volcanic activity.

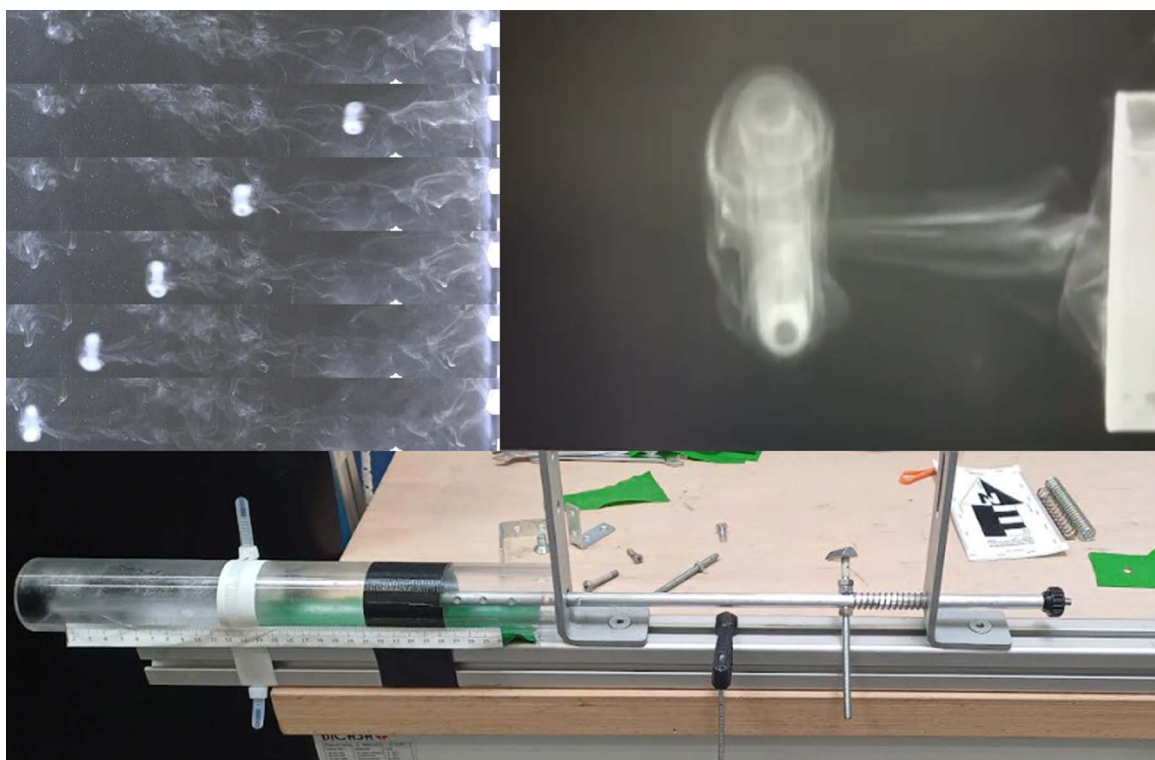


Figure 34 a) Experimental setup, consisting of a smooth-walled tube and a spring-driven piston. b) High-resolution, high-speed recording of vortex ring ejection from the tube nozzle during the pinch-off phase. c) Montage of video frames recorded with a 4K visible camera, showing vortex ring evolution and propagation.

Evaluation of Ground Surface Temperature using Thermal Gradiometers

Pongetti F., Acerra C., Iarocci A., Romeo G.

Original contribution prepared for the HPHT & LNTS Lab Annual Report 2025

For several years, we have been developing and testing various types of thermal gradiometers across a wide range of measurement scenarios.

A thermal gradiometer consists of spatially separated temperature sensors aligned along a linear axis, enabling direct measurement of the temperature gradient.

Specifically, when investigating natural soil or ground, we focus on the vertical axis, as heat naturally propagates in this direction, generating measurable thermal gradients.

The gradiometer is constructed as an array of temperature sensors mounted along a rigid probe at close intervals (typically a few centimeters). While Earth's surface temperature is a key metric across various geophysical disciplines, for large-scale spatial analysis, it is frequently monitored via infrared radiometry from ground-based observatories or satellite platforms.

Conversely, direct measurement of ground surface temperature via contact sensors at the air-soil interface remains challenging and highly susceptible to environmental noise and measurement errors. To address this, we evaluate soil surface temperature from a subsurface perspective. We have developed a laboratory experimental setup to verify the feasibility of estimating surface temperature within a localized area using a gradiometer. This device features closely spaced sensors, strategically embedded in the immediate proximity of the surface.

Experimental Setup

Figures 35a,b illustrate the initial configuration. The gradiometer, comprising five temperature sensors, is embedded within a granular soil sample (fine sand). It is oriented such that the uppermost sensor is in close proximity to the surface. An infrared (IR) radiometer is positioned above the gradiometer, with its field of view (FOV) centered on the sensor area. The entire soil container is placed atop a heating furnace, which is cycled on and off to induce a bottom-up thermal flux, thereby simulating a natural vertical temperature gradient. Data acquisition is managed by an Arduino microcontroller, which synchronizes the readings from both the gradiometer and the IR sensor, appending timestamps before transmitting the data strings to a recording unit.

Experimental Procedure

The primary objective of this experiment is to estimate the sand surface temperature using the five-sensor gradiometer array and to validate these results against the infrared (IR) sensor measurements. The IR data serves as the reference ground truth; consequently, the accuracy of the gradiometer is evaluated based on its convergence with the IR readings. In the laboratory, the sand sample was heated from below and subsequently allowed to cool (Figure 35c), reaching a peak surface temperature of approximately 40 °C. To validate the system in a real-world environment, similar experiments were conducted in-situ (Figure 35d), where thermal fluctuations are driven by natural atmospheric conditions and diurnal cycling. To ensure consistent thermal coupling, the same type of sand used in the laboratory was embedded into the outdoor test site.

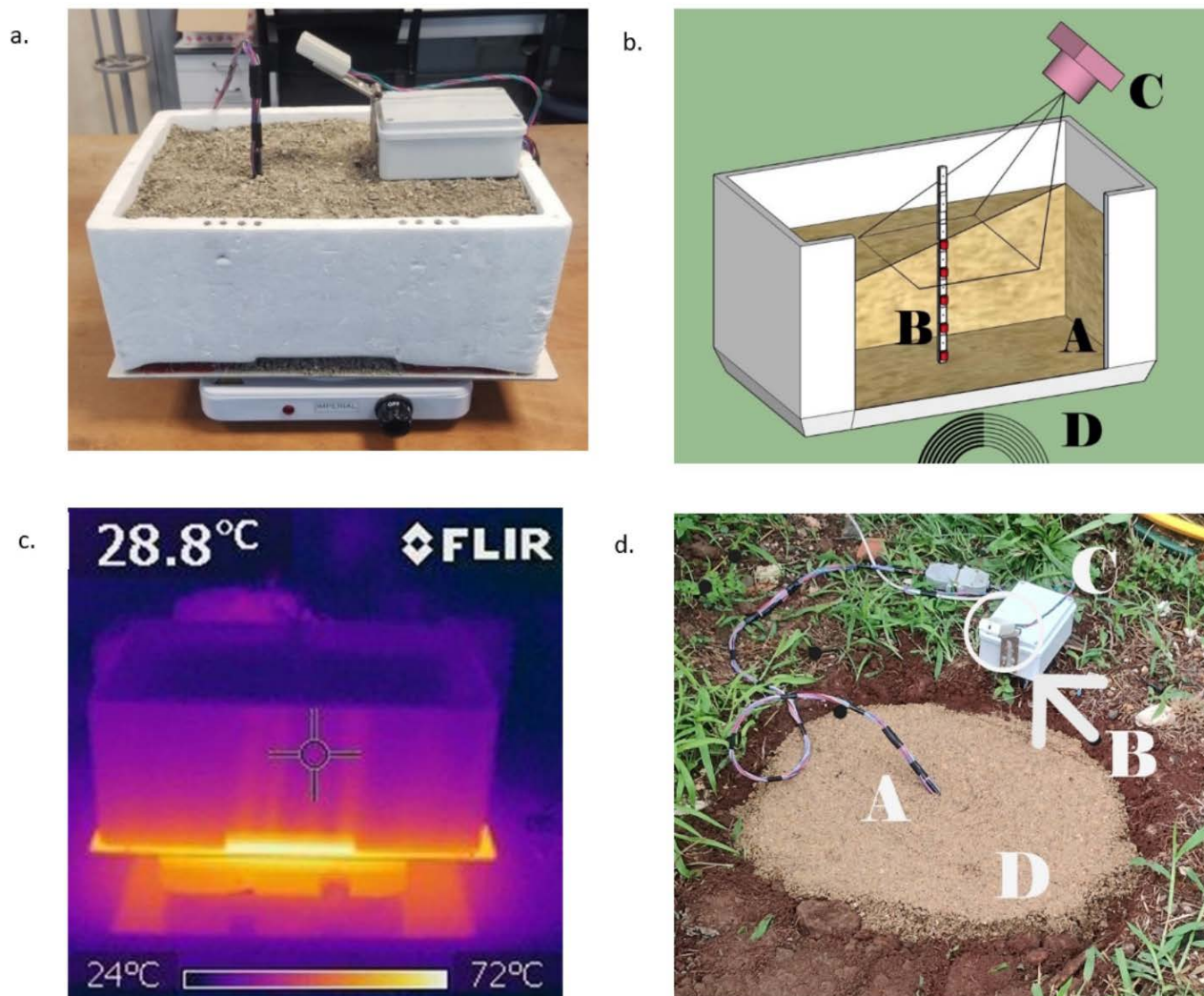


Figure 35 a) The indoor setup. b) The indoor setup block diagram: A) Box (thermally insulated) containing sand; B) buried gradiometer (in red contact thermometers; C) Infrared sensor pointing to measurement area; D) heating oven under the sand. c) Once turned on the oven it generates a thermal gradient. d) The outdoor experimental setup (with the same sand used in the laboratory); A) gradiometer; B) Infrared sensor; C) Data acquisition board; D) Sand.

Results

Laboratory data demonstrated strong correlation; however, in-situ measurements exhibited significant environmental noise, primarily attributed to fluctuating atmospheric and sky conditions. To account for these multifaceted influencing factors, a Machine Learning approach was implemented. Specifically, an Artificial Neural Network (ANN) was trained using input data from both the gradiometer and the infrared sensor to accurately reconstruct the surface temperature profile. This computational model aims to mitigate external interference and optimize the estimation process. Preliminary results are highly encouraging, demonstrating the feasibility of the proposed method for indirect surface temperature monitoring.

Experimental Setup: High-Speed Schlieren Visualization of Simulated Volcanic Jets

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Original contribution prepared for the HPHT & LNTS Lab Annual Report 2025

This experimental apparatus was developed to investigate the complex fluid dynamics of volcanic eruptions by recreating subsonic to supersonic jets and pressure waves in a controlled environment (Figure 36). The primary scientific objective is to parameterize transient eruptive processes, correlating visual data with pressure and velocity measurements to validate theoretical models and numerical simulations of natural volcanic jet behavior.

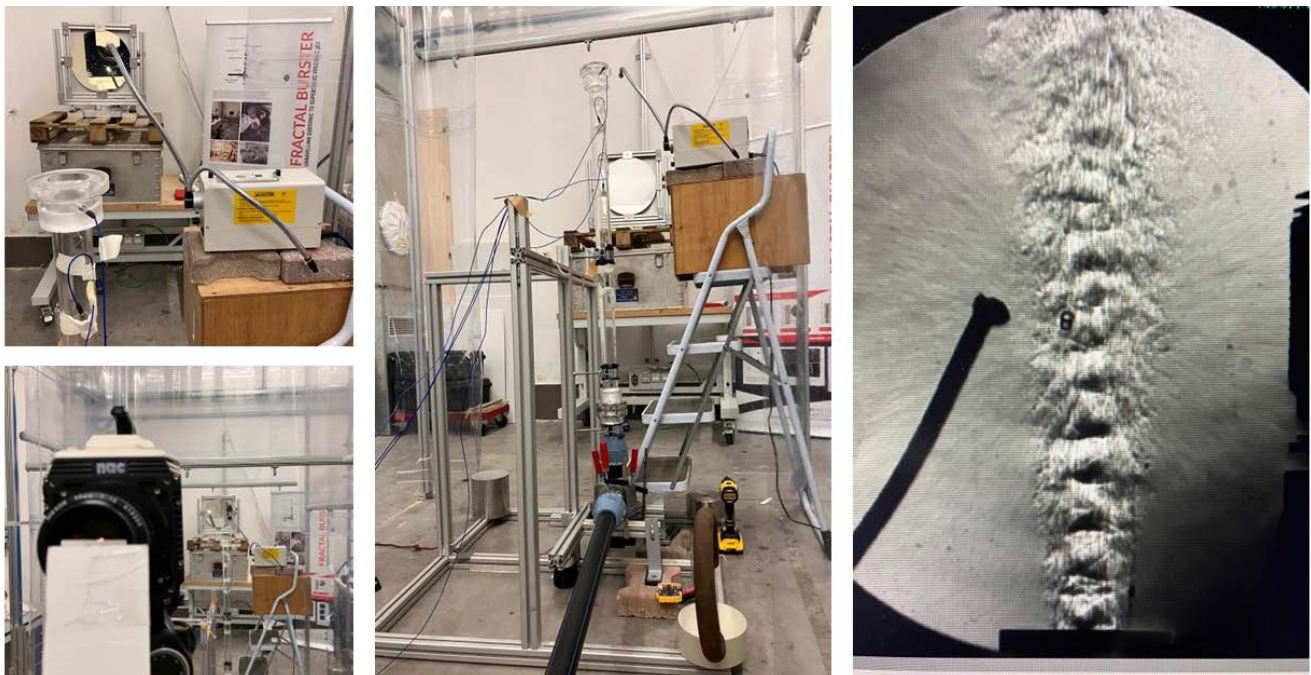


Figure 36 High-speed double-mirror Schlieren setup for simulated volcanic jets. (Top-left) The light source and the first mirror used to collimate the light beam. (Bottom-left) The high-speed camera positioned behind the knife edge. (Center) The “Jet Burster” experimental facility, showing the polycarbonate conduit and pneumatic system. (Right) High-speed Schlieren visualization revealing complex density gradients and shock structures generated by release of pressurized air.

The physical simulation of a volcanic vent is achieved through a custom-built pneumatic system termed the “Jet Burster.” This system comprises a high-transparency polycarbonate conduit acting as a volcanic analog, coupled to a pressurized gas reservoir at its base. The actuation is managed via a fast-acting solenoid valve; upon triggered release, a highly energetic pressure wave is driven up the tube. As the high-speed jet exits the conduit into the ambient environment, it mimics the fluid dynamic stresses and localized air density variations of a natural volcanic blast.

To visualize these otherwise invisible density gradients, the setup employs a double-mirror Schlieren imaging technique in a classic Z-pattern configuration. The optical system utilizes a high-intensity light source directed onto a first large parabolic mirror, which reflects a beam of collimated light across the test section above the conduit. As the light passes through the

transient flow field, localized variations in the refractive index-caused by shock waves or rarefaction waves-deflect the light rays. A second parabolic mirror focuses the beam toward a focal point where a “knife edge” is precisely positioned. This cutoff plane partially blocks the deflected rays, translating phase shifts into amplitude variations.

Due to the highly transient nature of these phenomena, data acquisition is performed using a high-speed camera positioned behind the knife edge. Operating at extremely high frame rates and short exposure times, the system enables the detailed capture of complex aerodynamic features developing near the nozzle exit, including supersonic shock patterns, vortex formations, and Mach disks. These features are rendered visible as distinct bright and dark regions, providing a high-resolution spatial and temporal record of the simulated eruption dynamics.

Laser range finder upgrade for SKATE setup (System for Kinematic Acquisition of Transient Eruptions)

Taddeucci J., Del Bello E., Scarlato P., Pennacchia F.

Original contribution prepared for the HPHT & LNTS Lab Annual Report 2025

The SKATE setup (System for Kinematic Acquisition of Transient Eruptions, Figure 37), is composed of multiple synchronized components. These include a thermal camera (Optris PI 640i, 640×480 pixels, 16 Frame Per Second, FPS, with two temperature ranges: 0-250°C and 150-900°C), a high-speed and high-resolution camera (DS-CAM-600, 1-250 FPS), a microphone (GRAS 146AE, 3.15 Hz to 20000 Hz, 50 mV/Pa), a GPS for time synchronization, and a data acquisition and triggering system (Dewesoft SIRIUS-SBOXe).

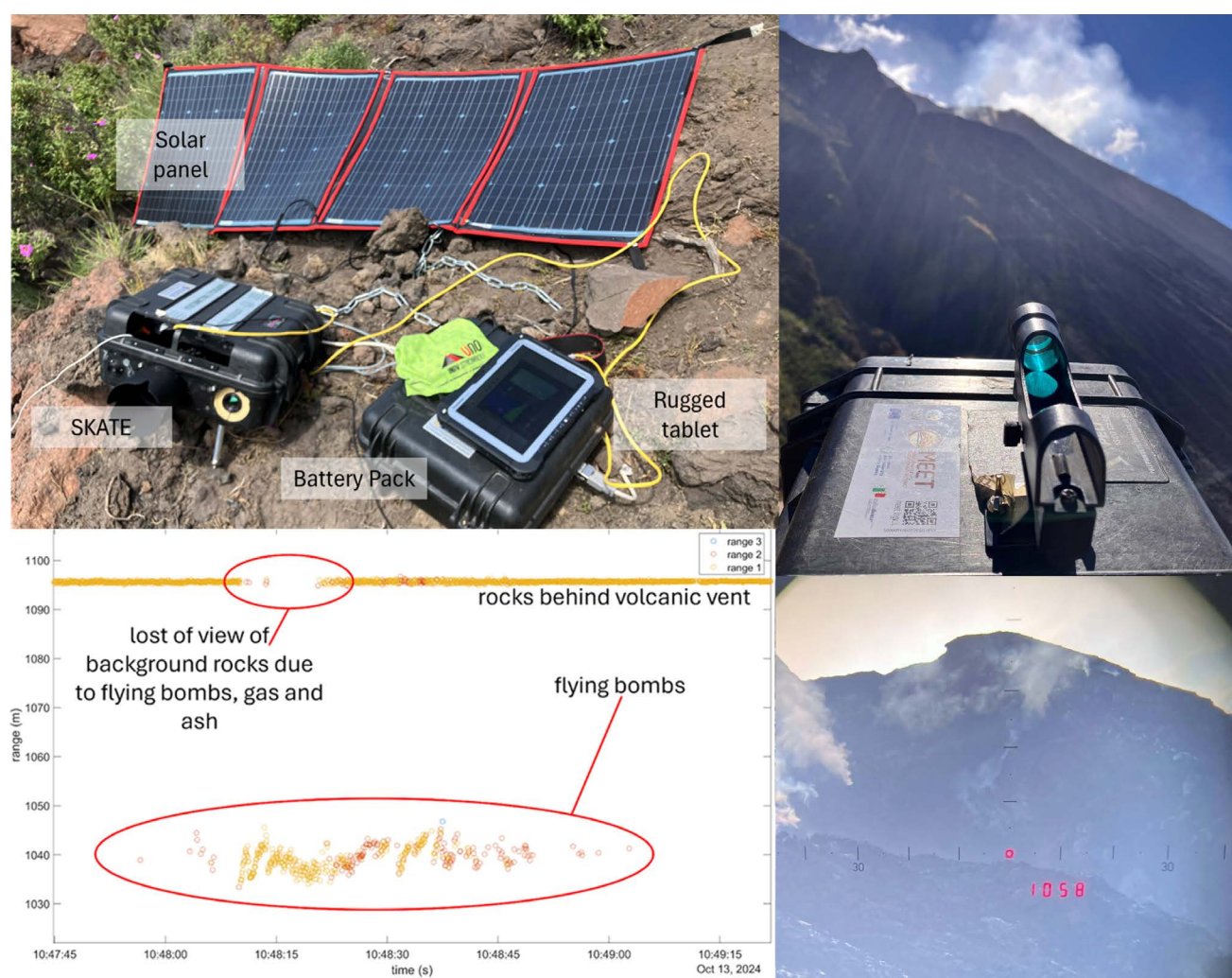


Figure 37 Top left: SKATE in its most recent and upgraded configuration. Top right: Close-up view of the newly integrated laser range finder in operation at Stromboli volcano (Italy), aimed at the active North Crater (N1). The measurement target is indicated by the red dot above the vent (bottom right). Bottom left: Preliminary results illustrating the time series of ranges (distance) recorded for ballistic bombs traveling through the instrument's field of view above the active vent.

The system allows for faster and safer deployment, reduces the weight and volume of equipment, and requires fewer operators for setup and installation. It enables continuous automated data acquisition for 24 hours. One limitation of the previous version was the lack of a 3-D perspective of the eruptive events, being the camera views unable to provide information about motion towards or away from the setup. To overcome this limitation, we implemented the integration in SKATE of a continuously recording laser range finder. The laser provides constant, at a rate up to 20 Hz, measurement of the distance from the setup of a selected point, with a precision better than one meter. The distance data are recorded in sync with the other skate data. Preliminary tests have demonstrated the capability of the laser to measure the distance of ash plumes and vent walls, thus complementing in the third dimension the spatial data provided by the cameras.



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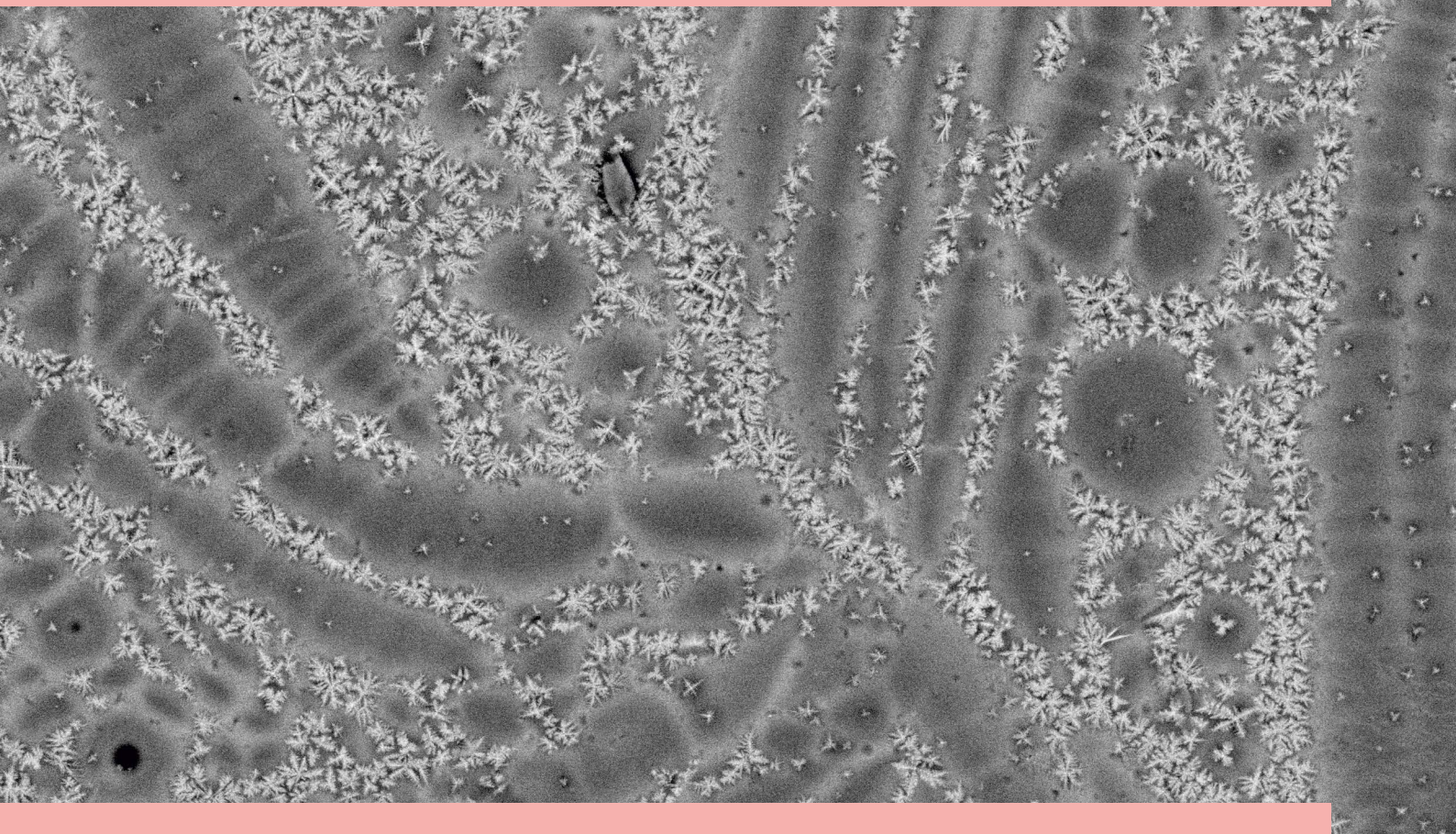
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