

Session 1

TALKS:

Volcano-tectonic systems: opportunities and challenges

V. Acocella

Volcano-tectonic systems are characterized by stress-deformation processes, occurring at different scales, related to the accumulation, transfer and eruption of shallow magma. These processes may be magma-induced and/or promote the propagation of magma, also providing the theoretical foundation to eruption forecasting.

This overview focuses on volcanic systems associated with faulting and seismicity, considering examples of caldera dynamics, volcano flank instability, dike propagation and regional tectonic activity. This provides the opportunity to highlight recent advancements, as well as major challenges for the next decades.

Deep Learning for a Clearer View of Magmatic Processes

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We have applied deep learning (DL) earthquake monitoring workflows to several restless magmatic systems including Campi Flegrei and the Aegean Volcanic Arc near Santorini. In both cases we increase the number of detected events by at least a factor of four, and in the process provide new insight into deformation driven by magmatic processes. In the case of Campi Flegrei we have shown that there are discrete fault structures under Pozzuoli, that the ring fault is active over a very narrow depth range, that the depth of seismicity of recent earthquake activity is less than ~ 4 km, and that hybrid earthquakes are located in a spatially confined region at less than 1 km depth. This monitoring capability is now operational at Osservatorio Vesuviano such that they can detect subtle changes in seismicity and will have a much richer observational foundation to inform the response to any future crisis. In the case of the Aegean Arc the monitoring environment is more challenging; however, we find a similar gain in the level of clarity of the depth and evolution of earthquake activity during the February, 2025 seismic crisis. The crisis has subsided for now; however, the Aegean Arc lacks a dedicated observatory to monitor the situation. Given the past history of eruptions on this arc, this is

concerning. The current deployment of deep learning for monitoring magmatic systems is applied unevenly and on an ad hoc basis. While deep learning approaches present some challenges in their reliability for operational monitoring, these challenges can be addressed. Our experience suggests that an international effort towards a more systematic approach would have the potential to accelerate progress in understanding magmatic systems and provide more reliable information for hazard response.

Quantitative comparison of different structural models of Campi Flegrei using full waveform similarity

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Campi Flegrei, a densely populated Holocene caldera west of Naples, has been experiencing a new phase of ground uplift since 2005, accompanied by intense shallow seismicity that reached unprecedented magnitudes (Md 4.4–4.6) in 2024–2025. This ongoing unrest is causing significant public concern and has triggered extensive tomographic efforts, leading to a growing number of studies aimed at constraining seismic wave propagation within this complex volcanic structure. However, these studies often yield conflicting results.

In this study, to assess the structural models of Campi Flegrei available in the literature and provide a clearer picture of the current understanding of the volcanic system, we performed 384 forward simulations of seismic wave propagation within the caldera using the spectral element method software SPECFEM3D (Peter et al., 2011). These simulations combine 64 earthquakes located within the caldera area with six different wavespeed models. The tested models include: (1D_AF) a 1D model by Zollo et al. (2003) without topography; (1D_A) the same model incorporating regional topography; (1D_B) a 1D model by Vanorio et al. (2005); (3D_A) a 3D model including local attenuation from Calò & Tramelli (2018); (3D_B) the 3D P- and S-wave seismic images by De Landro et al. (2025); and (3D_C) the local tomographic model from Giacomuzzi et al. (2024).

Simulations were carried out using event-specific scaled moment tensors derived from the focal mechanisms of Tan et al. (2025). The quantitative comparison between observed and synthetic waveforms across the different models was carried out using the Dynamic Time Warping (DTW) technique, providing a similarity measure between the two signals.

The analysis of the similarity metrics highlights that accounting for realistic topography in such a complex volcanic area improves the fit between observed and synthetic data. The transition from 1D to 3D structural models generally results in higher similarity values, emphasizing the importance of incorporating three-dimensional heterogeneities in seismic wave propagation studies. Among the tested models, the one proposed by Giacomuzzi et al. (2024) (3D_C) consistently yields the highest similarity values, outperforming the others. This is mainly due to its enhanced ability to reproduce the complexity of the observed waveforms, particularly beyond the first arrivals, where other models tend to fail. This framework enables the estimation of Mw for the analyzed events, for which only Md values are currently available. Given that the 3D_C model yields the highest similarity between observed and synthetic waveforms, the corresponding Mw estimates are regarded as the most physically reliable, providing a robust basis for future tomographic refinements and for investigating the relationship between Mw and Md.

Recent tectonic activity in the southern flank of Mt. Etna

R. Azzaro, S. Brooks, F. Guglielmino and the OE Monitoring Working Group

To be defined

Crustal Architecture and Tectonic Evolution of the Somali Margin: Implications for Deep-Subsurface Investigations

Yonis Ali Yusuf

The Somali margin is considered a key transition zone within the East African rift system with complex tectonic history and thick sedimentary sequence. With the Somali Petroleum Authority (SPA) progressing with its national hydrocarbon investigation program, the inclusion of deep crustal geophysical models is considered crucial for accurate subsurface imaging. In this contribution, the capability of applied geophysics as seismic velocity modeling and gravity-magnetic integration for the definition of the lithospheric characteristics of the Somali basin will be investigated, and deep-crustal tectonic features will be used to refine geothermal models. The aims of the present contribution are twofold: (1) to align the SPA technical exploration process with the advanced seismic

monitoring and modeling techniques developed by INGV and BSL and (2) to establish the geophysical baselines.

POSTERS:

Seismic and acoustic markers of solid loading in volcanic jets: a laboratory approach

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Tracking the evolution of the physical properties of volcanic plumes through geophysical signatures is a primary objective for both fundamental research and hazard monitoring. However, the dynamic fingerprints of explosive volcanic processes are difficult to constrain in natural seismo-acoustic records. A laboratory-based approach offers a distinctive advantage, allowing for the controlled manipulation of individual phases and property within a scaled analogue system. To map the properties of the elastic field associated with subsonic and supersonic volcanic jets under varying gas/solid ratios, we generated a dataset of 120 analogue jets using a shock tube. The setup was modified to allow controlled loading of solid particles (glass microspheres, 0.5–1 mm diameter) at the base of the driven section. We investigated the influence of driver pressure (2-9 bar) and particle masses (1-10g) using a synchronized sensor-array comprising three microphones, three monoaxial accelerometers positioned along the conduit, and a pressure sensor at the vent. For a subset of 60 experiments, jet dynamics were captured via dual-mirror Schlieren optical visualization technique and two high speed cameras.

Preliminary results indicate that the accelerometric signals respond strongly to the internal dynamics of solid-loaded flows. This is shown by a distinct partitioning of spectral energy in wavelet transforms and a clear shift in the mean frequency (spectral center of mass). Complementary Schlieren analysis reveals that the solid phase significantly alters jet morphology, by reducing shock-cell spacing, and thus, ultimately, Mach number. These findings establish a quantitative groundwork for mapping seismo-acoustic characteristics to key eruptive variables, moving toward more robust real-time characterization of explosive activity.

Forward modelling of regional S-waveforms in the central-southern Apennines (Italy): evidences for lateral crustal velocity contrasts and shallow axial attenuation

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We present a forward waveform modelling study to investigate the regional crustal structure of the central-southern Apennines, along a NNE-SSW profile. The profile cross-cuts the Apenninic chain axis and extends from the eastern Adriatic domain, characterized by a thick crust and thick seismogenic layer, to the western Tyrrhenian domain, dominated by tectonic thinning, distributed CO₂ gas emissions at the surface and volcanic structures. This region hosted the largest earthquakes in recent history, making precise knowledge of the crustal structure crucial for a comprehensive understanding of seismogenesis and seismic hazard assessment. We analysed and modelled seismic data from two lower crustal strike-slip earthquakes in the eastern segment of the profile (2018 Mw 5.1 and 2023 Mw 4.6), recorded by the Italian National Seismic Network (IV). The two events, located along the target NNE-SSW linear profile, provide a unique opportunity to study the westward propagation and evolution of seismic phases. Using a 2-D numerical modelling approach, we modelled direct (S_g) and Moho-reflected (S_{mS}) phases on transverse component seismograms, comparing the synthetic to the observed waveforms in terms of arrival times and waveform shapes. A faster Adriatic lower crust with an average shear-wave velocity of 3.85 km s⁻¹ supports the hypothesis of distributed crustal mafic intrusions at the margin between the Apenninic chain and Adriatic foreland. We estimate a local Adriatic Moho depth of 38 km, in agreement with previous investigations. Furthermore, we identify a strong attenuation zone across the Apenninic chain axis, extending directly from the surface down to 10 km depth, significantly impacting both seismogenic processes and waveform propagation. This first, regional-scale waveform study highlights the significance of waveform analysis for constraining seismic velocities and interface velocity contrasts in the Southern Apennines mountain range.

Fault Behaviour on Mt. Etna: seismotectonics constrains from mid-term Sentinel-1 InSAR Time Series (2015–2025)

R. Azzaro, S. Brooks, R. Burgmann, F. Guglielmino

Mt. Etna hosts a complex system of active faults accommodating the seaward sliding of the Eastern flank of the edifice. Among these structures, several strike-slip and oblique faults form a dense and interacting network bounded by the Pernicana Fault to the north and the Tremestieri–Trecastagni-San Gregorio fault system to the south. These faults are characterized by heterogeneous behaviour, with

locked and creeping segments that contribute differently to deformation and seismic hazard in this densely populated region.

To investigate the spatial and temporal evolution of fault activity, we analysed a ten-year Sentinel-1 SAR time series (2015–2025) acquired in both ascending and descending geometries. Interferograms were generated using ISCE2 and displacement time series were reconstructed with MintPy, allowing the derivation of millimetric-scale ground deformation velocities across the volcano's eastern flank. The analysed period includes the December 2018 intrusive and seismic sequence, culminating in the Mw 5.0 earthquake along the Fiandaca Fault. The InSAR time series provides a detailed view of deformation before, during and after this event, allowing the separation of long-term gravitational flank motion from transient co-seismic and post-seismic deformation.

To quantify fault slip, we applied a temporal differencing approach that compares displacement time series across the hanging-wall and footwall of individual fault segments. This method isolates the displacement associated with fault slip from broader deformation signals related to volcanic inflation–deflation cycles and large-scale flank motion.

The results reveal that deformation is distributed across multiple interacting fault segments characterized by distinct kinematic behaviours. Several structures show evidence of variable slip rates and temporal changes in activity following the 2018 earthquake. The ten-year InSAR dataset provides improved constraints on the distribution of creeping and potentially locked fault patches, offering new insights into fault interaction and their role in controlling deformation and seismic hazard on Mt. Etna's eastern flank.

Sassolite precipitation at the restless Campi Flegrei volcano in Italy and the role of hydrothermal mineralogy in volcano monitoring

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While volcano monitoring commonly relies on conventional geophysical and geochemical techniques, this contribution demonstrates how hydrothermal mineralogy provides a sensitive proxy for unravelling subsurface processes in active geothermal systems and volcanic calderas, thus improving the interdisciplinary approach for study the evolving state of an active volcano.

We present results from a decade-long mineralogical survey (2012–2025) at the main hydrothermal vents of the Campi Flegrei caldera (Italy), a natural laboratory currently undergoing an escalating phase of volcanic unrest characterized by ground deformation, seismicity, and enhanced degassing.

The caldera has experienced four unrest episodes since 1950, cumulatively producing at least 4 m of uplift and thousands of earthquakes (< 3.5 km; $M < 4.6$) following a long-lasting subsidence after the last eruption in 1538. During the ongoing unrest, the total uplift registered since 2006 was approximately 136 cm, 18 cm of which cumulated in 2024, when seismicity peaked at magnitude 4.4 and in frequency (6744 events, 1525 in May), and the fumaroles were anomalously higher in H₂S, CO₂/CH₄ and lower for $\delta^{34}\text{S}$ (‰). Concurrently, the well-known Pisciarelli solfatara showed a noticeable rise in hydrothermal activity and fumarolic tremor amplitude, along with significant morphological changes, actually miming a mud vent.

For several years, the hydrothermal assemblages at Pisciarelli were dominated by native sulfur, alunite, pyrite, kaolinite, and ammonium-bearing sulfates. In 2019, the unexpected appearance of sassolite —or crystalline boric acid— marked a major shift in the hydrothermal regime. Its precipitation coincided with a tenfold increase in boron concentrations in emitted muds, the disappearance of NH₄-sulfates, and a sharp rise in fumarolic H₂S flux, synchronous (if not preceding) the phase of accelerated uplift and increased seismicity.

By integrating new and published mineralogical, chemical, and boron isotope ($\delta^{11}\text{B}$) data with geophysical observations, we interpret borate enrichment and sassolite formation as evidence for direct extraction of hot, mineral-charged steam from deep ($>2\text{--}3$ km) Na–Cl brines equilibrated at the cap of an evolving magma body. We suggest that the magma body is at a late stage of evolution; in fact, the positive relation between B and K in rocks, glasses and melt inclusions corroborates boron incompatibly during magma evolution at the Campi Flegrei. Indeed, experiments indicate preferential boron partition into the exsolved hydrous fluid (brine). Therein, our proposed model for the Campi Flegrei aligns with Fournier's (Fournier, 1999) concept: boron moves from the residual melt into the pegmatitic and pneumatolic zones, entering hydrothermal intrusive breccia pipes at the brittle-plastic transition. To account for heavier boron in condensates compared to magma-related rocks, fluid separation from melt likely occurs at temperature of $>700^\circ\text{C}$.

Then, boron-rich brines were transferred to the shallow hydrothermal system through fracture networks activated by escalating bradyseismic deformation and intersecting the brittle-plastic transition.

A two-way link can thus be established between the geophysical anomalies accompanying the bradyseismic evolution and the ascent of hot boron-rich brines, which are related to the fluid-halo of a magmatic environment that switched from closed-to-open system conditions.

Since mid-2025, the renewed coexistence of sassolite and ammonium sulfates has accompanied declining H₂S emissions and a reduction in seismic energy release. A tempting hypothesis explaining these observations could be the exhaustion of the deep pulse. Under this hypothesis, sassolite

occurrence is highly instrumental in detecting periodic, magma-related disturbances of the deep system located below the cap rock layer at ca. 3km depth.