ID: 61

Towards real-time lava effusion rate estimates with video-lapse cameras: an example from the 2022 Mauna Loa eruption

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Lava effusion rate is a fundamental measure of the vigor and hazard potential of lava flow eruptions. This parameter impacts flow advance rate and runout distance, and is therefore one of the most critical datasets to have during an effusive crisis, but it can be one of the most difficult to obtain in practice. Video-lapse cameras, which capture short video clips at periodic intervals, are a potential tool for making frequent estimates of effusion rate. During the 2022 eruption of Mauna Loa, Hawaii, we deployed video-lapse cameras to test a particle image velocimetry routine, making frequent measurements of velocity of lava flowing in the main channel. Combining this time-series of velocity data with the mapped width of the channel, along with the estimated depth of lava, we derived a high-resolution (every 15 minutes) time series of effusion rate for the final 8 days of the eruption. The results capture relatively steady flow before an abrupt drop in effusion rates, which coincided with decreases in seismic tremor and SO_2 emission rate, and the eventual shut down in the eruption. The cameras in this proof of concept were inexpensive and non-telemetered, with results processed after manually retrieving data, which is not always practical in a timely manner. We envision a future system of a telemetered webcam periodically transmitting short video clips that are analyzed in an automated manner, on a timescale of tens of minutes. These could produce near-real-time estimates of effusion rates, with implications for tracking and forecasting flow behavior.

ID: 62

Tracking lava lake elevation in real time with continuous laser rangefinders

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Active lava lakes commonly fluctuate in level, with their elevation reflecting underlying processes such as magma supply rate, reservoir pressure, and shallow gas release. Continuous tracking of the elevation of lava lakes has been an important goal both for fundamental research and hazard forecasting. In 2018, the Hawaiian Volcano Observatory (HVO) began using a continuous (1 Hz) industrial laser rangefinder for tracking the elevation of the lava lake in Halemaʻumaʻu Crater, at the summit of Kīlauea volcano. Following the subsequent collapse and deepening of the crater, we upgraded to a more powerful (multi-kilometer range) model in January 2021, which has been operating continuously since that time. The laser rangefinder has captured the rise and refilling of lava in Kīlauea's summit caldera over the course of five eruptions, amounting to over 200 m of crater floor rise. Long-term refilling processes have included rising lava lakes, successive lava flow coverage, and endogenous uplift of the crater floor. Short-term (minutes) processes have been tracked as well, captured with a precision of approximately 20 cm, related to shallow gas-driven processes. Spurious returns due to rain, fog and gas emissions are mitigated with simple data filtering, and have not posed a serious problem. These data are shared in real-time with the public on the HVO website. The continuous laser rangefinder has been a highly effective tool for tracking lava lake rise and crater refilling. These devices may also be effective in other volcanic scenarios, such as tracking dome growth and instability, and crater lake levels.

ID: 95

Open-vent volcanoes fuelled by gas fluxing and intrusive magmas

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Open-vent, persistently degassing volcanoes—such as Stromboli and Etna (Italy), Yasur (Vanuatu), Villarrica (Chile), Bagana and Manam (Papua New Guinea), Fuego and Pacaya (Guatemala) volcanoes—produce high gas fluxes and violent strombolian or 'paroxysmal' eruptions that are extremely hazardous. Here we draw on examples of open-vent volcanic systems to highlight the principal characteristics of their degassing regimes and develop a generic model to explain open-vent volcanic behaviour in both high and low viscosity magmas and across a range of tectonic settings. We propose that volcanic activity at such volcanoes is largely driven and sustained by fluxing of an exsolved volatile phase through the shallow magmatic system, produced dominantly by intrusive magma bodies stored deeper in the crust. High gas fluxes flushing through the volcanic system trigger explosive eruptions and maintain a high thermal flux, necessary to sustain open vents and lava lakes at the surface. Extensive intrusive magmatic activity is aided in many cases by extensional tectonics in the crust, which may control the longevity and activity of open-vent volcanoes.

ID: 131

New insights on the highly explosive Petrazza eruptive activity at Stromboli (77-75 ka)

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The onset and explosivity of a volcanic eruption is generally related to the inter-action of several factors, including regional tectonics, volcano-tectonic activity and magma input rate from depth. At constant magma input rate, the trigger and increasing explosivity of an eruption can be related to shallow dynamics such as sector collapses and/or landslides, and the opening/closure of conduits (top-to-bottom). Conversely, a variable and magma input rate from depth can promote extreme differentiation processes (low input rate), magma mixing/mingling and/or gas flushing, finally leading to increased explosivity and energy of eruptions (bottom-to-top).

Here we present a new reconstruction of the pre- and sin-eruptive magma dynamics acting within the feeding system of Stromboli, and leading to the unusual high-energetic explosive eruptions (up to Sub-Plinian) of Petrazza, during the PaleoStromboli I eruptive epoch (85-75 ka). Field stratigraphy and volcanological interpretation combined with a petrological approach embracing whole rock geochemistry, textural and mineral investigations and geobarometric calculations have been carried out. Our results highlight that the decompression of the plumbing system generated by the transition from closed to open-conduit conditions is able to re-call a more mafic magma from depth, which mingled and partially and gradually substituted the residing one. Toward the end of the succession an event of extreme decompression of the magma feeding system triggered the ascent of a deeply-seated and amphibole-bearing magma, generating the most high-energetic explosive eruption, assumed as the larger for the Stromboli volcanic system.

ID: 193

Big or small? New constraints on explosive activity at Santiaguito, Guatemala

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We integrate monitored observations (visual, seismic, acoustic, thermal), with field measurements and laboratory investigations to resolve the cause for, and signals leading to, explosive activity—during phases of low and high explosivity—at Santiaguito, Guatemala.

During phases of low explosivity, magma fragmentation is shallow and controlled by lava dome dynamics, as observed through episodic piston-like motion displayed by characteristic tilt/seismic patterns. This cyclicity episodically concludes with gas emissions or gas-and-ash explosions, observed to progress along a complex fault system in the dome. The explosive activity is associated with distinct geophysical signals characterised by the presence of very-long period earthquakes as well as more rapid inflation/deflation cycles; the erupted ash further evidences partial melting and thermal vesiculation resulting from fault processes. The data suggest that this eruption dynamic can be sustained with high regularity and intensity of the explosions; analysis of infrasound data suggests that each explosion expulses on the order of 10^5-10^6 kg of gas and ash.

In 2015-2016, a period of high explosivity generated hazardous ash-rich plumes (up to 7 km high) and pyroclastic flows. Seismic and infrasound signals reveal longer intervals between explosions and deeper fragmentation levels, as the seismic energy of these events increased by ~4 orders of magnitude. Geochemical analysis suggests that this explosion intensification followed replenishment of the shallow reservoir from a deep, hot, volatile-rich magma. Geophysical data revealed no precursory signs of this intensification from ground deformation measurements or spaceborne thermal imagery.

We will discuss the hazards associated with this shift in explosivity.

ID: 226

Fe-rich melts in groundmass glasses reveal deep processes in basaltic volcanoes

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Stromboli, an active open-system volcano, is characterized by persistent activity, which includes a wide range of explosive eruptions, from ordinary to major explosions and paroxysms. Among these, the intermediate major explosions are more difficult to identify in terms of eruptive dynamics and associated precursors. To highlight the mechanisms that trigger and accompany the major explosions at Stromboli, we linked the textural and compositional characteristics of erupted products to composition of gas plume and to dynamics of gas-magma transfer in the upper plumbing system.

High-resolution chemical mappings of major elements in residual glasses indicate that in major eruptions abundant micron-scale filamentary structures are present, generally associated with bubbles, which are very rare in the products of ordinary and paroxysmal explosions. These structures have lower Cl, K_2O, TiO_2, Na_2O, SiO_2 and Al_2O_3, and higher FeO, CaO, MgO contents than surrounding glasses.

Models of bubble-melt interaction dynamics suggest that these filaments are related to bubble-driven mingling between different melts, induced by partial gas-melt decoupling. Decoupling timescales were derived based on the chlorine signature, indicating that filaments were generated at shallow depths (≤1 km). Normal activity is characterized by slower timescales, thus these textures are mostly obliterated by diffusion. The rapid ascent of magma during paroxysms does not allow widespread gas-melt decoupling.

The very short lifetime and the abundance of these textures suggest the arrival of small batches of gas-rich, deep-seated magma in the shallow system as a possible trigger for the major explosions at Stromboli.

ID: 321

Space-time evolution of the Etna volcano plumbing system during the last decade

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The 2020-22 paroxysmal sequence at Etna captured the attention of the volcanological community due to the extraordinary explosive activity and eruption frequency observed at the volcano. In this study, we contextualize this exceptional eruptive sequence within the framework of the post-2011 volcanic activity at Etna, producing a comprehensive picture of the spatial and temporal dynamics of magma storage and transfer across the volcano plumbing system. A careful examination and comparison of whole rock, crystal and glass chemistry for 2020-22 with the existing data for the post-2011 activity suggest divergent evolutionary processes since 2015-16, as well as the activation of the most mafic magmatic environments characterizing the modern Etnean feeding system. By combining thermodynamic simulations and diffusion chronometry, we provide new constraints on the chemical-physical properties of magmas feeding the recent paroxysmal activity and on the kinetics of magmatic processes taking place beneath the volcano. Our findings highlight how modes of storage and transfer observed during the 2020-22 paroxysmal sequence closely resemble those of the 2011-13 period. However, timescales of magma movements are much faster (days to weeks vs. weeks to months, respectively), presenting great similarities with transfer timescales leading to the powerful eruptions at the Voragine crater during 2015-16 (days to weeks). Significant volumes of mafic magmas entered intermittently the intermediate (170-250 MPa) plumbing system of Etna starting from the end of 2020, feeding volcanic periods of exceptionally high eruptive frequency and explosivity.

ID: 331

Lava dome cycles at Popocatépetl: insights into shallow magma dynamics from multiparametric satellite datasets

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Popocatépetl (Mexico) has experienced since its reactivation in 1994 successive episodes of lava dome construction and destruction. It is also characterized by strong excess degassing☐, as the emitted mass of SO_2 largely exceed the mass dissolved in the erupted magma. Here we investigate the shallow magma dynamics governing the repetitive dome cycles and peculiar excess degassing at Popocatépetl using multiparametric satellite datasets. We use high-resolution TerraSAR-X and medium-resolution Sentinel-1 SAR (Synthetic Aperture Radar) images acquired over 8 years (2012–2020) to: (1) quantify vertical variations of the inner-crater depth, revealing both short-term dome construction-subsidence cycles and long-term crater deepening and widening, and (2) analyze dome morphological evolution, revealing magma emplacement and withdrawal mechanisms with exceptional temporal and spatial detail, thanks to a deep-learning image enhancement approach. We compare this data with 15 years (2005–2020) of SO_2 gas emission and infrared thermal radiation observations from the satellite sensors OMI (Ozone Monitoring Instrument) and MODIS (Moderate Resolution Imaging Spectroradiometer), which confirm that magma volumes required to sustain the gas and thermal fluxes largely exceed the actual erupted magma volumes. This unique combination of observations offers a new comprehensive view of the eruptive dynamics and magma conduit processes operating at Popocatépetl, where gas retention and escape could explain the short- and long-term ups and downs of the magma column. This study opens new perspectives to constrain the overarching characteristics of open-vent volcanic activity, and paves the way to improved multidisciplinary satellite volcano monitoring in platforms such as MOUNTS (http://www.mounts-project.com).

ID: 333

Deciphering magma dynamics controlling the 2020-22 lava fountain sequence at Mount Etna volcano using tilt deformation and volcanic tremor analysis

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Between December 13, 2020, and February 21, 2022, a series of 62 lava fountains occurred at Mt. Etna volcano. Our study adopts a multidisciplinary approach, utilizing tilt deformation and volcanic tremor RMS amplitude time series data. Our investigation involved the assessment of deflations linked to the lava fountains, inflations occurring during intra-event intervals, the peak values of volcanic tremor RMS amplitudes, and a gradient parameter to gauge the rate of evolution for each phase and signal. We have identified three sub-periods reflecting the dynamics of magma storage and transport. During the initial period (February - April 2021), we consistently observed medium to high values across all considered parameters, suggesting the transfer of larger volumes of volatile-rich magma migrating from deeper reservoirs to upper portions of the plumbing system. In the subsequent period (May - June 2021), lava fountains exhibited shorter average durations, marking the lowest values throughout the eruptive sequence. This phenomenon may be attributed to reduced amounts of undegassed magma in the uppermost feeding system. In the third period (July - October 2021), there was a discernible uptrend of the aforementioned parameters, coinciding with reduction of the inflation velocity. Detailed analyses of tilt signals and volcanic tremor RMS amplitudes unveiled distinctive characteristics during episodes within the second period, marked by notable inflations contemporary with the beginning of lava fountains and periodic RMS amplitude patterns. This approach offers valuable insights into the evolutionary dynamics of paroxysmal events witnessed at Mt. Etna during the 2020-2022 timeframe.

ID: 419

Ten years (2013-2023) quantification of satellite-derived heat flux from multiple craters at the open-conduit Stromboli volcano

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Open-conduit volcanoes are characterized by active magmatic processes that release continuously heat flux, which is detectable by InfraRed satellite sensors. The measurement of volcanic thermal activity by using multisensor satellite data represents an advance in monitoring open-conduit volcanoes characterized by multiple craters. Results retrieved by MIR- and SWIR-based algorithms, respectively, for moderate (MODIS and VIIRS) and high-spatial (MSI SENTINEL-2 and OLI LANDSAT-8/9) resolution data are compared to investigate ten years (2013-2023) of thermal activity at Stromboli (Italy). The correlation between the VRP (Watt) and the VRE (Joule) measured by MIR-data with the Thermal Index by SWIR-data allows us to estimate the thermal budgets and the heat flux sourced by the multiple active craters hosted on the Stromboli summit terrace. By this approach, we link the distribution of the anomalies inside the crater terrace with the thermal flux sourced by each sector. Results outline temporary migrations in the single vents positions, but a long-term stable presence of two main sectors where thermal emissions concentrate. We discriminate thermal behaviors in the historically three recognized NE, C and SW craters, related to different source mechanisms of the thermal emissions during the pure strombolian activity, confirmed by ground-based studies. Heat flux results are compared with eruptive events, indicating a marked relation between thermal energy increase and the transition to higher energetic explosions (major explosions). Multispatial and multisensor satellite remote sensing techniques allow the long-term quantification of heat flux from craters at Stromboli, representing a great advance for studying and monitoring purposes of open-conduit systems.

ID: 467

Thermal emissions at open-vent volcanoes: results from the MIROVA database

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Along with magmatic-related products, open-vent volcanoes continuously emit a large amount of heat that can be measured from space. In this work, we used the global archive of thermal anomalies detected by the MIROVA system to characterize in space and time the activity that occurred at tens of persistently active volcanoes. The combination of data from multiple IR sensors (MODIS, VIIRS, MSI, OLI) reveals that open-vent volcanism may be characterized by two distinct thermal regimes: (*i*) a convective regime, where the heat emission is focused at the vent(s) and sourced by a convective/degassing magma column at shallow depth and (*ii*) an effusive regime, where the thermal flux is sourced by the outpouring of lava flow(s)/dome(s). Often the two regimes are concomitant or alternate over time, causing variable patterns in the cumulative energy radiated at each volcano. We suggest that satellite thermal analysis is a powerful tool for tracking spatio-temporal changes in thermal emissions that may anticipate, accompany or follow the transition from the steady-state to more energetic eruptions.

ID: 469

Improved understanding of eruptive triggering at open conduit volcanoes using continuous seismic recordings and complementary data

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Among the different approaches to monitor volcanoes, seismology forms the basis, and most active volcanoes are nowadays equipped with at least one seismometer. Seismology is unique amongst the Earth Science disciplines involved in volcano studies, as it provides real-time information; as such, it is the backbone of every monitoring program worldwide. With data storage capabilities expanding over the last decades, new data processing tools have emerged taking advantage of continuous seismic records. Recent advances in volcano monitoring have taken advantage of seismic noise to better understand the time evolution of the subsurface.

The well-established seismic interferometry has allowed us to detect precursory changes (dv/v or decorrelation) to eruptions at different volcanoes, thereby providing critical insights into the triggering processes. More recent approaches have provided insights into the genesis at open conduit volcanoes using seismic attenuation (DSAR: Displacement seismic amplitude ratio) and volcanic tremor. Yet, puzzling observations have been made requiring the use of numerical models and machine learning-based approaches, as well as complementary dataset to reach a more comprehensive understanding. This presentation will review recent insights gained into precursory processes to eruptions at open-conduit volcanoes using seismic noise and how we could possibly forecast them. These tools are freely available to the community and have the potential to serve monitoring and aid decision-making in volcano observatories.

ID: 504

Using geophysical monitoring data and eruption chronologies to illuminate conduit processes during paroxysms at Volcán de Fuego, Guatemala

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Volcán de Fuego presents a baseline of low-level (Strombolian to Vulcanian) explosive activity characterised by discrete small explosions that have relatively low impacts on local communities. However, larger-scale explosive events, generally referred to as ‘paroxysms’ or ‘paroxysmal cycles’, occur two to three times per year (on average since 2021). Paroxysms pose increased risk to nearby communities owing to the frequently associated pyroclastic flows. The paroxysms are typically marked by a transition from discrete small explosions to sustained explosive activity, sometimes accompanied by lava fountaining (with or without a lava flow) and/or the formation of an eruptive column of ash/tephra. This transition is reflected in changes in geophysical signals, such as an increase in seismic energy. As explosivity increases, the ash plume can become more prominent, and pyroclastic flows are often triggered.

Here, we use geophysical data and eruption chronologies based on reports from local observers to describe several paroxysms since 2021. We compare and contrast the background level of activity before and after these paroxysms, as well as the ramping up phase in the transition from background to continuous heightened explosivity, the transition back to discrete explosive activity, and the recovery period following the paroxysms. We also investigate a ‘failed’ paroxysm where activity ramped up but returned to baseline without escalating. These observations show important differences in the baseline activity, the ramping up phase, and recovery phase of paroxysms since 2021. We interpret these observations in the context of evolving conduit dynamics, including magma flow regime and degassing efficiency.

ID: 552

Monitorización en tiempo casi real de la actividad explosiva mediante señales sísmicas e imágenes visibles: un estudio de caso del volcán Sabancaya, Perú

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Desde noviembre de 2016, el volcán Sabancaya tiene vigente un nuevo proceso eruptivo con la ocurrencia diaria de explosiones volcánicas y la consecuente emisión de gas y ceniza volcánica hacia la atmosfera. Con el propósito de conocer oportunamente la altura de la pluma de ceniza, la velocidad de ascenso y la dirección de propagación, se desarrolló un sistema que integra algoritmos de inteligencia artificial a partir de datos sísmicos e imágenes provenientes del volcán Sabancaya, para detectar y caracterizar las explosiones volcánicas de manera automática y en tiempo casi real; y que además resulte útil para la modelización de la dispersión de cenizas y la identificación de riesgos para la aviación. Por ello, se construyó una base de datos de 1342 eventos explosivos registrados en el macizo volcánico, durante los años 2019-2021. En cuanto al procesamiento de imágenes, la arquitectura convolucional U-Net segmentó automáticamente un total de 3,110 imágenes o máscaras segmentadas manualmente, logrando una precisión del 98.9% en el entrenamiento y del 98.7% en la validación. Por otro lado, para la detección y clasificación de señales sísmicas relacionadas con erupciones volcánicas se utilizó el algoritmo STA/LTA optimizado, el cual permite la detección automática de señales sísmicas asociadas a plumas de ceniza (inicio y final) con una precisión de hasta un 97% respecto a su detección manual. Para la clasificación, se extrajeron 35 características de la señal sísmica en el dominio del tiempo, frecuencia y cepstral; luego, utilizando el modelo de bosques aleatorios, se obtuvo una precisión de 97%.

ID: 658

Waxing and Waning of Explosive Activity During Fuego's Eruptive Cycles

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Volcán de Fuego, Guatemala is persistently active with characteristic eruptive cycles that typically culminate in larger paroxysmal eruptions every 1-2 months. Much of the cycle includes explosive eruptions at the summit. Here we focus on ground tilt that precedes and accompanies these summit eruptions using data from both broadband seismometers and a tiltmeter located within 1 km of the active vent in the past decade. We identify events and classify them using an unsupervised learning approach together with dynamic time warping to measure similarity. The classification reveals two types of tilt signals with opposite polarity, the dominant of which (type 1) was identified in previous studies as a pressurization-related precursor to an explosive eruption. During the period of longest continuous tilt recordings, October 1, 2015, and January 13, 2016, we identified 268 type 1 events with durations between 7 and 39 minutes. These events are clustered within cycles of eruptive activity and exhibit intra-cluster waxing and waning both in event amplitude and frequency of events. In the four well documented cases, both the number and amplitude of tilt events decrease prior to the paroxysmal culmination of the cycle. We model the tilt events as pressurization-depressurization cycles in the shallow conduit. The gradual decrease in explosivity leading up to a paroxysm could reflect changing volatile concentrations or a gradual opening of the conduit that promotes effusion. A better understanding of the short and longer term features of the tilt record may promote improved forecasting at this and other, similar systems.

ID: 666

Forecasting paroxysmal eruptions at Volcan de Fuego, Guatemala, using high spatial resolution observations of crater morphology

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Since 1999 Volcán de Fuego, Guatemala, has had over 60 larger explosive events, typically described as paroxysmal, including June 3rd 2018 where many hundreds of people were killed by a pyroclastic density current sequence. The paroxysmal cycle has several consistent characteristics: an increase in seismic activity beginning a few days prior to the paroxysm, chugging sounds during strong degassing, production of lava flows, coalescence of discrete explosions into fire fountaining, sustained ash column generation, destruction of the ephemeral cone, and, sometimes, pyroclastic density currents from perched material. This sequence exclusively occurs when the crater's ephemeral cone has been rebuilt, and generally as the crater fills to capacity and overspill occurs. This means that if the remaining volume and fill rate can be measured, forecasting of paroxysms, or at least the opportunity to prepare for a larger eruption days-weeks in advance, may be possible. We have successfully hindcast several paroxysms in the period 2016-2018 (n=48) using a method that relies on a combination of high-resolution optical satellite imagery and digital elevation models derived from uncrewed aerial vehicles (UAVs). If proven, a forecasting method could be coupled with an event tree and alert level system with the potential to significantly improve early warning at Fuego.

ID: 761

Magma pressurization in conduit before Vulcanian eruptions at Sakurajima volcano inferred from conduit flow modeling

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Inflation of volcanic edifice before volcanic eruptions, which is caused by the subsurface pressurization process of magma, gas, and hydrothermal fluids, is an essential precursor for eruption forecasting. In the repeated Vulcanian eruptions at Sakurajima volcano, Japan, strain and tiltmeters have observed this precursor. Geophysical and petrological observations suggest that a solid plug exists in the shallow part below the vent during the preparatory process before the Vulcanian eruptions. This study aims to clarify the mechanism of the pressurization process in the volcanic conduit before the Vulcanian eruption at Sakurajima based on a numerical conduit flow model that considers the shallow solid plug. We developed a 1-dimensional steady conduit flow model composed of a viscous fluid and a solid plug in the shallow and deep parts, respectively, in which equilibrium volatile exsolution, equilibrium crystallization, and vertical gas escape processes are considered under the petrologically constrained magmatic properties. We found that the steady solutions of the conduit flow before the Vulcanian eruptions have a common feature: local excess pressure is generated just below the solid plug. The crustal deformation simulation by finite element method revealed that the conduit pressurization process could reproduce the observed magnitude of the tilt change during the Sakurajima eruptions under realistic geological conditions such as conduit radius and magma flux. This suggests that the conduit pressurization excited by the conduit flow dynamics plays a vital role in the precursory inflation before the Vulcanian eruptions.

ID: 73

The February-March 2021 lava fountains events of Mt. Etna South-East crater: insights from clinopyroxenes.

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Mt. Etna is the most active volcano in Europe with four active vents in the summit area. The South-East Crater (SEC) is the most active crater of the last 20 years and is characterised by episodic eruptions, i.e. sequences of paroxysmal lava fountains with rather variable frequency and duration from a few weeks to months. Between December 2020 and February 2022, the SEC produced over 60 paroxysmal events divided into a first phase (December 2020 – April 2021) and a second phase (May 2021 - February 2022).

We investigated textural and chemical characteristics of the clinopyroxenes population to constrain frequency of magma recharge episodes and eruption triggering mechanisms of 6 paroxysms representative of the first phase, from February 16 to March 10, 2021, including the February 28 paroxysm which erupted the most primitive magma. Clinopyroxenes show frequent sector zoning superimposed on complex concentric zoning showing two main compositional domains: 1) augitic composition (Mg# 68-75) which mostly characterises rims and is less frequent in cores and mantles; 2) diopsidic composition (Mg# 74-80) mainly found in cores and less abundant in mantle and rims. Barometric estimates using the new GAIA deep learning-based thermobarometry (Chicchi et al., 2022 EPSL) indicate a shallow reservoir (0.4-1.0 ± 0.3 kbar) for the augitic domain and a deeper reservoir (1.7-2.7 ± 0.5 kbar) for the diopsidic domain. Fe-Mg diffusion timescales point to the occurrence of multiple episodes of mafic recharges starting in December 2020 and up to a few days prior eruption in agreement with monitoring data.

ID: 102

Petrological analysis of the recent explosive phases (2019-2022) of Sangay volcano, Ecuador

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The change in eruptive dynamic represents a challenge for volcanologists interesting in unraveling the eruptive behavior of open-vent volcanoes. Since its reawakening in 2019, Sangay volcano (Ecuador) experienced a semi-continuous, low magnitude eruptive activity that was disrupted by some mild-explosive eruptions. Some Andean communities have been affected by these explosive eruptive pulses. Through component and chemical analyses we studied volcanic ash and lapilli emitted during the major explosive eruptions of 2020-2021 and some minor eruptions of 2022, to document the changes in eruptive dynamics and identify the potential triggering mechanisms. Major element data show a progressive decrease in silica content, from andesitic to basaltic andesitic compositions and a concomitant increase in magnesium content over time. Component and texture descriptions and variation in matrix glass chemistry support the idea that Sangay´s shallow plumbing system hosts magmas that has evolved in composition; with variable physical properties controlling the fragmentation process. Geochemical variations suggest that magmatic diversity is controlled mainly by fractional crystallization and, to a lesser extent, by recharge of magmas. Thermobarometric data yield magmatic temperatures from 1055 to 993°C and water contents of at least ~2-3 wt.%. Two triggering mechanisms are ocurring:on one side, eruptive transition can be related to the recharge of gas-rich mafic magmas; while on the other side, an increase in the gas flux from deep is also implied. This work contributes to a better understanding of eruptive behavior of active long-lived and open vent volcanoes, and how eruptive dynamics are affected by tephra properties and petrological evolution.

ID: 149

Geochemical and textural investigations of pyroclastic products from the June 3rd 2018 eruption of Volcán de Fuego, Guatemala

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The June 3rd, 2018, eruption of Fuego volcano (Guatemala) produced a complex sequence of small-volume pyroclastic density currents (PDCs) that inundated all sectors around the volcano and propagated >12 km on the southeastern flank, deposited ~50 million m3 of pyroclastic material.

The eruptive stratigraphy shows evidence of a sub-Plinian phase associated with tephra fallout and one PDC unit followed by at least seven stacked, massive flow units deposited by rapid stepwise aggradation of successive block-and-ash flow (BAF) pulses in the Las Lajas barranca on the southeastern flank.

This study investigates textural and geochemical changes throughout the June 3rd eruptive sequence. Using component analyses, juvenile clasts (scoria and glass) from each eruptive unit were selected for major and trace element analyses, bulk density calculation, and for quantification of vesicularity. In addition, thin sections of representative juvenile material were imaged with a digital microscope and a SEM, and processed using the FOAMS software (Shea et al., 2010). Following the method of Toramaru (2006), decompression rates using bubble number density were obtained for each unit. Results will help constrain the changes in eruptive conditions from the onset of the sub-Plinian phase to the end of the PDC sequence.

ID: 192

Magma Mixing triggers eruptions at Volcán de Pacaya (Guatemala)?

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Volcán de Pacaya (Guatemala) poses significant hazards to major population centers. Despite this, insufficient data exists to fully understand the magma evolutionary processes and adequately constrain eruption triggers. The goal of this research is to provide a detailed petrologic and geochemical study of Pacaya to link subsurface processes to eruptive activity and provide insight into magma plumbing system dynamics, which will inform volcanic hazard assessments.

Lava flows from 2008 to 2021 were analyzed for major element compositions of plagioclase and olivine via electron microprobe. Results show abundant reverse zoning in olivine from the 2008 and 2010 eruptions. Overall, average olivine rim compositions shift from Fo70 to Fo65 from 2008 to 2021. These olivine compositions suggest emplacement of a more primitive magma into the subsurface before the 2008 and 2010 eruptions, thus heating and mobilizing a portion of the subsurface magma mush. Olivine populations from the 2014-2021 eruptions suggest additional mixing/assimilation events between the magma mush and more primitive magmas, but the change in average rim compositions from 2008 to 2021 is consistent with subsequent cooling and fractionation in the subsurface magma reservoir, therefore indicating that these events were smaller in volume. Plagioclase zoning patterns highlight the complex, polybaric nature of mixing and recharge events. Therefore, mixing during magma evolution may be an important eruption trigger at Pacaya. Additional work on Pacaya is underway to fully understand the role of magma mixing on eruptive activity at these volcanoes.

ID: 290

VULCANIAN ERUPTIONS AT OPEN CONDUIT BASALTIC VOLCANOES. ARE THEY POSSIBLE?

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Vulcanian eruptions represent the sudden release of overpressure stored at the base of a viscous and degassed crystal- and bubble-bearing magma plug filling the conduit at shallow depths. The vulcanian eruption style is typical of close conduit intermediate to felsic volcanoes. Some of the main common observational characteristics of vulcanian eruptions are: (i) the relatively small magnitude (VEI3-4); (ii) the release of initial shock waves followed by a typical mushroom shape jet feeding a short-lived plume <10 km high; (iii) the relatively fine ejecta associated with strong vent clearing ballistic ejection; (iv) the high variability of vesicularity of pyroclasts. All these characteristics can be easily reconciled with the conceptual model of a top-down sudden decompression-driven fragmentation due to the failure of the shallow viscous magma plug or dome. The two sudden explosive eruptions occurred in 2019 at the open conduit basaltic Stromboli volcano share all observational features of the vulcanian style and the associated deposit types, including the occurrence of pyroclastic flows. This interpretation questions the common and exclusive association of vulcanian eruptions with close conduit intermediate to felsic volcanoes. Here we explore what the texture of basaltic-shoshonite pyroclasts of the July 3rd 2019 Stromboli explosive eruption can tell us about the mechanism of fragmentation and about the associated eruption style, aiming to clarify whether vulcanian eruptions can occur also at open conduit mafic volcanoes and in what cases these are possible.

ID: 307

Interpreting open conduit magma dynamics at Villarrica volcano using citizen-led petrological time series of pyroclastic products

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Villarrica is the highest-threat volcano in Chile. Since its last eruption in 2015, it has shown persistent lava lake degassing interrupted by periods of unrest with increased Strombolian activity, leading to rises in the volcanic alert level to yellow or orange. Here, we analyse nine lapilli-to-bomb-sized pyroclasts that erupted between December 2015 and September 2023, which local mountaineers collected near the crater after the cessation of increased activity with identified ejection dates. We carried out whole rock geochemistry, electron microscope imaging and electron microprobe analysis of mineral phases, glass, and melt inclusions on them. Results show a progressive involvement of more primitive basaltic magmas (i.e., hotter and deeper) during 2022-2023, compared to the 2015-2017 and other historical products. These melts bear An-rich plagioclase antecrysts with remarkable disequilibrium textures and oscillatory zoning. Geothermometry and barometry allow us recognising two crystallisation zones at ca. <4 km and 9-15 km, which may control surface activity. The measurements are complemented by rhyolite-MELTS simulations of plagioclase and olivine crystallisation, consistent with the petrologic observations and the geophysical monitoring signals (e.g., seismicity and thermal anomalies). Such long-term magma rejuvenation processes are like those observed during older historical eruptions at Villarrica. In addition to these scientific findings, we recognise a unique opportunity to build citizen-scientist synergies with mountaineers who regularly access the crater area to obtain valuable information that stakeholders and scientists could use in monitoring and risk assessment in benefit of people living and working at the volcano.

ID: 319

Hazard from ballistics during the 2020-22 paroxysmal eruptions at Mount Etna

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In recent decades, Etna produced several sequences of energetic lava fountains from the summit craters, feeding several-km high eruptive columns, as well as lava flows. The last sequence, which started on December 2020 and ended on February 2022, produced sixty-two lava fountains episodes from the South-East Crater. The major issue associated with this type of events is the fallout of ballistic particles around the summit craters, sometimes reaching some of the most touristy areas of the volcano. The rather frequent activity has posed primary questions on how the impact associated with the fallout of these particles can be estimated. We present in this work field data collected after the lava fountain of February 21, 2022, during which several large ballistics fell just southeast of the summit craters, in the area of the Barbagallo Craters (∼2900 m a.s.l.). Hence, we collected samples and performed laboratory analyses in order to retrieve their size, shape and density. Values obtained, together with the quantitative analysis of lava fountain, have been compared with results acquired through "Eject!", a calculator of ballistic trajectories during explosive eruptions. We therefore compared the main eruptive conditions occurred during the lava fountain of February 21, 2022 with other data obtained by other remote sensors. This work is a first step to identify a real-time and free available system capable of assessing the possible impact by fallout during the Mt. Etna lava fountains, in order to mitigate the risk associated to fallout of large ballistics.

ID: 322

Triggering and emplacement mechanisms of Pyroclastic Density Currents in basic volcanic systems

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Volcanic systems erupting mafic magmas are well known for producing predominantly effusive or weak explosive activity chiefly because of the physical and chemical properties of the magma itself. Even basic volcanoes in some cases can however give rise to extra-ordinary explosive phenomena with varying energy, producing occasionally also pyroclastic density currents (PDCs), which represent potential threat to populations living close the eruptive center or to visitors who frequent these volcanoes. Recently, this kind of phenomenon has been observed at several basic volcanoes, including Volcàn de Fuego (Guatemala), Stromboli (Italy) and especially Mount Etna (Italy), where several dozen PDCs have been observed and documented during the last decades.

Although some of these PDCs have similarities with the classic processes characterizing volcanic systems erupting more evolved magmas, some of the mechanisms giving rise to the formation of these events have never been observed elsewhere and are still poorly studied. In this work we present an analysis of the triggering and emplacement mechanisms of the most important PDCs produced in recent years, using some case studies among the previously mentioned volcanoes. This type of approach could therefore be essential for a more detailed assessment of the hazards related to this type of phenomena, in order to reducing volcanic risk, especially in areas densely populated and/or frequented by tourists.

ID: 323

Multi-disciplinary reconstruction of magma dynamics during the 2020-22 paroxysmal sequence at Mt. Etna volcano

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We present a multidisciplinary study combining volcanic tremor RMS amplitude and tilt deformation data analysis along with petrological and geochemical data collected for lava fountain activity between December 2020 and October 2021 at Mt. Etna. Geophysical data allowed the identification of 3 sub-periods of volcanic activity. During the first period, from February to April 2021, medium-high deformations and tremor values have been recorded, overall indicating significant volumes of volatile-rich magmas transferred from the deeper to the upper portions of the plumbing system. The second period, from May to June 2021, records the lowest deformation values of the entire eruptive sequence. These deformations are associated to a period of shorter durations of lava fountains and lower erupted volumes as a possible consequence of minor amounts of undegassed magmas in the uppermost feeding system, as also confirmed by SO_2 emissions measured over the same period at the plume. During the third period, from July to October 2021, an increasing trend of the above cited parameters coupled with decreasing inflation velocity was detected. Compositional variations of the erupted tephra highlighted important changes in the evolution of magmas during the entire period of paroxysmal eruptions, also evidencing episodes of injection of more primitive magmas that are consistent with the observed patterns of deformation and volcanic tremor. The integration of geophysical and geochemical data has proved to be valuable in detecting the main magmatic processes and transfers dynamics that have produced the distinct features observed during the summit eruptions.

ID: 364

Amphibole and clinopyroxene barometries of the Petrazza pyroclastics, PaleoStromboli I (85-75 ka), reveals the magma plumbing system architecture.

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Understanding the history and working-modes of an active volcanic system represents one of the most reliable points to better achieve a global picture of the present-day eruptive activity. We studied the Petrazza pyroclastic succession (PaleoStromboli I eruptive epoch, 85-75 ka), which represents an unusual high-energetic explosive cycle (up to Sub-Plinian) associated with a partially-totally closed conduit dynamics. For the purpose of reconstructing the architecture and geometry of its magma plumbing system, with reference to depths of crystallization of the mineralogical assemblage, we used thermobarometric calculations (Amp-TB2 single-amphibole, [1], and Cpx-only thermobarometry, [2]), which are widely used to model the physico-chemical parameters (i.e., P, T, H_2O and fO_2) at equilibrium magmatic conditions. In this study, we analyzed 33 amphibole phenocrysts of the Petrazza pyroclastic succession, the only one bearing amphiboles among the subaerial volcanic products of Stromboli. Amphiboles are Mg-hastingsites and Mg-hornblendes with a Mg# ranging from 0.63 to 0.71. They indicate a polybaric plumbing system where the magma underwent equilibrium "steady-state" crystallization at crustal levels (5-15 km depth, 133-398 MPa). The Cpx-only thermobarometer show crystallization pressures of 98-363 MPa (4-14 km depth) for the 24 analyzed crystals. The combination of both results suggests a magma plumbing system configuration for the Petrazza pyroclastic succession, and the Paleostromboli I volcano, comparable to the present-day one. However, the unique presence of amphibole suggests different pre-eruptive magma dynamics.

[1] Ridolfi, F. (2021): *Minerals*, **11**, 324

[2] Wang et al. (2021): *EJM*, **33**, 621

ID: 483

Modelling diffuse degassing at Stromboli (Italy)

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Stromboli's persistent eruptive activity is accompanied by significant releases of volcanic gases both as a volcanic plume and through soil diffuse degassing. Long-term time series of diffuse degassing measurements carried out in the summit area highlighted significant fluxes ranging from 2 to 85 kg $m^{-2}d^{-1}$. Data shows increased CO_2 degassing during periods of effusive eruptions and before paroxysms. Measurements also show that stations located at the summit and at sea level display consistent trends, suggesting that monitoring in the peripheral area may supply important information in case the summit area becomes unreachable.

We performed numerical modelling of gas propagation through the volcanic edifice, to reproduce the main feature of diffuse degassing in Stromboli. Simulations describe the non-isothermal, multi-phase flow of carbon dioxide and water through heterogeneous porous media. Simulations are performed assuming that gas ascent mostly occurs through fault zones. The computational domain accounts for the island topography and bathymetry and it describes a 200-m-wide permeable zone along one of the well-mapped faults of the island (N41). The gas is released into the computational domain along a vertical structure that represents the outer wall of the conduit. Simulations suggest that the observed gas fluxes at the summit and at sea level can only be reproduced by introducing heterogeneous permeabilities. The model is used to explore the role of a sudden gas release on the observed trends of diffuse degassing, at different locations on the island.

ID: 484

Tracking of eruptive activity changes at Multi-Vent volcanoes through joint seismo-acoustic analysis: Mt. Etna, Italy case study.

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Volcanoes with multiple summit vents represent a challenge for understanding the timing, style and evolution of eruptive activity, which may shift between different locations during a single event. In order to address this issues, an international researcher team, supported by INGV-MIUR Project Pianeta Dinamico-“Working Earth"-WP VT-DYNAMO-2023, conducted analyses of pre- and syn-eruptive seismo-acoustic data at Mt. Etna, Italy. We present observations from a joint seismo-acoustic deployment during the 2021 eruption of Mt. Etna, Italy, revealing changes associated with shifts in both style and location of activity across multiple craters. Seismic array data allowed to constrain changes in the location of volcanic tremor during unrest. We observed that tremor source migration across the summit area systematically anticipates the onset of the most intense phase of eruption; we infer that tremor source migration defines a pathway for magma flow between vent locations. We also estimated the Volcano Acoustic Seismic Ratio (VASR); our results demonstrated a more efficient radiation of seismic than acoustic energy during the most vigorous stages of eruption. This could be associated with progressive deepening of the seismic source, linked to sustained magma fragmentation, during eruptive activity. These results confirm the ability of seismo-acoustic data analysis to identify precursory changes in location and style of activity in the hours, and even days, preceding the onset of paroxysmal activity, thus, offering a valuable tool for volcano monitoring.

ID: 497

Translating magma mixing dynamics to ground deformation patterns: Utilising GALES to simulate magma-rock interaction and ground deformation at Mount Etna.

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We adopt a forward model approach to ground deformation through the use of GALES (GAlerkin LEast Squares) to simulate the mixing of magmas, of variable compositions and temperatures, coupled to the elastodynamic response of the surrounding medium. GALES is a finite element parallel C++ code which solves both fluid and elastodynamics equations.

Mass, momentum and energy equations in a multi-component fluid mixture, including the complex dynamics involved in the convection and mixing of magmas, are solved to compute stress distributions along the magma-rock boundaries, subsequently allowing us to derive synthetic time series for surface ground deformation.

The multi-component magma dynamics are computed within an interconnected geometrical plumbing system consisting of various predefined dykes and magma reservoirs, representing the feeding system of Mount Etna volcano. The system is constrained through the analysis of melt inclusion data, as well as ground deformation inversion estimates. The physical properties of the multiphase magmas, such as densities and viscosities, are derived with reference to the aforementioned melt inclusion data and computing volatiles' equilibrium saturation conditions using the SOLWCAD code from Papale et al. (2006).

These simulations are coupled with an elastodynamic domain that accounts for the heterogeneous mechanical properties of the rock medium through the integration of seismic tomography data, as well as real surface topography of variable resolutions.

ID: 655

Explosive activity of Reventador: seismic and infrasound insights of a persistent behavior of a long-term eruptive volcano

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Reventador is one of the most active volcanos in Ecuador with continuous activity since its violent reawakening in November 2002. Previous activity periods were documented in 1926-1929, 1958-1960, and 1972-1976. It is formed by a young cone that rises inside a 4 km wide amphitheater. Current activity has been dominated by the extrusion of blocky basic-andesitic and andesitic lava flows, lava dome growth and destruction, occasional pyroclastic flows, ash emission and strombolian explosions. The IGEPN upgraded its monitoring system in 2012 with three permanent broad band seismic stations and infrasound sensors with real time data transmission and processing. Since upgrading the monitoring system with infrasound sensors in mid 2013, more than 224,000 events have been recorded using an automatic trigger method with two periods with more explosivity, from mid 2014-to 2019 and from late 2020 to early 2023 with more than 1,500 events per month. Large explosions generate up to 4 km high ash columns, ballistics and occasionally small pyroclastic flows. This permanent instrumentation is a continuation of distant infrasound arrays (Ortiz et al., 2020), a short period seismic network and stand-alone deployments (Lees et al., 2008; Ortiz et al., 2019; Ruiz et al., 2019).

ID: 664

Detecting and characterizing tremor emission episodes during the 2022-2023 Cotopaxi eruption using network and array methods

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Cotopaxi volcano, located in the Ecuadorian cordillera a mere 60 km from the capital Quito, is frequently cited as one of the most dangerous volcanoes in the world. In 2015 and again in 2022-2023, Cotopaxi experienced VEI1-2 eruptions, consisting of abundant ash emission episodes lasting anywhere from minutes to days. In this study, we focus on the 2022-2023 eruption, and utilize a dense permanent broadband seismic monitoring network maintained by the Instituto Geofísico (IGEPN). We both detect and characterize the seismic tremor associated with ash emission episodes and locate the tremor using an amplitude decay technique, inverting for and incorporating a new attenuation relation in the process. In addition, as part of a pilot project, the University of Edinburgh installed two small-aperture nodal arrays (7 and 5 elements each) on differing flanks, with each collecting 6 days of data in May of 2023. We employ the spectral width technique to the multiple tremor episodes recorded by the arrays and extract back-azimuths and apparent velocities at multiple frequencies. Results from both network and array methodologies give broadly similar results. Finally, we document significant fluctuations in the spectral content of the emission tremor over time. For future work, we will attempt to relate changes in spectral bandwidth to either ash content, SO_2, or plume heights as observed on the visible camera network. Since Cotopaxi is a partially open system, parameterization of bulk properties of the 2022 emission tremor will serve to strengthen risk management protocols in future eruptions.

ID: 685

ESTUDIO PETROGRÁFICO DE LA "IGNIMBRITA AEROPUERTO DE AREQUIPA" DEL PLEISTOCENO (PERÜ)

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La ignimbrita Aeropuerto de Arequipa (IAA), comúnmente denominada sillar, aflora en la ciudad de Arequipa y alrededores. Esta ignimbrita posee una edad de 1,65 Ma. Durante más de 3 siglos, la IAA ha sido materia prima para la construcción de las viviendas y monumentos históricos de la ciudad de Arequipa, ciudad que hoy es patrimonio Cultural de la UNESCO. El estudio petrográfico de 30 muestras de la IAA, muestra que están constituidas por una matriz de ceniza volcánica, que engloba fragmentos de líticos, de pómez y cristales. La ceniza está constituida por polvo fino de vidrio en partículas soldadas. Los fragmentos líticos son principalmente de andesita, traquita, pumita y riolita, escasamente se observan fragmentos de traquita, brechas oxidadas y pórfidos dacíticos. Estos presentan formas subredondeadas a subangulossas, con dimensiones entre 3 y 20 mm en promedio y excepcionalmente hasta 35 mm. Los tabiques de vidrio volcánico, con formas toscamente rectangulares, de bordes angulosos y de dimensiones variables, alcanzando escasamente los 17 mm. Los cristales más abundantes son el cuarzo, plagioclasas y biotita, son más escasos los anfíboles y ortosa. Las dimensiones de estos cristales alcanzan hasta los 2 mm. También se realizaron estudios de Difracción de Rayos X de 30 muestras, de las cuales, 26 presentan patrones con picos definidos y 4 patrones presentan sólidos amorfos. A partir de los 26 difractogramas analizados se identificaron 5 minerales: albita, anortita, biotita, cristobalita y sanidina. Estos corresponden de manera similar a los identificados en el estudio petrográfico con secciones delgadas.

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Thermal and seismic analysis of the recent activity of Popocatépetl volcano, Mexico

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Popocatépetl, located in central Mexico, is currently the country's most active volcano and poses a significant volcanic risk to densely populated areas nearby. Since 1994, it has been in a state of frequent activity, exhibiting small to moderate-sized Vulcanian explosions, gas and ash emissions and intermittent lava dome growth. Popocatépetl volcano is closely monitored by the National Center for Disaster Prevention (CENAPRED) in Mexico. Last year, in a collaborative effort with the University of Colima, a fixed-mounted thermal camera was installed at the north of the volcano to provide continuous infrared monitoring of its recent activity. We present the results of the thermal analysis applied to the 2023 Vulcanian explosions, as well as to an episode of increased activity that peaked on May 19-21 accompanied by near-constant emissions of steam, gas, ash, and ejections of incandescent tephra at short distances onto the flanks.

Aditionally, we analyze the seismic activity focusing on the search of temporal changes within the spectral content of the volcanic seismic signals, employing diverse time-frequency representations applied to the SSAM, frequency index, dominant frequency, spectral centroid and discrete wavelet decomposition at different scales. We discuss the performance of the different spectral features for forecasting eruptive episodes and for evaluating the progress of volcanic processes during ongoing eruptions. We also emphasize the importance of incorporating and combining additional monitoring techniques to better track the dynamics of the volcanic processes.