ID: 99

Estimation of vapor mass at the sources of long-period seismic events for risk assessment of phreatic eruption

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Although several studies have reported that long-period (LP) events occurred prior to phreatic eruptions, the eruption risk has not been assessed quantitively from LP activity. The LP event has been interpreted as the oscillation of a crack filled with hydrothermal or magmatic fluids, and thus quantifying the source properties (crack size and fluid properties) contributes to monitoring the fluid amount in the crack. In this study, we developed a method to estimate the source properties from the lowest spectral peak frequencies, quality factors, and seismic moments of LP events using the analytical and empirical formulas proposed by the previous studies (Maeda and Kumagai, 2013; Taguchi et al. 2021). We applied this method to 243 LP events observed at Kusatsu-Shirane volcano, Japan, in 1989−1993. As a result, the vapor mass in the crack showed increasing and decreasing trends repetitively during this period, which negatively correlated with the frequencies. Thus, the temporal changes in the vapor mass can be estimated from those in the frequency. If a phreatic eruption is triggered by the pressurization due to an increase in the vapor amount in the crack, eruption risk can be assessed from the temporal changes in the frequency of LP events.

ID: 182

Stratigraphy of the prehistoric-historical hydrothermal crater field of Nisyros (Dodecanese archipelago, Greece): insights for hazard evaluation in a touristic geosite

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Nisyros is a Quaternary calc-alkaline composite volcano in the Dodecanese archipelago, last active ~15,000 years ago. A series of prehistoric-historical hydrothermal eruptions occurred within the summit caldera and infilling lava domes, in the southern Lakki plain, where a large fumarolic field is active. In the field, we recognized seven eruption units related to the hydrothermal craters of (in chronostratigraphic order) Kaminakia (unknown age), Megalos (Big) Polyvotis (unknown age), Stephanos (older than 1414-1420), Andreas or Mikros (Small) Stephanos, Polyvotis (1871-1873), Alexander (Flegethron) (1873) and Mikros (Small) Polyvotis (1887), whereas other small craters have no deposits recorded. Their stratigraphy is established based on angular discordances, thickness and grain size variations, and interlayered stratified lacustrine deposits. The eruption units are m-thick, poorly sorted deposits of ash-supported lapilli and blocks (up to 1,5 m) of hydrothermally altered lavas, with no fresh juvenile material, interpreted as proximal fallout deposits with ballistic ejecta and subordinate pyroclastic density currents and water-rich mass flows, with a max runout of ~400 metres from the crater margins. Most of the craters intersect each other, with max diameter of ~400 metres, and max depth of 20 metres. We infer that the hydrothermal explosions have been triggered by the sudden depressurization of the shallow geothermal reservoirs (250–700 m deep) induced by fracturing and seismicity along the main NE-SW fault system, with a probable input of hot magmatic fluids. This study represents the basis for hazard evaluation in the caldera floor of Nisyros, which is visited by many tourists every year.

ID: 188

The fatal Whakaari/White Island December 9, 2019 eruption: an independent review

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The rise of adventure tourism puts people close to active volcanic hazards and is inherently dangerous. On 9 December 2019, the Whakaari (White Island) stratovolcano phreatically exploded. Forty-seven people were on the island: 22 died, and 25 were injured. We reviewed data collected by GNS Science between 2010 and 2019. There were six explosive eruptions between August 2012 and April 2016, but the 9 December 2019 eruption was ~10 times more powerful, and the buildup was more energetic and prolonged. Monitoring data supported GNS's decision to raise the volcano alert level (VAL) to 2 on 18 November 2019, and to remain at VAL=2 until the fatal explosion occurred 3 weeks later, despite increasing unrest. There were significant changes in seismicity within 36 hours prior to 4 of the 7 explosions, but no consistent pattern. The monitoring programs and data interpretations followed and met recognized international best practice and used accepted conceptual models. The societal risk to tourist groups visiting the volcano was underestimated. Significant eruptions had a recurrence rate of 3-4 years since 1925, suggesting a 4% chance of a tourist group being impacted by an eruption each year. The risk of eruption was significantly greater during unrest periods (VAL=2+), which corresponded to ~5% of the time. There were 3 eruptions in 8 days in October 2013, yet the day after the 27 April 2016 eruption, tourism continued, suggesting risks were poorly understood by tour operators, and they had unrealistic expectations regarding GNS's ability to provide real-time warnings.

ID: 325

Dynamics and hazard of phreatic explosions at Vulcano Island (Aeolian archipelago, Italy)

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Phreatic events may represent the typical precursors to magmatic eruptions of varying intensity, but they can also manifest as isolated or repeated episodes within the activity of volcanoes hosting significant hydrothermal systems. Despite their generally lower intensity compared to magmatic/phreatomagmatic activity, phreatic explosions pose important hazards, especially in densely populated and tourist areas. The recent unrest at the La Fossa volcano (Vulcano Island, Italy), which began in September 2021, has drawn attention to the potential occurrence and expected dynamics of phreatic explosions during the reactivation of the volcanic system. Documentation of phreatic activity at the La Fossa volcano has been limited, with detailed studies primarily focused on the significant activity of the Breccia di Commenda (1230 CE). In this multidisciplinary study, relying on historical and sedimentological evidence, we focus on small-scale (less than 10^5 m^3 erupted products) phreatic explosions occurred in the XIX century, preceding by decades the 1888-90 magmatic event. Field data reveal the occurrence of pyroclastic density currents and ballistic showers potentially able to affect the La Fossa crater slopes and the currently inhabited area. Using three-dimensional, multiphase-flow eruption modelling, we explore the possible reconstruction of eruption dynamics, the role of crater geometry, and the interaction with the volcano topography. Numerical simulations allow the mapping of different hazardous phenomena, including the areas potentially affected by pyroclastic currents and ballistic fallout. The developed model, calibrated on this event, can be used for an assessment of phreatic eruption hazards in the framework of the ongoing hydrothermal unrest at Vulcano.

ID: 439

Diffuse emission of dioxide carbon from El Hoyon Volcano: a preliminary assessment

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Active volcanic and hydrothermal systems are widespread in El Salvador. We present preliminary data about diffusive CO_2 outgassing from Crater El Hoyón. A destination for over 700 tourists every year. The system is characterized by significant thermal anomalies, diffuse outgassing, boiling thermal waters, numerous fumarolic areas and an impressive steam jet. Two surveys were carried out in May and August 2023, with the aim to map for the first time the CO_2 degassing and soil thermal anomalies. Seventy CO_2 flux measurements were carried out with the accumulation chamber method, simultaneously with soil temperature measurements at 10 and 40 cm depth. The highest CO_2 fluxes were measured in the first campaign, with a median value of 215 g $m^{-2}day^{-1}$ and a range from 83.4 to 723 g $m^{-2}day^{-1}$. Fluxes in the second campaign were lower, with a median value of 0.98 g $m^{-2}day^{-1}$ and a range of 0.19 – 31.8 g $m^{-2}day^{-1}$. Such a big difference could be related to the climatic conditions during the two campaigns, dry in the first one and wet in the second, strongly impacting on soil permeability. Probability plots suggest a contribution from deep outgassing linked to the active volcanic system. This is further confirmed by the good correlation between CO_2 efflux and soil temperature, indicating a common pathway for gas and heat escape from the hydrothermal system. Further investigation and new measurements campaigns are required, in order to quantify the total CO_2 output, identify anomalies, and investigate the isotopic carbon footprint to establish its origin

ID: 520

Historical small-scale phreatic eruptions at Milos Island (Greece) as seen from geological and archaeological investigations

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Phreatic eruptions are among the most hazardous volcanic phenomena. This is because they are usually unheralded by precursors, making their forecast difficult. Due to their enigmatic priming conditions, the study of past events and their deposits is of paramount importance for constraining triggering conditions, intensity and magnitude of the explosions.

Milos island hosts a large geothermal field. Hydrothermal fluids extensively altered the Lower Pleistocene lava domes in the eastern part of the island. Silica-rich hydrothermal pools were widely present in the area at time of Roman occupation (2nd-3rd century), and largely exploited for mining of hydrothermal water and silica-rich muds. The hydrothermal pool area was extensively destroyed by the occurrence of many shallow phreatic explosions, forming more than 250 craters. Roman potteries are ubiquitous in the erupted deposits. The historical accounts report Milean population abandoned the island, probably as response to the phreatic explosions. We aim to shed light on the driving mechanisms of these phreatic eruptions, by means of morphometry of explosion craters and their spatial distribution, joined with stratigraphy of the deposits and geochemistry of fragmented material and substratum.

The craters have small diameters (< 20 m) and rarely occur as isolated but rather as nested. The estimated explosion energy is ca. 10^{10}-10^{12} J, depths ca. 2-10 m and temperatures of the hydrothermal system up to 370 °C. These data allowed us to formulate a conceptual model for the triggering of phreatic eruptions in Milos, providing important clues for present day hazard evaluation on the island and elsewhere.

ID: 563

Recent unrest at Campi Flegrei caldera increases the potential for a phreatic/hydrothermal explosive event

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The possible occurrence of phreatic and/or hydrothermal explosive events characterizes active volcanic shallower geothermal systems. Active calderas often host widespread fumarolic and hydrothermal activity, which makes these environments prone to favor such phenomena. A relevant example of a similar structure is the Campi Flegrei active caldera, where the Solfatara volcano resulted from phreatic events of varying energy that led to the formation of a maar/diatreme-type structure, which still hosts hot, intense fumarolic and hydrothermal activity, both within the crater and on the external flank.

The Campi Flegrei caldera manifested an unrest phase since 2000. The first signal of this still ongoing phenomenon was the increase in volatile magmatic species at Solfatara, followed by the formation of a new fumarole and hydrothermal field in the close area of Pisciarelli, which during time presented higher discharge of gas flux and mud spatter episodes from the main vent area. A new Audio Magnetotelluric 3D model accurately defines the configuration of the geothermal reservoir. The coupling with structural analyses evidence the most significant structures involved in the evolution of the caldera unrest, shredding light on detecting the primary fluid rising pathways and the nature of the resistivity anomaly as a proxy of the deep and shallow geological structure. With the addition of a comparison with the very recent seismicity involved in the ongoing bradysesimic crises, the MT model helps determine possible future hydrothermal/phreatic scenarios for the investigated area.

ID: 282

Experimental Study of Impact Absorption Effect of Overlying Artificial Pumice Layer for Dealing with Ballistic Rock Impact

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In Japan, since the disaster caused by the 2014 phreatic eruption of Mt. Ontake, evacuation shelters have been installed and existing facilities such as mountain lodges have been reinforced for impact resistance near the crater of the active volcanoes. Existing guidelines suggest reinforcing methods using aramid fibers, but this method is expensive and has become a concern when reinforcing evacuation facilities. Therefore, we investigated a reinforcement method using pumice, available near the volcano. Following Yamada et al. (2018), experiments were conducted on the impact absorption effect of the pumice layer on wooden and reinforced concrete (RC) structures using a simulated ballistic ejecta mass of 2.66 kg (equivalent to a diameter of 128 mm). Artificial pumice with a composition similar to natural pumice was used in this experiment, and the artificial pumice layer covering the structures was varied from 0 to 31 cm thick. As a result of the experiment, we confirmed the impact absorption effect of the artificial pumice layer on both structures, and the effect was enhanced by increasing the thickness of the artificial pumice layer. However, it should be cautioned that there is a limit to the dead load in the case of wooden structures. On the other hand, RC structures have sufficient dead load capacity, so it is more effective to cover them with an artificial pumice layer as much as possible.

ID: 449

Geochemical survey of volcanic gasses at touristic areas at El Salvador volcanoes

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El Salvador's volcanoes are one of the country's main tourist attractions. Every year thousands of local and foreign tourists visit these active volcanic areas, notwithstanding numerous associated dangers. These areas often lack of warnings on the potential risks and a robust and systematic geochemical monitoring of volcanic activity is absent. A preliminary geochemical survey was carried out at the most visited volcanic sites. It included diffuse soil CO_2 flux measurements and the assessment of air quality through a multi-gas type sampler. Moreover, 11 gas samples were collected to determine their chemical and isotopic compositions. The highest CO_2 flux values were obtained at El Hoyón crater, with a median value of 4.9 mol m^{-2} day^{-1}, whilst the lowest values were from El Boquerón, with a median value of 0.1 mol m^{-2} day^{-1}. Chemical composition of the gases showed a mixing pattern between a CO_2-dominated (up to 976,200 µmol/mol) end-member of deep origin and a N_2-dominated atmospheric component. Helium values arrived up to 4.6 µmol/mol. Only La Viejona site presented a slight enrichment in methane (up to 155 µmol/mol), whilst only one site showed enrichment in H_2S (up to 22,800 µmol/mol).

ID: 530

Reevaluation of volcanic risk related to phreatic eruptions examples from Costa Rica

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Phreatic eruptions are particularly hazardous for tourists in volcanic areas, besides to the local communities, because of their unpredictability, as recently in Ontake (2014) and Whaakari (White Island, 2019). This increases substantially the vulnerability of people who have access to the summit areas of a volcano, as one of the main factors that contribute to define the concept of risk as the combination of hazard, exposure and vulnerability. Accordingly, phreatic eruptions are usually associated to a low hazard because their occurrence is underestimated due to the difficult preservation of the corresponding deposits in the geological record. However, their effective risk is underestimated particularly if we consider volcanic areas with a growing touristic income, often with clear peak seasons.

We consider the cases of the Rincón de la Vieja, Poás and Turrialba active volcanoes (Costa Rica), where dozens of phreatic eruptions occurred between 2009 to 2023. These eruptions impacted the human and livestock health and affected the country’s economy. The countermeasure of the local Civil Protection abolishing visits to these volcanoes, backlashed by the business of bringing tourists illegally and dangerously close to the active craters, resulting in less control on the situation. We will discuss critically the practices adopted to manage and mitigate the risk related to recurrent phreatic eruptions according to (i) the still limited knowledge and predictability of the phreatic eruptions, (ii) the chaotic touristic approach to active volcanoes, and (iii) the difficult communication aimed at increasing the awareness of the risk posed by these eruptions.

ID: 684

Comprender la actividad explosiva del volcán Copahue: un paso necesario para la gestión del turismo volcánico

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El volcán Copahue, situado en los Andes argentino-chilenos (37º51'S, 71º09'O), es un estratovolcán que alberga una laguna caliente y ácida en su cráter activo y presenta recurrente actividad explosiva freática a freatomagmática de baja magnitud. Los peligros volcánicos asociados a este sistema y la proximidad de las villas turísticas de Caviahue y Copahue, a 5 y 9 km del cráter activo respectivamente, lo posicionan en el primer lugar del ranking de Riesgo Relativo para la República Argentina. La actividad turística en la zona moviliza miles de personas todos los años, atraídas principalmente por el centro de esquí, el complejo termal y las excursiones al cráter. Además de representar un riesgo directo para la seguridad de las personas, la inadecuada gestión del turismo en este escenario volcánico podría aumentar el impacto socio-económico en las comunidades locales. Dado que las erupciones freáticas suelen ocurrir repentinamente y con pocos precursores, este trabajo busca contribuir a una mejor comprensión de estos fenómenos. Para eso, nos enfocamos en la actividad eruptiva del período 2018-2022, caracterizada por inestabilidad volumétrica de la laguna y explosiones freáticas con emisión de ceniza y SO_2. A partir de un análisis multiparamétrico, utilizando imágenes satelitales Planet y Sentinel 5P, modelos meteorológicos como el CFSR y CHIRPS, y datos sísmicos, se observó que la actividad explosiva coincidió con momentos en los que el tamaño de la laguna cratérica era reducido o inexistente. Se identificó, a su vez, que este proceso siguió un patrón estacional relacionado con la temperatura ambiente y las precipitaciones.