ID: 97

Cascading volcanic hazards of collapsed mafic volcanoes: an overview of the types and timescales of magmatic response.

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Sector collapses are catastrophic landslides that can occur at any volcano. They can destroy and reshape the morphology of volcanic edifices, transforming geomorphology, hydrology, and ecosystems in the long term (hundreds to thousands of years). However, how collapses influence the magmatic plumbing systems still needs to be systematically described. Here, I present mounting field, petrological, and numerical evidence of the types and timescales of magmatic response to collapse at mafic (i.e., basaltic to basaltic andesite) volcanoes. Minor lateral collapse (0.001-0.1 km^3) can drive transient transformation of vent architecture and landscape modification influencing lava drainage, as during the growth of the Tajogaite cone in 2021 (La Palma, Canary Islands). At Pacaya (Guatemala), its millennium lateral collapse (0.6 km^3) produced an instantaneous directed blast and exacerbated subsequent Strombolian activity by basaltic magma decompression. Substantial mass removal (8.6 km^3) at Planchón volcano (Chile, 48 ka) did not affect magma composition, indicating a monotonous, high-rate basalt production. Contrarily, the collapse of Antuco (Chile, 6.4 km^3; 7.1 ka) triggered intermediate magma's effusive and explosive eruption by unlocking a "dormant", shallow crust differentiated reservoir that persisted active by three ky. These findings point to the reservoir overpressure, the edifice unloading magnitude, and the magmatic flux to explain such different responses. The results are relevant for volcanic hazard assessment and monitoring techniques to reduce volcanic risk in communities near gravitationally unstable or recently collapsed volcanoes.

ID: 128

Volcanic Debris Avalanches: the last major volcaniclastic process to be recognized

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Volcanic debris avalanches characterize almost all stratovolcanoes in different geodynamic settings around the world. The burst of interest in lateral-collapse events in the last decades has led to the recognition of a thousand events from nearly 600 volcanoes. The last major volcaniclastic process to be widely recognized and understood, large-volume debris avalanches have been found to be a relatively common occurrence across a wide spectrum of volcanic features and settings. The instability of a volcanic edifice is promoted by many factors often related to volcanic activity and tectonics along with exogenous processes such as weathering and climate events. The surface features, and their internal structures and sedimentology are relatively well studied, but their mode(s) of transport and emplacement are still not completely understood. From source to distal areas, volcanic debris avalanches are highly complex and variable, ranging from sliding-block motion and dry granular flow in proximal reaches, transforming to long-runout landslides in the medial zone, to pore-fluid-(semi)saturated debris flows in distal and marginal areas, with a range of transitional behaviours between them. Understanding the mechanisms of transport and emplacement and the factors that promote volcano instability provides critical information for hazard assessment. The aim of the present work is to discuss the many aspects of these processes giving to the audience some key tools to understand these fascinating, as well as highly destructive volcanic phenomena.

ID: 156

Inter-eruptive lahars at El Chichón Volcano (Mexico): susceptibility analysis and numerical modeling

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El Chichón volcano, located in the southern part of Mexico, in one of the most active volcanoes in Mexico; in 1982 was the scene of the largest Plinian eruption recorded in Mexico during the last century. The volcano is in a climatic region with extreme rainfalls that usually accumulate more than 3000 mm per year, and frequently affected by hurricanes. The most recent events were caused by the Eta hurricane in 2020 and Karl tropical storm in 2022, in addition to an atypical rainfall in the same year that accumulated 440 mm of rains in 24 hours. During these episodes, hundreds of soil slips originated and transformed to inter-eruptive lahars affecting several communities in the area.

In this work, we present a morpho-hydrological characterization of 33 catchments that drain from volcano, including their geology and land use changes to identify the factors promoting mass wasting processes. Moreover, rainfall frequency analysis was performed with data from six weather station for the period 1987-2017, and three precipitation scenarios with return periods of 5, 10, and 20 years were defined. Based on these results, rainfall-runoff simulations using the FLO-2D code allowed to obtain discharge curves for each catchment, which were than used to simulate inter-eruptive lahars from the volcano slopes. Hazard maps for inter-eruptive lahars based on the probability of occurrence and flow magnitude are here presented. They represent a new contribution to the actual hazard map of the El Chichón volcano and an essential instrument necessary to contribute to risk management.

ID: 295

Insights into the Rheological Weakening of Erodible Substrates and the Implications for Continuum Modelling of Bulking in Geophysical Flows.

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We study the rheology of erodible beds at the micro-scale with the aim to obtain a better understanding of the processes governing entrainment in geophysical flows (GFs - e.g., pyroclastic density currents) and ultimately hone boundary condition formulations in depth-averaged models (DAMs - i.e., large-scale continuum models used in risk management). We employ discrete element method (DEM) to construct simulations of mono-disperse dry erodible beds in the shear cell configuration at constant pressure. We propose a new approach of tracking the flow-substrate interface (FSI), based on a critical inertial number $I_c=5\times10^{-4}$ at the kink of the velocity profile. Entrainment is observed in horizontal beds, a phenomenon that is not taken into account in current DAMs. In inclined erodible beds, the relation between erosion rate and flow properties does match those employed in DAMs, demonstrating the link between the micro and macro-scales in dry granular flows. We find that the rheology of erodible beds deviates from local at inertial numbers $I<10^{-2}$, a range where many GFs sit. A weakening of the bed below the static coefficient of friction is seen accompanied by an increase of granular temperature and enhanced packing fraction with respect what is predicted by local rheology. The coefficient of friction at the FSI coincide with values described by the whole column at low I, implying that the failure of erodible beds is controlled by a weaker non-locality, leading to enhanced erosion. Future work should address the effect of pore pressure and polydispersity on GF entrainment.

ID: 298

Compositional systematics in volcanic flank collapse deposits off Fogo (Cape Verde): Origin and emplacement processes

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Volcanic flank collapses are known to have great tsunamigenic potential, but their causes, frequencies, volumes, and potential impacts are poorly understood. Fogo is one of the most active volcanoes on Earth posing non-neglectable threats to the population of the Cape Verde archipelago located offshore West Africa. The volcano is associated with a number of geohazards such as (explosive) eruptions, landslides and giant tsunamis caused by flank collapses. These hazards widely distribute volcaniclastic material over submarine areas albeit their extend and emplacement processes remain poorly constrained. In this study we investigate emplacement processes and spatial distribution of event layers identified in 9 sediment cores recovered during RV Meteor voyage M155 within proximal to distal areas south of Fogo Island. From the pilot study of two cores, we established an effective method for differentiating volcaniclastic horizons from volcanic flank collapse. This method is based on quantitative petrography in combination with statistically acquired electron microprobe analysis, revealing variability in clast abundance and chemical signature that provide the tool to distinguish and correlate the volcaniclastic layers in the cores. Structural analysis of the sediments gives additional insights on transport and depositional processes thus providing a promising method to characterize these flank collapse deposits. The determination of volcaniclastic layers subject to flank collapse events over time is crucial to estimate tsunami potential of Fogo volcano. Ongoing geochemical and sedimentological analysis of the entire net of cores will inform on emplacement processes, frequency and recurrence rate of mass wasting events associated with volcanic flank collapses.

ID: 316

Volcanic Island Sector Collapse: Implications for subsequent mass movements from marine records drilled with MeBo70 offshore Montserrat (Lesser Antilles)

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Volcanic island sector collapses produce some of the volumetrically largest mass movements on Earth. They may trigger devastating tsunamis that pose hazards to coastal communities and endanger seafloor installations. We present four MeBo70 sediment drill cores from up to 63 mbsf that were obtained during the Meteor expedition M154-2 offshore Montserrat in 2019 to provide insights into the interplay between volcanic activity, subsequent mass wasting events, and their emplacement processes. To reconstruct the volcanic activity and establish an event chronostratigraphy from the marine sediment records off the Montserrat volcanic island, we analyzed samples from four drill sites for their componentry and geochemical composition. The sediments predominantly comprise mud-rich facies interbedded with fine to coarse-grained sands with variable proportions of volcanic and biogenic clasts. In a small number, coarse volcanic sands to volcaniclastic gravels were encountered. Tuffaceous deposits are even less frequent. Semi-quantitative petrographic analyses of selected samples by polarized light microscopy provides clast inventories to differentiate between sediment units. Geochemical fingerprinting of major and trace elements of volcanic glasses by electron microprobe and LA-ICPMS elucidates this differentiation. The geochemical glass analyses further show different basaltic to rhyolitic compositions in the range of Arc Tholeiitic and Calc-alkaline series, dominating the different event layers. The analyzed samples represent different stages of volcanic island evolution with periods of increased volcanic activity and eruptions, dome/flank collapses, submarine mass wasting events, and periods of relative inactivity.

ID: 334

The relationship between volcano growth, eruption style and instability at Anak Krakatau, Indonesia, and implications for future hazards

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Edifice destabilisation is a common volcanic process and although relatively infrequent, large-scale gravitational collapses can occur across all volcano-tectonic settings. Growing evidence suggests that cycles of edifice growth and destruction, through variable loading of the underlying magma reservoir, influence magma storage conditions and eruptive behaviour on a range of timescales. However, difficulties in developing high-resolution reconstructions of pre- to post-collapse volcanic activity limit our understanding of these relationships.

In December 2018, Anak Krakatau underwent a substantial failure of its south-western flank, following a period of heightened but not atypical eruptive activity. Unlike most historical lateral collapses, this major structural failure occurred just 91 years after Anak Krakatau's emergence above sea-level in 1927. As a result, the volcano offers a uniquely well-documented record of a complete cycle of edifice construction, failure and subsequent regrowth.

This work combines remote sensing, 3D reconstructions and analysis of past eruption records to examine Anak Krakatau's volumetric evolution at 33 points since its initial formation. Results indicate that following collapse Anak Krakatau entered an accelerated ongoing phase of regrowth, with 4-years of rapid volumetric increase equivalent to 62-years of historical growth (1950-2012). Evaluating this structural development provides an analogue for understanding edifice growth and stability at other volcanoes globally, and is key to constraining the future growth and stability of Anak Krakatau itself. This is critical in developing improved hazard management strategies in this densely populated region, where a challenging set of cascading hazards results from the partially submerged setting and frequent eruptions.

ID: 450

Rheological characterization of lahar interstitial fluid from Popocatépetl volcano, Mexico.

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Lahars are sediment-water mixtures that flow under the force of gravity on volcano slopes. The interaction between the interstitial fluid and the large-solid clasts that compose them plays a critical role in determining their physical behavior. Volumetric concentration, granulometric distribution and composition of the interstitial fluid (clay and silt plus water), are the main factors that influence their rheological behavior. This behavior affects the mobility and emplacement mechanisms of lahars. Therefore, in this work, the rheological parameters (apparent viscosity and yield strength) of the interstitial fluid of syn-eruptive and secondary lahars of Popocatépetl volcano, Mexico, were measured by a method under constant strain rate conditions (ranging from 50 to 100 s^{-1}) using a rotational viscometer.

The interstitial fluid showed a first order relationship between strain rate and shear stress. In addition, a decrease in apparent viscosity was observed with increasing strain rate. These trends suggest a Bingham thinning behavior under these strain conditions. Apparent viscosity increased by 2-3 times for a volumetric concentration increase of circa 3.75% and the yield strength increased by an order of magnitude. Syn-eruptive lahars, composed of clay-sized and pumice material, showed apparent viscosity values two times higher and yield strength values up to an order of magnitude higher, compared to secondary lahars. Our data suggest an exponential relation between volumetric concentration and the rheological parameters, which can be used as set up parameters in lahar numerical simulations. Finally, the study of interstitial fluid behavior allowed the identification of behavioral thresholds associated with lahar movement.

ID: 288

Inundation and evacuation of shoreline populations during landslide-triggered tsunami: An integrated numerical and statistical hazard assessment

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The volcano island of Stromboli (Italy) is known for its local tsunamis generated by landslides in the Sciara del Fuoco, as demonstrated by the events of December 2002 when a tsunami with a run-up of 10 m inundated coastal areas. With very short warning time ranging from less than a minute to only a few minutes, mitigation efforts and evacuation from the Strombolian coast must be carefully planned. As a result, sea-floor detection systems have been installed, linked to on-shore sirens. However, except for 2002 events little natural data are available for tsunami hazard assessment at Stromboli, so numerical modelling of tsunamigenic landslides was required. Our numerical modelling was used to create 156 tsunami and coastal inundation extent models, and 156 tsunami beacon signals were produced and linked to their associated hazard scenarios. Inundated zones were statistically merged with population distributions varying with season and time-of-day. This resulted in the creation of 156 specific evacuation models, with routes and times to reach a safe area from the inundated area, and appraisal for the time needed to escape versus the wave arrival time. The creation of an impact score linking the predicted inundation extent and the tsunami beacon signals for each hazard scenario allows assessment of the extent of any future tsunami, and to adapt evacuation plans accordingly. Evacuating an island hosting several thousand tourists every summer with very little warning time supports the absolute necessity for such mitigation efforts, aimed at informing hazard planners and managers, and all other stakeholders.

ID: 466

THE LAIMA-UASLP GRANFLO: A LABORATORY FOR LARGE SCALE GRANULAR FLOWS EXPERIMENTS

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Geological granular flows encompass some of the most perilous phenomena on Earth. Despite their immense danger, there is still much to uncover regarding their development and deposition. Direct observation during their formation poses significant challenges due to their unpredictability, huge destructive potential, inherent danger, and their tendency to move within an impenetrable cloud of ash or underwater.

Since few decades, one method that has been employed is conducting large-scale experiments in flumes equipped with various types of sensors. At the LAIMA-UASLP (Mexico) laboratory, a suite of instruments has been developed to facilitate the study of both dry and wet granular flows through analog experiments. The laboratory features two experimental flumes, measuring 8 and 14 meters respectively, and a 1.5-meter-long variable-width flume. Each flume is equipped with a range of sensors, including normal pressure sensors, laser barriers, time-of-flight sensors, geophones, flat response microphones, high-speed camera systems, and PIV programs to measure velocity both vertically and longitudinally. Furthermore, the resultant deposits are reconstructed using a local photogrammetry system, enabling the creation of 3D digital models for quantitative morphometric analysis.

In this work, we will not only highlight the primary characteristics and functionality of the flumes within our laboratory but also discuss upcoming developments, ongoing collaborations with national and international research groups, and we show a selection of our current preliminary results.

ID: 488

The Granular Effect: Exploring Factors Influencing Volcanic Landslide Runout Through Analogue Experiments

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Volcanic landslides, capable of extreme runouts and secondary hazards such as debris flows and tsunamis, pose a destructive hazard to communities and infrastructure. Despite the importance of accurate modelling and hazard assessment, their propagation processes remain enigmatic, with models relying on empirical parameters to reflect their low apparent friction. The scarcity of large events, inaccessibility and poor preservation of deposits make analogue experiments a crucial tool in investigating volcanic landslides. Dry landslides, such as debris avalanches, can be considered dry granular flows with dynamics controlled by particle interactions, internal and basal friction coefficients, and path geometry. This study explores the processes of energy dissipation and momentum transfer in such flows, referred to as the granular effect. In addition, we explore the granular effect as a potential factor for the unexplained low apparent friction coefficient and long runouts of volcanic landslides. The findings suggest that the volume, grain-size distribution and path geometry can enhance the mobility of granular flows. Particle collisions transfer momentum from the back of a flow to the front, enhancing spreading and runout. Additionally, fine particles at the base of a flow reduce frictional surfaces, encourage rolling and increase runout. Furthermore, the geometric and dynamic scaling considerations, fundamental for experimental design and interpretation, are evaluated. Our results suggest that the flow regime and specific processes observed in small systems can be biased by scale, generating conditions which do not reflect landslides in the field. This highlights the importance of dynamic scaling in recreating landslide conditions in analogue experiments.

ID: 585

Soil-slip susceptibility assessment on Popocatépetl volcano

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On September 19, 2017, the Puebla-Morelos earthquake (Mw 7.1) impacted the Popocatépetl volcano, resulting in hundreds of shallow landslides recorded on the flanks of the edifice. The most significant events (soil slips) were concentrated in an ENE-WSW band along three ravines. These areas experienced liquefaction processes, transforming into debris flows that traveled up to 7.7 km from the rupture area. These events haven't been previously documented in the Popocatépetl volcano nor included in the current volcanic hazard map. This work focuses on studying these events and the factors that allowed their occurrence to estimate the regions susceptible to these processes in possible similar future events. A discriminant analysis, combined with a landslide inventory and quantitative analysis using the "weights of evidence" approach, identified the conditioning factors in generating these processes.

The results reveal that the affected regions were predisposed, and the earthquake acted as a triggering mechanism. The steep slopes created by lava flows from previous eruptions and a saturated, unconsolidated volcaniclastic coverage of the most recent Plinian eruptions served as conditioning factors that reduced the slopes' resistance. Furthermore, the ENE-WSW sector where these events occurred runs parallel to the volcano's main faults and aligns with the current tectonics dominating the region.

In conclusion, the regions most susceptible to soil slips are those located west of the cone, where the high slopes and thin layers of pumice and ash deposits constitute the most vulnerable factors that, added to partial saturation of the soil, produce a metastable zone.

ID: 595

An inventory of Volcanic Debris Avalanches of the Puna region (Central Andes)

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Volcanic debris avalanches represent a substantial natural hazard. Notably, even inactive volcanoes remain susceptible to edifice collapse. The Puna region of the Central Andes hosts some of the world's tallest volcanoes and an abundance of sector collapse events. This region is ideal for studying a volcanic debris avalanche because of the low denudation rates, the presence of steep-sloped volcanoes prone to collapse, and the excellent exposure of deposits due to the arid conditions and sparse vegetation. We present a database of the volcanic debris avalanche deposits and associated edifices of the Puna, characterizing their morphometries through DEM analyses. The database architecture is designed to ensure that all contained information is both consistent and comparable, facilitating data analysis. Our methodology encompassed the manual digitization of scars and volcanic debris avalanche deposits, coupled with the calculation of morphometric parameters using the TanDEM-X 12 m resolution DEMs within a GIS framework. Computed parameters include length, width, area, volume of the scars and deposits. Aperture width and angle, height, slope, azimuth, elongation, and closure factor of the scars are measured. Height, declivity, thickness, runout, drop height, and friction coefficient describing the deposits are also calculated. At present, the database comprises ca. 15 avalanche entries, many of which pertain to deposits not previously identified. This database provides insights into the spatial and temporal distribution of avalanches across the Puna. It aids in understanding the relationships between volcanic structures, collapse triggers, tectonic structures, hydrothermal alteration zones, and stability. Such analyses can contribute significantly to hazard mitigation.

ID: 597

Reología de lahares sineruptivos en el volcán Popocatépetl (México)

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Actualmente una de las herramientas más importantes para la elaboración de mapas de peligros por lahares son los modelos numéricos. Dichos modelos requieren de información del terreno y del evento (volumen, tipo de lahar, viscosidad) para ser calibrados con precisión. Entre los parámetros más importantes, después de los modelos de elevación y la magnitud, se encuentra la viscosidad y la resistencia crítica (reología). A pesar de esto, la mayoría de los estudios de reología de lahares se han enfocado en su dependencia con la concentración de partículas y poco se ha estudiado acerca de la influencia de la temperatura que, en lahares sineruptivos, puede alcanzar los 80°C. Por lo tanto, en este trabajo se presenta la caracterización reológica de suspensiones de sedimento fino, constituidos por agua y ceniza, en rangos de temperatura entre 50 ºC y 80 ºC. Para ello se utilizó un viscosímetro rotacional, calibrado en condiciones de tasa de deformación propias de un lahar. El material utilizado proviene de depósitos de lahar sineruptivos, asociados a actividad pliniana, del volcán Popocatépetl. Finalmente, este trabajo es pionero en la caracterización de suspensiones de agua y ceniza, en condiciones diferentes a temperatura ambiental, y permitirá comprender acerca de la dinámica de lahares formados a partir de la removilización de depósitos piroclásticos.