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Editorial: Volcanoes' change of mood and their impact: effusive—explosive eruptions and *vice versa*

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Editorial on the Research Topic
Volcanoes' change of mood and their impact: effusive—explosive eruptions and *vice versa*

Most volcanoes in subduction settings with magmas ranging in composition from mafic to felsic may change their eruptive regime between effusive and explosive. For instance, volcanoes such as Pinatubo (Philippines), Mount Saint Helens (United States), Guagua Pichincha and Tungurahua (Ecuador) or Popocatépetl (Mexico), routinely change their eruptive regime between effusive and explosive or from explosive to effusive yet the triggers of regime change are not fully understood (Pallister et al., 1992; Dingwell, 1996; Wright et al., 2006; Cashman et al., 2008; Delgado Granados et al., 2008; Wadsworth et al., 2020; Razvan-Gabriel et al., 2021; Samaniego et al., 2011). This leads to considerable uncertainty in the forecasting of eruptive style and magnitude and in the selection of forecasting parameters that enable mitigation of the threat from such volcanoes (Cassidy et al., 2018). This is especially critical when volcanoes have been presenting continuous activity and changes in regime might only be preceded by very smooth or short-term changes in monitored parameters.

The mood swings of volcanoes' eruptions comprise various temporal and spatial scales, as volcanoes perform this switching between effusive and explosive events (Cassidy et al., 2018). Such changes can occur on time scales of months, years, decades, or even centuries. In the short term, during eruption, volcanoes can also switch between effusive and explosive behavior on time scales ranging from fractions of a second to hours or days (Ruprecht and Bachmann, 2010; Venzke, 2013). For large stratovolcanoes, effusive volcanism can occur in one part of the volcanic edifice, while it can behave explosively in another sector (Smith and Houghton, 1995). Even in monogenetic volcanic fields, volcanoes can behave effusively, explosively or exhibit a combination of both, through a central conduit or from fissures controlled by the stress field prevalent in the region.

It is important to review the processes that lead to explosive and effusive eruptions of magmas of different compositions (Sparks, et al., 1977; Pallister et al., 1992;

Williamson, et al., 2010). These processes can occur in silicic magmas, as well as in magmas of andesitic or basaltic composition (Newhall and Melson, 1983; Cashman and Sparks, 2013; Cassidy et al., 2015), as was observed in the recent eruption of Cumbre Vieja, on the island of La Palma, Spain (Romero et al., 2022; Benito et al., 2023; Birnbaum et al., 2023; Taddeucci et al., 2023).

The role of parameters such as magma viscosity (Lavallée et al., 2007), abundance and loss of magmatic volatiles (Newhall and Melson, 1983; Jaupart and Allègre, 1991; Parmigiani et al., 2016; Preece et al., 2016; Campion et al., 2018), the geometry of the conduits (de Michieli Vitturi et al., 2008), the basement conditions and groundwater (Collinson and Neuberg, 2012; Ball et al., 2015) have all been brought into consideration. Variations in magma supply from depth (in terms of mass and chemical fluxes) may also influence the ascent rate (Scandone and Malone, 1985; Scandone et al., 2007; Preece et al., 2016), crystallization (Nishimura et al., 2005; Wallace et al., 2015), decompression (Alidibirov and Dingwell, 1996; Tarasewicz et al., 2012) and degassing of magma (Edmonds, 2008; Takeuchi et al., 2009; Owen et al., 2013) yielding temporal and spatial variations in eruptive style.

The collection of contributions gathered in this special edition of Frontiers demonstrates that more studies are needed to understand the causes of mood changes at volcanoes. Basaltic (e.g., Ikenaga et al.) as well as silicic systems (Aubin et al.) require new ways to envisage the acting processes driving the changes in behavior (Martin-Del-Pozzo and Santos Morales). All methodologies are useful to elucidate these changes, and the morphological analyses are key for volumetric estimates combined with thermal information (Vallejo et al.).

Ikenaga et al. observe that most studies of explosive volcanism concern silicic magmatic systems. Yet explosive basaltic volcanism such as the eruption of Etna in 122 BC (Coltelli et al., 1998), the 1886 eruption of Tarawera (Walker et al., 1984), or the eruption of Parícutin volcano in 1943–1952 (Pioli et al., 2008) demonstrate the importance of studying mafic explosive-effusive switching in eruptive style and consequences for associated hazards. In studying the 1777–1792 An'ei basaltic eruption of the Izu-Oshima volcano, Ikenaga et al. reconstructed the transition of eruptive style of a complex eruption consisting of lava flows and explosive products, based on a combination of geological data, historical documents, and chemical analyses, and the development of magma plumbing models. The eruption started at the summit crater with weak explosive activity producing scoria. This was followed by more intense explosions, with the resulting deposit being classified into Units A-C. Unit B also started with weak explosive activity which increased its intensity until the climatic phase of November 1778 when Unit C was ejected. It is noteworthy that the amount of Al_2O_3 and the modal phenocryst contents in the magma showed an increase with the progression of the eruption. Ikenaga et al. documented a transition from relatively weak activity with Strombolian explosions, associated with aphyric magma (Unit A; 1.0–4.3 × 10^7 m^3), to short-period activity with more intense sub-Plinian explosions (Unit C; 1.3–3.2 × 10^7 m^3), associated with porphyritic magma. They explained this transition as resulting from the evacuation of magma from multiple reservoirs with different contents of plagioclase phenocrysts. Simultaneously, lava flows with different petrological features as compared with those of the scoria from explosive eruptions suggest also multiple magma reservoirs and pathways.

As noted by Aubin et al., two eruptions in 2008–2012 in Chile (Chaitén and Cordón-Caulle) exhibited lava extrusion and the explosive release of pyroclasts simultaneously, challenging sequential eruption style models for rhyolitic eruptions (Castro and Dingwell, 2009; Castro et al., 2013; Schipper et al., 2013; Heap et al., 2019). Wadsworth et al. (2020); Wadsworth et al. (2022) explain the contemporaneous eruption of degassed pyroclasts and lava via variable amalgamation and sintering of pyroclasts at depth following fragmentation, a process involving an occlusion of the eruptive conduit following the accumulation of variably sintered magma. Effusion of degassed lava ensued, and the continuous degassing re-sintered magma along the conduit walls to be subsequently re-fractured accompanied by explosive gas expansion (Castro et al., 2012; 2014; Schipper et al., 2013; Saubin et al., 2016; Wadsworth et al., 2022). Aubin et al. have tested this conceptual model using microlite number densities (MND) in obsidian pyroclasts from the 1340 C.E. North Mono eruption, California, United States. (Sieh and Bursik, 1986; Bursik, 1993) backed up by hydrothermal experiments (800°C, 10–50 MPa, 1–7 h). They observe 1) MND increases with time during the eruption; 2) feldspar and pyroxene microlites exhibit multiple morphologies; 3) microlite orientations correlate with the dominant morphology of vesicles (generally well aligned in samples with ellipsoidal vesicles, but poorly aligned in samples with spherical vesicles, and could be either aligned or unaligned into planes in samples with distorted vesicles). The experimental results show 1) an increase of MND with time, 2) a single morphology of microlites, and 3) random orientations regardless of pressure or temperature. The experimental results suggest that microlites could have grown in ≤~7 h. The authors conclude that MND increases with time as volatile concentrations decrease throughout the eruption. The variety of microlite morphologies and orientations support the idea of a repeated in-conduit fragmentation and sintering, consistent with the idea that each individual obsidian pyroclast is the product of ash sintering at multiple depths in the conduit prior to finally being erupted. At the beginning of the eruption, fragments of obsidian formed in magma stalled at crustal depths were entrained. Obsidian pyroclasts were extracted from many depths in the conduit, preserving an array of volatile contents and microlite textures. Near the end of the explosive phase, higher MND record longer periods of stalling while dissolved volatile contents record vapor-melt equilibration at shallow depths in the conduit. At the end of the eruption, the obsidian pyroclasts were more degassed and stalled for longer periods before they explosively erupted from shallow depths. Microlites became well aligned as the conduit was blocked by sintered ash and with higher strain rates. Sintered degassed lavas with well oriented microlites were extruded with the continued fragmentation and degassing of ash at depth.

Traditional techniques such as photogrammetry performed with the new tools developed by advanced technology (such as Unmanned Aerial Vehicle or UAV) to produce digital elevation models (DEM) using structure from motion (SFM) techniques and complemented with several other remote sensing tools (e.g., IR thermal cameras; or the volcanic radiative power -VRP- from MIROVA; Coppola et al., 2016; Coppola et al., 2020) may provide new insights into the switching between eruption styles from a geodetic/geomorphological perspective. For the case of long-lived-eruptive volcanoes such as El Reventador in Ecuador Vallejo et al. have presented an alternative view of the destructive and constructive processes, during the long-lasting activity following the paroxysmal eruption on 3 November 2002, which destroyed the upper part of the summit. They document morphological changes which they attribute to an interplay of destructive and constructive processes caused by a combination of explosive and effusive events influenced by the dynamics and architecture of the magmatic system. On the basis of a large dataset of thermal and visible imagery resulting from 20 years of continuous monitoring activity at Instituto Geofísico (Ecuador), combined with DEMs constructed from imagery obtained during reconnaissance flights and VRP; Vallejo et al. describe in detail the transitions and coexistence of Strombolian and Vulcanian eruptive activity at El Reventador volcano from November 2002 to November 2023. The eruptive activity comprised of three destructive events (November 2002, leaving a north-south branched crater; June 2017, NE border crater collapse; and April 2018, NW flank collapse) and two constructive periods (refill of the crater in November 2002-early April 2018, and refill of the northwestern flank scar in late April 2018 until 2023). The DEMs enable the estimation of volumes removed (34.1 $\times 10^6$ m^3 of volcanic material during destructive events or added 64.1 $\times 10^6$ m^3 during constructive events). They infer a maximum height of stability of the volcano at 3,600 ± 10 m, arguing that this cone height corresponds to a lithostatic load threshold, limiting the elevation of magma ascent.

Changes in volcanic behavior, like those discussed above, are complex and are likely to result from variations in a combination of processes, such as magma ascent velocity, conduit geometry, magma composition and volcanic degassing. For the first case, the ascent and stalling of batches of magma can be documented through the observation of the geomagnetic field at volcanoes (Yukutake et a., 1990; Zlotnicki et al., 1993; Sasai et al., 2002; Martin Del Pozzo, 2012). In this collection, Martin-Del-Pozzo and Santos Morales present a time-series of magnetic data recorded at Popocatépetl volcano, Mexico, using signals from a monitoring network between October 2018 and December 2019, documenting changes from effusive to explosive behavior associated with the extrusion of lava domes. The volcano changed its eruptive behavior between March 15 to 18 July 2019, during which no lava domes were observed. Although there was an important decrease in activity in this interval, unexpected explosions in March and June, produced ash plumes as high as 14,000 m a.s.l. As the local geomagnetic field can be affected by variations due to magnetic storms, micropulsations, and other external effects, Martin-Del-Pozzo and Santos Morales processed the raw magnetic data using the weighted difference method of Rikitake (1966) to enhance the magnetic changes associated with volcanic activity, and used the discrete-time continuous wavelet transform (Torrence and Compo, 1998) to evaluate the local variations of energy within the time series. They separated the magnetic data into three periods of 5 months to observe the volcanic processes before, during and after dome growth in 2019. They evaluate whether the internal behavior of the volcano can be recognized from the volcano magnetic signals which are the result of a sum of superimposed thermomagnetic and piezomagnetic processes. Magma ascent along the conduit may have induced negative magnetic anomalies during the high energy periods. Sudden more energetic explosions can be explained in terms of magma batches with different compositions that could have induced changes in the rheology of lava extruded, with more viscous degassed, ascending andesitic magma being pushed up, whilst compacting due to gas loss. This contribution shows the importance of correlating several sources of geophysical data and integrating geochemical and mineralogical composition information. Particularly, the observation of the geomagnetic field at volcanoes can be used for monitoring and hazards assessment.

The causes for the mood changes at volcanoes will hopefully be the subject of upcoming studies considering factors associated with the source of magmas from deep areas of >10 km in the mantle, through the mantle-crust interface, to shallow conditions (<10 km). Recent work by Valade et al. (2023) imaging the morphological evolution of lava flows and internal features of Popocatépetl volcano's crater using remote sensing techniques shows the importance of gathering together different sources of data to understand the effusive-explosive behavior at volcanoes. Further, an attempt should be made to give a temporal perspective, which is a very challenging Research Topic considering that observational evidence and monitoring can span fractions of a second, whereas geological observations (stratigraphic, petrologic, and tectonic) encompass years (in the order of 10 to 10^5 of years) covering the entire compositional range from mafic to silicic. The geophysical perspective (gravimetry, magnetometry, seismology, remote sensing), should allow to recognize a change of regime in different periods, as suggested by Martin-Del-Pozzo and Santos Morales. Additionally, it is essential to have a spatial perspective that considers the migration of volcanism on different time scales, for both polygenetic and monogenetic volcanoes, to understand regime changes in a three-dimensional context. Taken together such studies may provide an important glimpse into the effects that these regime changes have on the environment and their impact on climate change. The societal benefits will include the improvement to risk mitigation efforts with the goal of the prevention of loss of life.

Author contributions

HD: Conceptualization, Writing–original draft, Writing–review and editing. DD: Supervision, Writing–review and editing. SH: Validation, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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