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Invited review

Similarities and differences in the historical records of lava dome-building volcanoes: Implications for understanding magmatic processes and eruption forecasting

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ABSTRACT

A key question for volcanic hazard assessment is the extent to which information can be exchanged between volcanoes. This question is particularly pertinent to hazard forecasting for dome-building volcanoes, where effusive activity may persist for years to decades, and may be punctuated by periods of repose, and sudden explosive activity. Here we review historical eruptive activity of fifteen lava dome-building volcanoes over the past two centuries, with the goal of creating a hierarchy of exchangeable (i.e., similar) behaviours. Eruptive behaviour is classified using empirical observations that include patterns of SO_2 flux, eruption style, and magma composition. We identify two eruptive regimes: (i) an *episodic* regime where eruptions are much shorter than intervening periods of repose, and degassing is temporally correlated with lava effusion; and (ii) a *persistent* regime where eruptions are comparable in length to periods of repose and gas emissions do not correlate with eruption rates. A corollary to these two eruptive regimes is that there are also two different types of repose: (i) inter-eruptive repose separates episodic eruptions, and is characterised by negligible gas emissions and (ii) intra-eruptive repose is observed in persistently active volcanoes, and is characterised by continuous gas emissions. We suggest that these different patterns of can be used to infer vertical connectivity within mush-dominated magmatic systems. We also note that our recognition of two different types of repose raises questions about traditional definitions of historical volcanism as a point process. This is important, because the ontology of eruptive activity (that is, the definition of volcanic activity in time) influences both analysis of volcanic data and, by extension, interpretations of magmatic processes. Our analysis suggests that one identifying exchangeable traits or behaviours provides a starting point for developing robust ontologies of volcanic activity. Moreover, by linking eruptive regimes to conceptual models of magmatic processes, we illustrate a path towards developing a conceptual framework not only for comparing data between different volcanoes but also for improving forecasts of eruptive activity.

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1. Introduction

Volcanic activity can be manifested in many different ways. From a volcanic risk perspective one important variety of eruptive activity is extrusion of lava domes at intermediate and silicic volcanoes. Recurrent hazards associated with dome-building activity include: pyroclastic flows and volcanic blasts associated with the collapse of lava domes and edifice instability; fountain-fed pyroclastic flows associated with Vulcanian to sub-Plinian explosions; and copious tephra fall. Worldwide, such volcanic activity has been responsible for over two thirds of volcanic fatalities since 1600 C.E. (Auker et al., 2013).

Within the Smithsonian Global Volcanism Program (GVP) database there are 205 recorded dome-building volcanoes that have been active in the Holocene (Siebert et al., 2010). Of these, 117 have erupted in the last millennium and 89 have erupted since 1900 C.E. (Ogburn et al., 2015). Historical eruptions have lasted many months, years or even decades (Newhall and Melson, 1983; Sparks, 1997; Ogburn et al., 2015). Over historical timescales volcanic activity can be regarded as continuous, albeit fluctuating, but may also include complex episodic and sometimes cyclic fluctuations in intensity, duration, frequency and eruptive style.

Lava dome formation requires particular conditions, which suggests that magmatic processes at dome-building volcanoes have shared characteristics. Specifically, the lavas of dome-building volcanoes have low average eruption rates (~10^{-2} to 10^{-1} km^3 $year^{-1}$) and high viscosities (10^6 to 10^{11} Pa s; Yokoyama, 2005) that are commonly associated with high groundmass crystallinity (Cashman, 1992) and, consequently, substantial yield strength (Calder et al., 2015). Nevertheless, dome-building volcanoes can exhibit markedly different eruptive histories, including both the duration of individual eruptive episodes and the potential for explosive activity. This variability reflects the general conceptual tensions in volcanology where: (1) there is a belief that individual volcanoes are unique, as exhibited by the complex nature of their eruptive records, and (2) the concept that eruptive activity is driven by common magmatic processes that produce certain eruptive styles and volcano morphologies (Cashman and Biggs, 2014).

In this review we identify characteristics of fifteen lava-dome building volcanoes that are similar (exchangeable) or unique (not exchangeable), as well as those that are common only to a sub-group of volcanic records. In volcanology, for example, the concept of exchangeable characteristics can be used to define the common traits for all volcanoes, and to infer the conceptual system that this definition represents. Using this idea, the basic exchangeable characteristics of a volcanic system - implied by the definition of a volcano by Borgia et al. (2010) - are simply magma, eruption, and edifice. We ally to this the idea that the volcanic system (and thus the conceptual construct of volcanism) should be hierarchically organized, such that identifying and characterising different hierarchies allows individual volcanoes to be distinguished in space and time (Szakács, 2010). For this reason, we develop a hierarchy of different eruptive behaviours using observations from the historical records of fifteen well-characterised dome-building volcanoes. By characterising exchangeable behaviours we can assess inaccessible elements (e.g., the magmatic system) from observed elements (e.g., surface phenomena). A similar approach is employed in medical sciences, where individuals (i.e. humans) are unique, but different groups of humans are known to have similar health traits (Spiegelhalter, 1986; Best et al., 2013).

Using a hierarchical construct for eruptive behaviours at dome-building volcanoes we consider the conceptual system that can explain the different sets of shared traits and characteristics. Specifically, we ask whether the diversity in behaviours can be explained by subsystems of the magmatic system (e.g., shallow crustal reservoirs) or whether it requires a more holistic view of crustal magmatic processes (i.e., a transcrustal reservoir system that extends from the surface through the crust and into the mantle). This approach allows us to evaluate emerging paradigms for eruptive activity based on the destabilisation and reorganisation of igneous mush systems (e.g., Cashman and Giordano, 2014; Christopher et al., 2015), and to interpret the role of connectivity within a magmatic system on the pattern and style of eruptive activity at dome-building volcanoes.

An additional application of our study relates to the implications of a hierarchical construct on the analysis of volcanic datasets. An important issue relates to the concept of volcanic activity as a point-process of discrete events as this influences how magmatic processes are interpreted and how probabilistic forecasts are made. We also examine the implications of different patterns of eruptive behaviour on forecasting the activity of one volcano using observations from other (perhaps better characterised) volcanoes of the same type. We discuss the issues when selecting evidence to make eruptive forecasts and contextualize this in regards of forecasting the onset of eruptive activity.