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Large and small volcanic eruptions

Agust Gudmundsson (1) and Nahid Mohajeri (2)

(1) Royal Holloway University of London, Department of Earth Sciences, Egham, UK (rock.fractures@googlemail.com), (2) Department of Geography, University College London, 1-19 Torrington Place, Gower Street, London WC1E 7HB, UK.

Despite great progress in volcanology in the past decades, we still cannot make reliable forecasts as to the likely size (volume, mass) of an eruption once it has started. Empirical data collected from volcanoes worldwide indicates that the volumes (or masses) of eruptive materials in volcanic eruptions are heavy-tailed. This means that most of the volumes erupted from a given magma chamber are comparatively small. Yet, the same magma chamber can, under certain conditions, squeeze out large volumes of magma. To know these conditions is of fundamental importance for forecasting the likely size of an eruption.

Thermodynamics provides the basis for understanding the elastic energy available to (i) propagate an injected dyke from the chamber and to the surface to feed an eruption, and (ii) squeeze magma out of the chamber during the eruption. The elastic energy consists of two main parts: first, the strain energy stored in the volcano before magma-chamber rupture and dyke injection, and, second, the work done through displacement of the flanks of the volcano (or the margins of a rift zone) and the expansion and shrinkage of the magma chamber itself. Other forms of energy in volcanoes - thermal, seismic, kinetic - are generally important but less so for squeezing magma out of a chamber during an eruption.

Here we suggest that for (basaltic) eruptions in rift zones the strain energy is partly related to minor doming above the reservoir, and partly to stretching of the rift zone before rupture. The larger the reservoir, the larger is the stored strain energy before eruption. However, for the eruption to be really large, the strain energy has to accumulate in the entire crustal segment above the reservoir and there will be additional energy input into the system during the eruption which relates to the displacements of the boundary of the rift-zone segment. This is presumably why feeder dykes commonly propagate laterally at the surface following the initial fissure-segment formation. The additional energy through work goes into increasing the length and the opening of the volcanic fissure/feeder dyke, thereby allowing more magma to flow out of the chamber before it closes and the eruption ends.

For stratovolcanoes, more strain energy can be stored before eruption if the volcano is composed of layers with widely different mechanical properties. Thus, other things being equal, a stratovolcano can normally store much more strain energy, for a given size of a magma chamber, than a basaltic edifice. It follows that when an eruption occurs in a stratovolcano, there is normally a higher proportion of its magma that is driven out than during an eruption in a basaltic volcano. For a gas-rich magma, the great compressibility of the gas may also help to maintain the excess pressure in the chamber so as to squeeze out more magma. Generally, the greater the stored strain energy before eruption, the greater is the likelihood that the eruption becomes large.