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The dynamics of gas bubble motion within persistently-active volcanoes and implications for monitoring changes in volcanic activity

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Persistently-active volcanoes are characterised by long-lived degassing, lasting from years to millennia, without any significant eruption of magma. The volumes of gas released at persistently-active volcanoes imply that the gas must be able to efficiently segregate from the melt, and that degassed melt must be recycled within the magmatic system. This presentation will focus on the fluid dynamics of gas bubble motion within the magmatic system in order to identify major controls on volatile speciation and infrasonic measurements that form the basis of important volcano monitoring measurements.

The different volatile species within a magma exsolve to differing extents during the near-surface degassing of persistently-active volcanoes. The concentration ratios of volatile species that remain dissolved in the melt after degassing record the extent of degassing that any particular batch of melt has undergone, and in general this is related to eruption style. Emitted ratios of the volatile species S and Cl are monitored at volcanoes in an attempt to develop predictions for future volcanic activity, and recent results for Stromboli, Masaya and Nyiragongo volcanoes suggest that these are remarkably constant. In an attempt to interpret this observation, we start with the simplest mathematical model of volatile solubility, where equilibrium degassing occurs at or near to the surface (closed-system) and degassed magma is returned to deeper in the system. We assume no particular geometry as this will be complex and different for each volcano. We find that emitted volatile ratios remain constant despite persistent degassing, and the emitted ratios are also unaffected by replenishment of

the underlying reservoir by volatile-rich, co-genetic magma. This result has important implications for volcanic hazard assessment – injection of fresh, volatile-rich magma will not necessarily manifest itself as a change in emitted gas ratios.

Other volcanoes, such as Etna and Kilauea, exhibit variable S/Cl ratios, probably indicating open-system degassing. In order to investigate open-system degassing, a more sophisticated model was developed to study the distribution of gas bubbles within the magma chamber, based on the circulation produced by a turbulent plume of small bubbles interacting with a thermally-convecting magma. We identify two end-member regimes based on the relative strength of buoyant plume motion and thermal convection: at high convective velocities, the bubbles are uniformly distributed within the chamber; at low convective velocities a two-layer stratification is developed, with the depth of the bubbly layer dependent on the buoyancy flux in the plume and the chamber geometry. These different regimes can control the ratios of volatile species of different solubility in volcanic gas emissions; in the absence of detailed solubility laws we use approximate relationships to investigate the effect of system geometry and volatile flux.

In the conduit, volatile fluxes are controlled by bubble growth and coalescence, leading to the development of distinct flow regimes. Although the dynamics of basaltic eruptions have been explained using the framework of gas-liquid flow regimes observed in laboratory experiments for industrial applications, it is not clear how to quantitatively relate the laboratory experiments in small tubes and relatively low viscosity liquids (typically water), to flows in volcanic conduits. For instance, engineering experiments indicate that slug flow, characterized by periodic rise of bubbles larger than the conduit diameter, does not occur in tubes larger than about 0.1 m in diameter. Laboratory analogue experiments using highly viscous liquids suggest that individual bubbles form stable clusters, and do not necessarily coalesce to a conduit-scale single bubble. The clustering process can be described by a Pareto distribution, suggesting that clustering occurs between many bubbles simultaneously, rather than in a pair-wise manner. We present results of laboratory analogue experiments investigating the dynamics of bubbly flow in confined viscous liquids, in particular focussing on how acoustic measurements of bubbles bursting at a free surface can be used to interpret infrasonic monitoring measurements at persistently-degassing volcanoes.