Magmatic foams: the Halemaʻumaʻu lava lake

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ABSTRACT

Magma is a high-temperature silicate melt that contains dissolved gases when in the Earth's crust. Decompression during magma ascent causes exsolution of the gas — principally water — to form bubbles, which provide the buoyancy that drives volcanic eruptions. Gas volume fractions of $\phi = 0.7 \sim 0.95$ are commonly reached by the time the magma reaches the surface, such that the magma erupts as a foam. Here, we consider the structure, dynamics, and evolution of a long-lived body of magmatic foam: the Halemaʻumaʻu lava lake, which occupied a pit crater at the summit of Kīlauea volcano in Hawaii from 2008 to 2018. The lake was fed from below by a continuous influx of fresh magma, balanced by an outflux of degassed magma back into the crustal plumbing system. The lake, which reached maximum areal dimensions of $\sim 190 \times 250\,\mathrm{m}$ and a depth of $> 200\,\mathrm{m}$, was composed of basaltic silicate melt (viscosity $\mu \sim 100\,\mathrm{Pa\,s}$) suspending a high volume fraction of bubbles with dimensions in the micron-to-millimetres range; the lake therefore represents a large body ($> 10^6\,\mathrm{m}^3$) of viscosity-stabilised foam. The lake showed a variety of behaviours, including surface flow expressing underlying convection, 'spattering' (episodic or sustained bursting of decoupled bubbles with diameters of order metres), violent overturn, and fill/drain cycles. We present analysis of the hydrostatics and gas-phase solubility of the lava, which indicates that gas volume fraction is as high as $\phi \sim 0.95$ at the surface, remains in the foam range down to around 80 m depth, then drops suddenly to zero by 95 m depth. We consider the implications that the lake's density structure has for the dynamics and evolution of the lake, and their relationship to the observed surface phenomena. Lava lakes represent a rare opportunity to observe and study magmatic foams, which are usually hidden within the crust; we consider the broader implications of our analysis for basaltic volcanic eruptions in general.