Formation, maturation, and failure of viscosity-stabilized foams:
Application to volcanic eruptions

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Volcanic eruptions are driven by the formation and growth of bubbles in magma. Magma within the Earth's crust is a molten silicate liquid containing dissolved water. Decompression during magma ascent causes water to exsolve as steam bubbles. On eruption, magma typically has a gas fraction in the range $0.5 \lesssim \phi \lesssim 0.95$ (Figure 1). The gas fraction controls the density and viscosity of the magma which, in turn, determine the nature of the eruption. Understanding the behaviour of magmatic foams is therefore essential for understanding volcanic eruptions and their impacts. Lava lakes (Figure 1a) provide a window onto magmatic foam processes that are usually hidden within the volcanic plumbing system, and hence a means to validate models. These include foam flow, maturation, and failure, which produces large, decoupled bubbles that burst explosively.

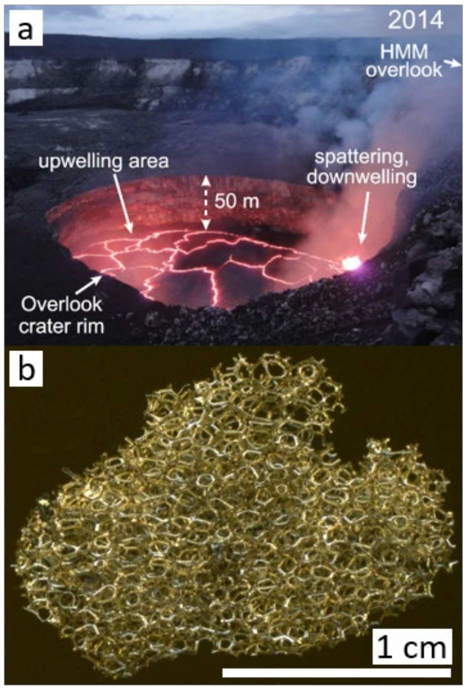

Figure 1: Magmatic foam at Kilauea Volcano (Hawaii). a) lava lake containing 10^6 m^3 of magma foam. b) Reticulite: glass foam produced during fountaining eruptions.

Basaltic magma has a liquid viscosity of $10^2 - 10^4$ Pa s, which is sufficiently high to produce a foam that is stable for hours to days despite the absence of a surfactant phase. Whereas surfactant-stabilized foams are well understood, the behaviour of viscosity-stabilized foams, like magma, remains largely uninvestigated.

This project will investigate and quantify the stability and dynamics of viscosity-stabilized foams. A particular focus will be the mechanisms through which large bubbles can form, decouple, and ascend through a foam to burst at the surface: the origin of an important class of volcanic explosions. Experiments on surface-tension dominated foams with high gas fraction suggest that this decoupling may occur through a sub-critical bifurcation as the bubble size increases. Our aim is to develop a continuum model of film rupture that explains how small bubbles coalesce to form these large bubbles, and to incorporate this into discrete numerical simulations of the rheology of suspensions of deformable particles. This will allow us to identify the critical conditions at which the yield stress is exceeded, to cause magmatic explosions.

The project combines mathematical formulation, numerical modelling, and laboratory experiments; the balance among these different components will depend on the skills and interests of the student. The student will receive training in experimental techniques, analytical, mathematical, and numerical techniques. The student will also receive training in physical volcanology and will have the opportunity to undertake a three-month placement at the University of Hawaii with co-supervisor Houghton. The project will yield fundamental insights into viscosity-stabilized foams, develop practical tools for modelling their behaviour, and apply them to a frontier problem in volcanology and hazards research.