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# How do crystal-rich magmas outgas?

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Crystals can occupy ~0 to 100% of the total magma volume, but their role in outgassing remains poorly understood. In particular, the upper half of this spectrum – when the particles touch – involves complex flow behaviours that inevitably affect the geometry and rate of gas migration.

We use analogue experiments to examine the role of high particle concentrations on outgassing mechanisms. Mixtures of sugar syrup and glass beads are squeezed between two glass plates to allow observations in 2D. The experiments are performed horizontally, so buoyancy does not intervene, and the suspensions are allowed to expand laterally. Gas flow regimes are mapped out for two sets of experiments: foams generated by chemical reactions, and single air bubbles injected into the particle suspension.

Chemically induced bubble nucleation and growth throughout the suspension gradually generated a foam and allowed observations of bubble growth and migration as the foam developed. High particle fractions, close to the random maximum packing, reduced foam expansion (i.e. promoted outgassing). In the early phases of the experiments, they caused a flushing of bubbles from the system which did not occur at low crystal contents. High particle fractions also led to melt segregation and phase re-arrangements, eventually focusing gas escape through connected channels.

A more in-depth study of particle-bubble interactions was carried out for single bubbles expanding in a mush. These show a clear change in behaviour close to the limit for loose maximum packing of dry beads, determined experimentally. At concentrations below loose packing, gas expands in a fingering pattern, characterized by a steady advance of widening lobes. This transits to a "pseudo-fracturing" regime at or near loose packing, whereby gas advances at a point, often in an episodic manner, and outgases with little to no bulk expansion. However, before they can degas, pseudo-fractures typically build up larger internal gas pressures. As with foams, phase re-arrangements appear central to this change in behaviour: pseudo-fracture penetration causes a compaction of particles in the vicinity of the gas, and segregation of syrup toward the edges of the experiment. Further increasing the crystal fraction causes rigid or locked particle networks, and bubbles grow through filter pressing, segregating the liquid from the particle phase without dislocating the particle network. These regime transitions are dominantly controlled by particle fractions, while other factors such as viscosity and gas flow rate play minor roles.

We hypothesize that particle networks that form at such high solid fractions provide further resistance to bubble growth. In doing so, however, they offer an alternative: bubbles can grow through local particle re-arrangements, with minimal disruption to the rest of the suspension. To conclude, degassing in crystalline magmas involve complex underlying dynamics: although high particle concentrations increase magma viscosity, which could promote bubble overpressure and fragmentation, with sufficient time crystals may promote phase re-arrangements that favour open system degassing and therefore limit bulk expansion.