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Getting the gas out – developing gas networks in magmatic systems

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Volcanic eruption style, and explosive potential, are strongly controlled by the pre-eruptive history of the magmatic volatiles: specifically, the more efficient the gas loss prior to eruption, the lower the likelihood of primary (magmatic) explosive activity. Commonly considered gas loss mechanisms include separated flow, where individual bubbles (or bubble clouds) travel at a rate that is faster than the host magma, and permeable flow, where gas escapes through permeable (connected) pathways developed within a (relatively) static matrix. Importantly, gas loss via separated flow is episodic, while gas loss via permeable flow is likely to be continuous. Analogue experiments and numerical models on three phase (solid-liquid-gas) systems also suggest a third mechanism of gas loss that involves the opening and closing of 'pseudo fractures'. Pseudo fractures form at a critical crystallinity that is close to the maximum particle packing. Fractures form by local rearrangement of solid particles and liquid to form a through-going gas fracture; gas escape is episodic, and modulated by the available gas volume and the rate of return flow of interstitial liquid back into the fracture.

In all of the gas escape scenarios described above, a fundamental control on gas behaviour is the melt viscosity, which affects the rate of individual bubble rise, the rate of bubble expansion, the rate of film thinning (required for bubble coalescence), and the rate of melt flow into gas-generated fractures. From the perspective of magma degassing, rates of gas expansion and film thinning are key to the formation of an interconnected (permeable) gas pathway. Experiments with both analogue and natural materials show that bubble coalescence is relatively slow, and, in particle-poor melts, does not necessarily create permeable gas networks. As a result, degassing efficiency is modulated by the time scales required either (1) to produce large individual bubbles or bubble clouds (in low viscosity melts) or (2) to develop sufficient porosity for full connectivity of a bubble network (in high viscosity melts). In contrast, our experiments suggest that the presence of solid particles may greatly enhance gas escape. On the one hand, the addition of solid particles increases the bulk viscosity of the mixture, which reduces the migration rate of large single bubbles. On the other hand, the strength of networks created by touching crystals inhibits bulk magma deformation and forces smaller bubbles to deform to occupy the spaces between particles, thereby increasing both the bubble shape anisotropy and, correspondingly, the probability of bubble coalescence. Gas pathways created in this way take advantage of inhomogeneities in the spatial distribution of crystals and allow large-scale gas release at relatively low vesicularities. This mechanism of gas escape is likely to be important not only in mafic arc volcanoes, where shallow conduits are likely to be highly crystalline, but also for degassing of crystal-mush-dominated magmatic systems.