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An experimental investigation into the effects of pores and crystals on magma rheology

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The rheology of magma has a key control on eruption style; transitions in flow dynamics can be linked to changes in porosity, crystallinity and melt chemistry. Physical interactions due to the presence of both crystals and bubbles in a volcanic melt can influence a system's rheology by causing variations in viscosity and strain dependent flow behaviour, making eruption style difficult to predict. Ergo it is essential to gain an insight into the manner in which crystalline, porous magmas flow and fail.
By conducting uniaxial compressive strength (UCS) tests on both volcanic rocks and synthetic samples at room and high temperatures, a deeper understanding of how these materials behave at volcanic conditions can be attained. Here we have taken advantage of a suite of highly crystalline (~50 vol.%) dacite from Mt Unzen, with varying porosity (9-32 vol.%), along with a sintered glass with a range of atmospheric air filled pores (<3, 20 and 30 vol.%) and TiO_2 particles (0-50 vol.%).
Mt Unzen experiments have revealed that the UCS systematically decreases with an increase in porosity, matching other volcanic rocks in the literature and UCS is strain rate dependent. The latter of which, along with the observation that UCS increases at higher temperatures, has not previously been observed in glass-bearing volcanic rocks and was seen in both samples from Mt Unzen and in the glass-particle mixtures. From the synthetic sample tests at room temperature we see that the UCS does not vary with crystal content (across the range measured), but at high temperature preliminary results suggest strength decreases with particle volume.
Gent's parallel plate technique was applied to calculate the viscosity of samples that appeared to flow under the applied stresses. Both natural and synthetic samples demonstrated a non-Newtonian, shear thinning response to applied strain rates. For the natural Mt. Unzen samples it appears that viscosity does not scale with porosity; which, at 50 vol.% crystals, is supported by experimental and modelling data in the literature[1]. Although experiments are yet to take place on porous synthetic samples, tests on the dense samples reveal that viscosity is proportional to crystal content.
Conclusions drawn from these experiments both confirm and contradict results published in the literature, which we interpret as a demonstration that multi-phase magmas are more complex than previously suggested. In order to help resolve these complexities we recently undertook a series of high-temperature compression experiments on the synthetic magma in-situ at the Diamond Light Source, the results of which will shed light on the way in which crystalline, porous materials flow and fracture.

[1] Truby JM, Mueller SP, Llewellin EW and Mader HM. 2015 The rheology of three-phase suspensions at low bubble capillary number. Proc. R. Soc. A