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The effect of porosity and crystallinity on magma rheology at Unzen volcano, Japan

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Eruptions of lava domes are some of the most unpredictable and dangerous volcanic phenomena, and their frequent occurrence highlights the priority of improving our understanding of the mechanisms at play during magma ascent. For example, between 1991 and 1995 Mt. Unzen sustained an extensive period of dome growth. During this time approximately 2.1x10^8 m^3 dense rock equivalent of magma was emplaced at effusion rates of 0.1-4x10^5 m^3d^{-1}. Repeated partial collapses of the dome generated frequent pyroclastic density currents which caused several fatalities and damage to populated areas near Shimabara City.

One of the keys to grasping the switch between effusive to explosive behaviour, as well as the onset of a dome collapse event lies within understanding the rheological behaviour of upwelling magma. Although the conditions which lead to failure of magma are now increasingly studied, we lack an understanding of the influence of mechanisms at play during magma deformation.

Strain rate and temperature play primary roles in the transition of silicate melts from viscous bodies to elastic solids; this regime change is known as the viscous-brittle transition and is bound by the glass transition of the interstitial melt, which signals the beginning of either fracture or flow. Crystals and pores present in the system can alter the position of the viscous-brittle transition.

Laboratory experiments which aim to simulate realistic volcanic conditions permit the controlled study of volcanic processes, and help determine the behaviour of multi-phase magmatic suspensions. For magma with high crystal contents (>40%) rheology is strongly influenced by the crystalline phase and is strain rate dependent. Here we present the results of high-temperature deformation experiments on variably porous (9-33%), crystal-rich (>50%) dacite lavas from Unzen volcano, Japan.

Uniaxial compression tests were carried out on dacitic samples from Unzen at room temperature (~20˚C) and high temperature (900˚C), with strain rates of 10^{-1}, 10^{-3}, $10^{-5}s^{-1}$. For high temperature experiments we also performed dynamic, stepped strain-rate experiments. We discuss how the strain rate influences the rheological response of the magma, noting a decrease in viscosity, with increasing strain rate, which evidences non-Newtonian, shear-thinning behaviour. All experiments with a brittle responses show a nonlinear decrease in failure strength with porosity. In addition, the data clearly show that magma at 900˚C is stronger than its room temperature rock counterpart.

We conclude that the strength of multi-phase magmas is strongly influenced by porosity across all temperatures, while crystal load is more important at temperatures above the glass transition, influencing the rheological properties and producing shear thinning behaviour. However, we also note that magmas are stronger at higher deformation rates, which has important implications for linking hazard to eruption rate, and we note that the same magma is stronger at high temperature, suggesting that in dome building volcanoes it may be the cooling, residual lava that is at higher risk of collapse than freshly erupted lava.