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Non-Newtonian rheological behaviour for magmas at arc volcanoes

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Models of volcanic eruption and magmatic processes are still badly hampered by the lack of multiphase magmatic flow laws. Most rheological models estimate the viscosity of multiphase lavas via the Einstein-Roscoe equation, but this simplification cannot be used for high-crystallinity and it does not consider the non-Newtonian, strain rate dependency of viscosity, and such an understanding is dearth. Here, experiments on natural samples using a unique high-load, high-temperature uniaxial apparatus were carried out to simulate multiphase lava deformation under various strain rates in order to correct this situation. Samples from Unzen, Colima, Anak Krakatau and Bezymianny (containing 50, 55, 70 and 80 % phenocrysts, and 5, 8, 23 and 9 % vesicles, respectively) were chosen for this study. Multiphase lavas do indeed exhibit an important component of shear thinning. The remarkably singular dependence of viscosity on strain rate yields a novel, universal rheology law at eruptive temperatures. These results appear to invalidate the adequacy of Einstein-Roscoe-based formulations for highly-crystalline lava rheology. At very high strain rates, our work reveals the importance of considering micro-cracking and viscous dissipation; thus explaining the occurrence of seismic swarms along the conduit margins, consequently supporting plug-like magma ascent models. We anticipate that unresolved questions of magma ascent, lava dome deformation and eruptivity will be better served via this general flow law.