Rheology of bubble- and crystal-bearing magma: an analogue dataset

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Magma is commonly a complex mixture of three phases: a viscous silicate melt, crystals, and a gas phase. The degree of interaction between bubbles and crystals, and the relative proportions of these phases, exert a major control on the bulk flow behaviour of the magma or lava. Generally, the addition of solid particles increases the viscosity of a suspension and potentially causes non-Newtonian effects such as shear thinning or yield strength, whereas bubbles can either increase or decrease viscosity, depending on the flow regime. Whilst numerous studies exist on the rheology of two-phase suspensions, the bubble-particle interactions in three-phase systems and their effect on rheology to date remain largely unexplored.

Here we present, for the first time, a comprehensive rheometric dataset of analogue three-phase experiments. More than 40 experiments were performed, covering a broad parameter space with 0 to 45 vol% solid glass spheres, and 0 to 28 vol% bubbles mixed into a Newtonian magma-analogue liquid (Golden Syrup). Rheometric tests were carried out on a ThermoHaake MARS II Rheometer, and include steady (stress-strainrate flow curves) and transient (oscillatory) experiments.

The resulting flow curves were modeled to obtain the three Herschel-Bulkey parameters (consistency, shear tinning index, and yield strength) of the suspension as a function of particle and bubble content. The oscillation tests delivered complex viscosity values as function of strain rate and strain rate change, under consideration of the suspension's bubble size distribution. Results suggest that the role of the solid and gaseous phase, respectively, varies considerably with the dynamic properties of the flow: in steady flow conditions, the solid particles exert a major influence on the bulk rheology of the system, whilst under transient flow conditions the effect of bubbles becomes increasingly important.