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Crystals in magma: flow dynamics and rheology of particle-bearing melts

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Volcanic activity is naturally linked to the flow of magma. For the assessment of hazards associated with a volcanic eruption, i.e. the prediction and modeling of magmatic flow processes, it is of pivotal importance to understand the basic principles of magma rheology as accurately as possible. Magma rheology depends primarily on melt chemistry and on the relative proportions of the three phases melt-gas-crystals. Whilst the viscosity of many melt compositions has been accurately measured, the effect of adding particles to them is still poorly constrained.
Unlike bubbles, the presence of crystals in a Newtonian melt – due to their rigid character – always increases the viscosity of the mixture and may additionally introduce various non-Newtonian rheological effects. The viscosity of the mixture is a function of both the concentration and geometry of the added particles and can be several orders of magnitude larger than the viscosity of the pure melt.
We have performed analogue experiments on suspensions of particles with different geometries in Newtonian silicone oil. The particles used were glass beads (spherical), glitter (oblate), wollastonite (prolate), and SiC grit (angular), in a size range of 100-350μm. Rheological properties, including viscoelasticity, have been measured using a Haake MARS rotational rheometer. The effects of the respective particles on suspension rheology during two experimental phases (transient flow initiation and steady flow) have been determined: (I) When flow commences, the initially randomly distributed particles realign and reorganize in less flow-resisting configurations. Depending on the particle geometry, this motion results in distinctive strain-dependent viscosity patterns. (II) During steady shear flow, the suspended particles cause different degrees of relative viscosity increase, shear thinning and yield strength behaviour, mainly depending on their aspect ratio. These effects have been quantified and fitted to existing rheology models.