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Rheology of magmas with bimodal crystal size and shape distributions: insights from analogue experiments

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The fluid mechanics of magma in a volcanic conduit is strongly influenced by the rheological changes that arise from microphysical processes such as vesiculation, degassing, and crystallization. Increase in crystal content lead to increase in the viscosity of magma (melt and bubbles plus crystals). During ascent, magma can undergo a complex history of crystallization, thus it is not uncommon in volcanic rock textures to find microlites in association with pre-existing phenocrysts which nucleated in the magma chamber or in the deeper portions of the volcano plumbing system. Progressive increase of microlite volume percentage can thus dramatically affect the rheology of rising magma within the conduit consequently influencing the eruptive style of a volcano. This process is relevant over a broad spectrum of magma compositions.

We performed analogue experiments simulating increasing prolate microlite content on the rheology of a magma with different starting amounts of equant phenocrysts. Rheology of the samples has been measured through controlled shear stress tests in a rotational rheometer using a parallel plate geometry. Investigated samples are made of solid fibres and spherical particles of different dimensions immersed in a Newtonian liquid phase. In order to isolate the role of different crystal content, shape and size distribution, we used bubble-free suspensions. The suspensions have been blended adding different proportions of smaller prolate particles to a fixed amount of larger isometric ones. Experimental data were modelled using the semi-empirical model by Costa et al. (2009). The adjustable parameters of the model were calculated for monodisperse mixtures of spherical particles and fibres respectively. We found that a blend of spherical and elongated particles is satisfactorily described using an interpolation of the adjustable parameters between the values obtained for the monodisperse spheres and those obtained for the monodisperse fibres.

Our experiments confirm the influence of particle concentration and shape on the deviation from Newtonian behaviour. Such effects are anticipated at lower solid fractions for suspensions of particles with higher aspect ratios. Above a critical solid fraction the onset of yield stress is registered, this corresponding to the limit where particle-particle interaction is not negligible anymore and the overall arrangement of the suspended particles reaches jammed condition. Flow curves at this point show an inflection, i.e. for a given strain-rate, the effective viscosity increases at a slower rate with increasing particle volume fraction. Nevertheless flow curves illustrate that progressive increase of prolate microlites to equant phenocrysts-bearing mixture can increase the relative viscosity of up to three log units when crystallinity reaches about 40%. Our experiments also show that for very concentrated bimodal suspensions particle-particle interaction is effective in establishing both concentration and grainsize distribution profiles of crystals. This causes changes in the rheological profile perpendicular to the shear flow, with higher viscosity along the flow axis where the crystal concentration is higher. This effect may explain the pronounced inflection characterizing the flow index of suspensions containing non-isometric particles. Moreover, in our experiments we have verified that shape variablity of natural crystals can be simplified by adopting solid particles with simpler symmetry (spheres, rods) when the aspect ratios of particles reflects that of crystals in a magma.

References

Costa, A., L. Caricchi, and N. Bagdassarov (2009), A model for the rheology of particle-bearing suspensions and partially molten rocks, Geochem. Geophys. Geosyst., 10, Q03010, doi:10.1029/2008GC002138.