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How crystals affect magma rheology

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The presence of solid particles in a liquid melt inevitably affects its flow behaviour: the crystals increase the bulk viscosity of the magma, and may impede flow at low driving stresses and cause shear thinning at increasing strain rates. Despite a multitude of theoretical and experimental investigations on suspension rheology no comprehensive flow model exists that satisfactorily accounts for the effects of particle concentration, particle shape and strain rate.

We here present the data of an analogue experimental study, aimed to cover a broadest possible parameter space. We have measured suspensions of monodisperse particles of varying aspect ratio, from oblate to prolate, and covering particle volume fractions ϕ from dilute to highly concentrated. Rheology is characterized by fitting the experimental data to the model of Herschel & Bulkley (1926), yielding three rheometric parameters: consistency K (cognate with viscosity); flow index n (a measure of shear-thinning); yield stress τ_0. We develop models to predict these three parameters in dependence of particle aspect ratio.

We relate our rheological observations to the underlying particle motions via Jeffery's (1922) theory. We extend Jeffery's work to calculate, numerically, the Einstein coefficient for a suspension of many, initially randomly oriented particles. This provides a physical, microstructural explanation of our observations, including transient oscillations seen during run start-up and changes of rheological regime as ϕ increases.