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Scale-dependent magma rheology: insights from laboratory experiments

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Many geological processes regarding magma, from the settling of crystals and nodules in a magma chamber to the upwelling of magma bodies in lithosphere, take place in systems that are heterogeneous in composition, density and mechanical properties. However, description and prediction of magma flows in these systems requires the definition of an “effective rheology”. An important issue then is the scale on which this rheology will remain valid.

We therefore present here an experimental study using aqueous dispersions of superabsorbent polymers. In water, these polymer powder grains swell up to 200 times and form elastic gel grains whose size can be controlled by controlling the size of the initial powder. The rheology of the water-grains dispersions therefore combines viscous, elastic and plastic aspects. It can be investigated using the free-fall of spheres of different diameters (between 3 and 30 mm-diameter) and densities. As the typical size of the gel grains was varied between 1 and 8 mm, there is a range where it becomes comparable to the size of the falling spheres. We therefore systematically studied the influence of the grain size on the effective rheology of the aqueous dispersions.

We observe three different regimes for the fall of the spheres. (1) A steady-state motion where the sphere reaches a constant terminal velocity, as in Newtonian fluids. It happens only for high density contrast between sphere and fluid and for spheres that are large enough compared with gel grain sizes. (2) A no-motion regime appears when spheres are not buoyant enough to overcome the yield stress of the fluid. (3) In between, a “stick-slip” regime develops where spheres have an irregular vertical motion and horizontal oscillations. The two first regimes are typical of a visco-elasto-plastic fluid, with a yield stress that depends on the size of the gel, but also on the size of the intruder. The third regime directly comes from the interaction between the sphere and the gel scales, showing how the effective rheology is scale-dependent.