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Combined Laboratory and Numerical Study on Thermal Plumes in Yield-Stress Fluids : Implications for Midocean-Ridge Systems

A. Massmeyer (1), A. Davaille (1), T. Rolf (2), P. Tackley (2), and E. Di Giuseppe (1)

(1) UPMC Univ Paris 06, Univ Paris-Sud, CNRS, F-91405. Lab FAST, Bat 502, Campus Univ, Orsay, F-91405, France. (massmeyer@fast.u-psud.fr), (2) Institute of Geophysics, ETH Zurich, Zurich, Switzerland

Diapirs form by hot magma migrating through the lithosphere. While hot instabilities in a Newtonian mantle are known to rise as a mushroom-shaped plume, the upwards migration of hot material in “soft“ geological materials (presenting solid as well as viscous properties) is still far from understood. We are therefore studying this problem experimentally and numerically, to shed some light into this problem. The results give an idea about which basic properties are needed in mid-ocean ridge systems.

The Laboratory setup consists of a localized heat-source placed in a plexiglas-tank containing a mixture of water, glycerine and Carbopol. Due to the existence of a continuous network of interacting micron-sized hydrogel particles, the solution presents a yield stress and is shear-thinning. The rheology is described by a Herschel-Bulkley model. The fluid’s rheological properties can be controlled by changing either the proportion of Glycerol and water or the Carbopol concentration.

In our experiments we systematically studied the influence of rheological properties and supplied heat. Depending on the Yield parameter Y_0, which compares the thermally-induced stress to the yield stress, three different regimes are observed. For low Y_0, no convection develops. For intermediate values, a small-scale convection cell appears and remains confined around the heater. Only for high Y_0, a thermal plume develops. The morphology differs from the mushroom-shape typically encountered in Newtonian or in purely shear-thinning fluids.

The experiments show that the onset time is delayed compared to a Newtonian case and depends on Y_0. Combined temperature and velocity field measurements show that a plug flow develops within the plume thermal anomaly, therefore producing a rising finger-shape. Moreover, although the heat supply is continuous through time, the uplift of such plumes is not: the thermal anomaly marks some ”pauses” as it rises through the gel column.

In addition we implemented a regularized Herschel-Bulkley model into a viscoplastic numerical code. Despite some differences in the spatio-temporal evolution, the results equally show a long onset-time and a morphology comparable to the one observed in the laboratory.

Our experiments are able to explain several features obeserved for an off-axis diapir in Oman, especially the strong shear localization along the diapir edges. It further suggests that this diapir was emplaced in a partially molten lithospheric matrix. Therefore this type of hydrogels might be a good candidate to get some new insights into the complex rheological behavior of such geological ”soft” systems.