Viscous Sheet Falling on a Layer of Yield-Stress Fluid : from Folding to Sinking

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Résumé

On geological time scales (several millions of years), the Earth's mantle flows in convective patterns. Volcanism and earthquakes are well-known signatures of this activity. Seismology tomographic studies show that the cold thermal boundary layer at the surface, sinks back into the mantle as a quasi 2D plate but becomes wider at 660 km. Since mantle rocks rheology depends on pressure, and therefore on depth, it has been suggested that a change in the rheology may occur at 660 km from newtonian to yield stress behavior. The question we address here is how the cold 2D plate interacts with this rheological boundary and what are the necessary conditions for the plate to enter below 660 km.

We led two series of laboratory analogous experiments. The plate is modeled by a sheet of sugar syrup extruded through a slot of variable length. In the reference experiments, the sheet falls on a solid plate, while in the second series, it falls on a carbopol solution, modeling the mantle. The height of fall and the carbopol yield stress were systematically varied. Both sugar syrup and carbopol solutions were characterized with a rheometer. The visualization is made from the front and the side. Results are expressed in terms of the yield number Y, the ratio of yield stress over buoyancy, and the Bingham number, the ratio of yield stress over viscous stress.

We observed that the viscous sheet folds both on the solid plate and on the carbopol, and that the folding dynamics are quantitatively the same. Then in the carbopol layer, we observed in time three regimes of penetration: 1) for $Y > 0.9$, the viscous sheet does not penetrate the carbopol and the growing pile of folds spreads on the carbopol surface. 2) For $0.3 < Y < 0.9$, the folding viscous sheet accumulates at the surface in a growing pile, which eventually sinks in. 3) For $Y < 0.3$, the viscous sheet enters directly in the carbopol. We also investigate the analogy of the experiments with solid spheres falling in yield stress fluid. Though the agreement is not perfect, the solid sphere model captures the main behavior. Comparison with tomographic images shows that the sinking mantle plates are mostly in regime 2, which allows us to estimate the lower mantle yield stress.

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