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The importance of plumes to trigger subduction of a sluggish lid: examples from laboratory experiments and planets

Anne Davaille (1) and Suzanne Smrekar (2)

(1) FAST (CNRS / UPMC / Univ. P-Sud), FAST, ORSAY, France (davaille@fast.u-psud.fr), (2) NASA Jet Propulsion Laboratory Pasadena, CA 91109, USA (ssmrekar@jpl.nasa.gov)

The possible role of plate tectonics in creating habitable zones and the conditions required to start plate tectonics are currently hotly debated due to the discovery of many Earth-sized exoplanets. The initiation of subduction is both the gateway to plate tectonics and a key link between interior convection and lithospheric rheology. Modeling the details of plate failure and the initiation of subduction is very challenging due to the complexity of mantle rocks.

We carried out experiments on convection in aqueous colloidal dispersions heated from below, and dried and cooled from above. The rheology of these fluids depends strongly on solid particle fraction f_p, being Newtonian at low f_p, and presenting yield stress, elasticity, and brittle properties as f_p increases. Such a behaviour is analogue to the rheology of mantle rocks as temperature decreases. So if drying is sufficiently rapid in the laboratory, a skin forms on the fluid surface and may participate (or not) to the convective motions, depending on the experimental parameters. Moreover, we observed that (1) the existence of upwelling plumes help trigger subduction, the asymmetric subduction zone being localized on the rim of the plume impingement zone under the lithosphere; (2) depending on the lithospheric rheology, the nascent subduction can then either stop as the result of subducted plate necking, or continue to sink smoothly.

Inspection of the geological record on Earth suggests that such a strong association between plumes and subduction may have been instrumental in the nucleation and growth of cratons, the onset of continuous plate tectonics, and present-day initiation of subduction around some large oceanic plateaus. On Venus, interpretation of geophysical data sets suggests that Quetzelpetlatl corona overlies an active plume. The narrow trough found along 2/3 of the margin of the corona has a flexural signature and is likely an example of subduction initiated at the rim of a plume. If this is correct, Venus is an example of a sluggish rather than stagnant lid planet in that convection can produce failure and subduction of the lithosphere. Since subduction appears to be only limited, this process is distinct from terrestrial style plate tectonics.