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On the importance of plumes to initiate subduction and plate tectonics

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Understanding the details of plate failure and the initiation of subduction remains a challenge 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 memory, yield stress, elasticity, and brittle properties as f_p increases. Such a behaviour is analogue to the rheology of mantle rocks as temperature decreases. When drying is sufficiently rapid in the laboratory, a visco-elasto-plastic skin ("lithosphere") forms on the fluid surface. Depending on its rheology, and on the different scales of convection existing in our laboratory mantle, we observed different modes of one-sided subduction initiation. However, not all of them lead to continuous plate tectonics. If subduction is definitely a necessary condition for plate tectonics, it is not sufficient.

Amongst the different modes of subduction initiation, we observed two of them where one-sided subduction was induced by the impingement of a hot plume under the skin, the trench being localized on the rim of the plume impingement zone under the lithosphere. Then depending on the lithospheric rheology, the nascent subduction can then either stop as the result of subducted plate necking, or continue to sink smoothly. Due to the brittle character of the skin, the subduction trench will never describe a complete circle, but several tears and/or transform faults will develop as subduction and roll back proceed.

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.