
Introduction: Planets long-term cooling, as well as surface phenomena such as plate tectonics, volcanoes and earthquakes, are mainly controlled by the existence and patterns of convective motions in their solid-state mantle. The latter strongly depend on rocks' rheology. Two main regimes are usually considered: « Stagnant Lid » where convective motions develop below a lithosphere which remains stagnant, and « Plate Tectonics » with the continuous rejuvenation of the planet surface by subduction of its cold gravitationally unstable lithosphere. However the necessary conditions for the latter regime are still debated. We run new laboratory experiments with visco-elasto-plastic colloidal dispersions to explore the problem, and a diversity of regimes was observed besides the two end members already mentioned. Moreover, an experiment always passed through a succession of different regimes, and this should also be the case for a planet.

Laboratory experiments: We used colloidal dispersions whose rheology varies from viscous to elasto-visco-plastic to brittle when their water content decreases (Di Giuseppe et al, 2012). So as an analogy to cooling from above, the fluid is dried from above. It can also be heated from below in order to produce active upwellings. Humidity, temperature, fluid thickness and solution concentration were systematically varied, which results in changing the intensity of convection and the magnitude of the rheological parameters of the fluid. As the fluid surface dries, a denser chemical boundary layer (CBL) develops, constituted of a thin brittle film on top of a more ductile layer; and convection develops under this stagnant lid.

Fig.1: One-sided subduction. Top: top view, the yellow arrows indicate the direction of roll-back; bottom: side view along vertical cross-section AB.

Spontaneous episodic initiation of one-sided sub-

duction: When the bottom of the tank was insulated, so that there was no hot upwellings formation, convection was driven by cold instabilities only. Two main mechanisms were observed to break the skin. In some cases, solutal small-scale convection was sufficient to trigger subduction. But the most common case was drying-induced stresses which cause the skin to buckle, and then induce plastic failure, thereby initiating subduction of the gravitationally unstable skin. Subduction is always one-sided and proceeds quickly by trench roll-back (fig.1). Then the whole process starts again. Shear banding and a lubrication layer on the top of the subducting slab seem to be key ingredients to break the surface plate and initiate subduction episods.

Plume-induced subduction: When the fluid was also heated from below, hot plumes were observed to trigger one-sided subduction along part of their rim (fig.2). Depending on the strength and the buoyancy of the lithosphere, this could trigger episodic gravitationally sustained subduction, or continuous plate tectonics, or on the contrary, subduction could stop after slab break off. Subduction therefore appears as a necessary condition for Plate Tectonics, but is not a sufficient one. Moreover, in the laboratory, we never observed continuous Plate Tectonics without the existence of hot plumes.

Fig.2: Plume induced subduction. Top: image at the onset of subduction. Bottom: superposition of 20 images 1 min apart, showing slab roll-back. The plume material is materialized in red.