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Dynamic regims and evolution of planetary mantles: insights from laboratory experiments with complex rheology fluids

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Planetary 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 inside the planets solid-state mantles. The planets in the solar system present very different dynamic regims: plate tectonics (Earth), episodic complete (Venus?) or partial (Moon, Europa ?) resurfacing, intense volcanism (Io), stagnant lid convection (Mars), etc... A key ingredient to produce this diversity is probably the complex rheology of mantle's material, but this relationship is still not very well understood.

We report here new laboratory experiments on mantle convection using a fluid, whose rheology varies from brittle to visco-plastic to purely viscous when its water content and its temperature change. So as an analogy to cooling from above, the fluid is dryed from above, its surface being kept at a constant humidity. It is also heated from below to produce active upwellings. Humidity, temperature, fluid thickness and rheological properties were systematically varied. As the fluid dries at the surface, a thermo-chemical boundary layer (CBL) develops, constituted of a thin brittle film on top of a more ductile layer. Folds and cracks are visible on the surface film. Depending on the intensity of convection, the presence of hot upwellings and the rheology variation across the top CBL, the different regims encountered on planets are observed. These are classified in a regime diagram. The existence of a brittle film seems necessary to observe asymmetric subduction. Moreover, the experiments demonstrate that a planet does not stay in the same regime throughout the geological times, but evolves through a suite of different regimes.