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From magma ocean to plate tectonics: the role of thermal contraction

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A clear understanding of the transition from a liquid magma ocean (MO) to a convective solid mantle is still lacking. Part of the problem is that there is still no clear view of all the physical phenomena at play during this crucial stage. The formation of a solid and therefore very viscous lithosphere has often been considered to trigger a new pattern of motion where convection occurs below the lithosphere which remains stagnant. Such a regime drastically reduces the heat flux out of the planet and reduces its chance to transition towards a plate tectonic mode where the lithosphere can break and subduct in the mantle.

When we simulated the secular convective cooling of a 1-D magma ocean in interaction with its outgassed atmosphere, our coupled model indicated that a thick solid lithosphere (> 1 km) would only form both rapidly at the very end of the MO stage, and sufficiently far from the star depending on the volatile content. However, as a consequence of its rapid solidification and cooling, the lithosphere could undergo large stresses due to thermal contraction. If those stresses exceed the lithospheric strength, the lithosphere could break and subduct.

We present here new laboratory experiments run in visco-elasto-plastic colloidal solutions that show this very behaviour. Scaling laws deduced from the experiments highlight in which conditions a smooth transition to a subduction-dominated regime prevails. These conditions depend strongly on the cooling rate of the lithosphere at the end of the MO, which in turn depends on the initial volatile contents of the planet, its size and its distance to the star.