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Evolution and Consequences of Magma Ocean Solidifcation

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The various and intense energy sources involved in the early stages of planetary formation, such as kinetic energy of accretion, decay of short-lived radiogenics, release of gravitational potential energy upon core formation, and tidal effects, are thought to have caused partial or possibly entire melting of the mantle of terrestrial planets and moons [Elkins-Tanton2012]. Global or local liquid magma oceans could thus have formed, whose solidification upon planetary cooling could have exerted a significant impact on the differentiation and subsequent evolution of the interior of terrestrial bodies. The solidification of such magma oceans likely proceeds from the bottom upwards because of the steeper slope of the mantle adiabat with respect to the slope of the solidus, and controls the initial compositional stratification of the solid mantle, which, in turn, can play an important role in shaping the earliest forms of mantle convection and surface tectonics. We investigate the thermal evolution of a whole-mantle magma ocean using the finite-volume code Gaia [Huettig2013]. We run two-dimensional simulations of magma ocean cooling and crystallization and investigate in particular the conditions for which the onset of solid-state thermal convection is possible before mantle solidification has completed. We assume an adiabatic temperature profile in the magma ocean and various cooling rates of the surface temperature according to coupled magma ocean-atmosphere models [Lebrun2013]. Upon reaching a critical melt fraction that marks the formation of the so-called rheological front, [Solomatov2007], we self-consistently solve with Gaia the conservation equations of solid-state mantle convection in the partially molten domain assuming a viscosity strongly dependent on temperature and melt content. By varying the reference Rayleigh number and the magma ocean cooling rate, we show that, even for a surface temperature decreasing very rapidly at a rate of 1000 K/Myr, a sufficiently high Rayleigh number guarantees the onset of solid-state convection prior to complete crystallization of the mantle. This finding can have important consequences for the initial distribution of compositional heterogeneities generated through the magma ocean fractional crystallization.

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