Evolution and consequences of magma ocean solidification

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Energy sources involved in the early stages of planetary formation could have caused partial or possibly entire melting of the mantle of terrestrial planets and moons [1]. Global or local liquid magma oceans could thus have formed, whose solidification, from the bottom upwards, upon planetary cooling could have exerted a significant impact on the differentiation and subsequent evolution of the interior of terrestrial bodies. Initial compositional stratification of the solid mantle, as a result of magma ocean crystallization can play an important role for the subsequent planetary evolution and surface tectonics [2] [3].

In this study, we investigate the cooling and crystallization of a whole-mantle magma ocean and in particular the conditions for the onset of solid-state thermal convection before complete mantle solidification. To this end we employ two-dimensional Cartesian box simulations using the finite-volume code Gaia [4]. 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 [5]. Upon reaching a critical melt fraction that marks the formation of the so-called rheological front, [6], we self-consistently solve 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 between 10^6 - 10^9 and the magma ocean cooling rate between 100 - 0.01 Ma, we show that, even for a rapidly decreasing surface temperature, 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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