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From magma oceans to solid mantle: insights from numerical simulations using a phase change boundary condition

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After accretion and formation of the Earth, our planet went through at least one episode of magma ocean. When the temperature of this magma ocean decreases below a certain value, it starts solidifying. Several studies suggest that magma ocean solidification started at mid-mantle depths and two crystallisation fronts moved in opposite directions: the surface magma ocean front upwards and the basal magma ocean front downwards. As a consequence, solid mantle appeared. The convection in the solid mantle creates dynamic topography at the interface between solid and liquid parts. This topography can be eroded by melting/crystallisation or by viscous relaxation. The way dynamic topography is eroded can change the compositional field and dynamics of solid mantle.

In this work we investigate the dynamics and thermo-compositional evolution of a solid mantle bounded by magma oceans. We use the convection code StagYY. Our setup is a solid mantle represented by 2D spherical annulus geometry and two magma oceans parameterised as 0D objects at top and bottom boundaries. We make use of a new boundary condition that allows material to flow through the boundaries, and parameterisation of fractional crystallisation and melting processes at the boundaries. Because iron partitioning occurs preferentially in the oceans, the continuous melting/refreezing of material at the boundaries changes composition of solid and liquid parts with time.

Our results show that the thermal evolution of solid part is strongly controlled by the presence of magma oceans above and below. Because material can now flow through the boundaries, different patters of convection arise depending on the timescale used for melting/crystallisation processes. If this timescale is very short, we show that the extreme case of degree-1 mode of convection (translation) happens. On the other hand, if this timescale is big, material cannot flow through the boundaries and viscous relaxation is responsible for erasing dynamic topography. Regarding compositional evolution, we show that solid part gets iron depleted, while both magma oceans get enriched in iron. With time, iron content in both solid and liquid layers reach a steady state. We show that the equilibration time is strongly dependent on the way dynamic topography is eroded.