Mantle compositional heterogeneity arising from magma ocean crystallisation followed by long-term differentiation: Modelling from a molten Earth to the present day

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There is geochemical evidence both for primordial material and recycled material in the mantle. Large deep mantle structures that are inferred to be chemically distinct, as well as small-scale heterogeneity distributed everywhere, may thus be made of a mixture of differentiated materials that formed at different times, from an early magma ocean phase to ongoing melting at the present day. Early solidification of a magma ocean may have left the mantle compositionally stratified, while throughout Earth's history melting in the shallow mantle has produced crust, most of which was recycled into the interior and some of which may have segregated above the core-mantle boundary, joining possible enriched products from early differentiation, internal differentiation and basal magma ocean solidification to produce a Basal Melange (BAM)[1].

We will present simulations of mantle evolution from a 100% molten state (magma ocean) to the present day. This allows both early and long-term differentiation processes to be included in a self-consistent manner, using the simulation code StagYY. Dynamics occuring in regions that are mostly solid are fully resolved, while turbulent convection in regions that are mostly molten is parameterised by the use of an effective diffusivity. We investigate and characterize the evolution of a magma ocean as a function of various uncertainties including the shape of the solidus/liquidus (controlling whether crystallization starts in the middle or at the base), melt-solid density difference, fractional vs. batch crystallization, iron partitioning, and early cooling rate. Solid-state convection probably onset before the magma ocean is completely crystallized, making a strongly stratified mantle unlikely, but some early deep layering may have resulted. The core rapidly cools to the rheological transition of the mantle, making a straightforward basal magma ocean difficult to maintain; compositional differences due to iron partitioning are needed. Selected cases are run for subsequent billions of years beyond the magma ocean stage to predict modern-day mantle structure, with a focus both on the deep mantle and volumetric distribution of chemically distinct components.

[1] Tackley (2012), Earth Science Reviews 110, 1-25.