Modelling the thermo-chemical evolution of the mantle from a totally molten state to the present day

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Melting has always played a key role in Earth evolution. Early solidification of a magma ocean may have left the mantle compositionally stratified and/or may have continued in the form of a long-lived basal magma ocean (BMO). Ongoing upper mantle/transition zone melting, perhaps associated with water and carbonate, may have caused 'internal differentiation', resulting in dense enriched products that sink. 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 BMO solidification to produce a Basal Melange (BAM).

We now have the capability to simulate mantle evolution from a 100% molten state (magma ocean), which allows both early and long-term differentiation processes to be included in a self-consistent manner, using the simulation code StagYY. Our models use an approach previously developed for 1-D magma ocean modelling by Y. Abe, in which 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. The models treat fractional melting using a eutectic model plus iron partitioning, include segregation of melt and solid, coupling to a parameterized core, and a radiative surface boundary condition with heat loss slowed by an atmosphere. 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, and cooling rate. Depending on parameters, we find that the magma ocean may have solidified with a ~uniform or a stratified composition. Solid-state convection may onset before the magma ocean is completely crystallized. The core rapidly cools to the rheological transition of the mantle, making a straightforward basal magma ocean difficult to maintain. Selected cases are run for subsequent billions of years beyond the magma ocean stage to predict modern-day mantle structure.