Evolution of a dense magma ocean at the base of the mantle

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Since the discovery of the ultralow-velocity zones in the lowermost mantle, evidence for the presence of partial melt at the bottom of the mantle have continually accumulated. The maintenance of the magnetic field for at least 3.2 Gyr requires cooling of the core over that period and implies an even larger quantity of melt in the lowermost mantle in the past than at present. We investigated the implications of such an hypothesis in terms of thermal and chemical evolution of the mantle and found that it can offer a explanation for several different observations.

The mass of melt decrease, controlled by the energy balance, is exponential to first order, with a time scale set by the heat capacity of the core and the phase diagram of the mantle, typically of order 1Gyr. The melt is denser than the overlying solid that crystallizes from it, due to a larger Fe content. In addition, the huge viscosity contrast renders entrainment of melt by convection in the mantle negligible. The melt is then the ideal deep mantle reservoir and can contain about 20% of the Earth's budget in incompatible elements. Moreover, because of the difference between the partitioning coefficients of Sm and Nd, the crystallization of the this melt over time creates a positive $\varepsilon_{^{142}\mathrm{Nd}}$ in the solid and the complementary negative one in the liquid when compared to chondrites. This can then explain the systematic difference of chondrites with all terrestrial samples.

The existence of melt in the lowermost mantle for most of Earth's history, implied from geophysical arguments offers a solution for some of the most important geochemical problems of the mantle.

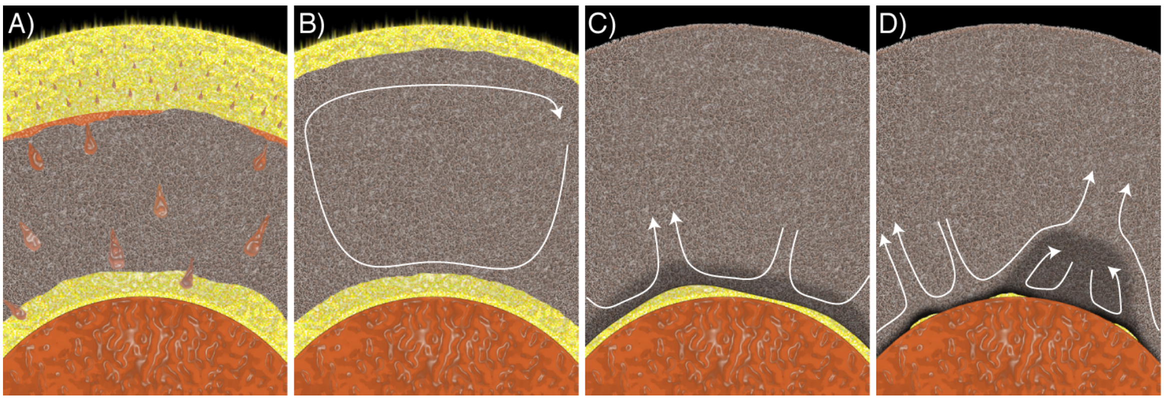

Figure 1: Four stages of the evolution of the deep Earth. (A) formation of the core. The gravitational energy released heats up the core and the lower mantle, allowing the latter to partially melt. The Fe-enriched melt is denser than the solid in equilibrium and stays at the bottom of the mantle. (B) Crystallisation of the mantle proceeds from the middle, up- and down-ward. The up-ward crystallisation is controlled by radiation to space and occurs in about 10 Myr. The downward crystallisation is limited by convection in the already solidified part of the mantle and is buffered by the heat capacity of the core, and is then protracted (C). The progressive enrichment in Fe of the melt and the solid establishes a chemical stratification at the base of the mantle (C) which becomes stable against entrainment by large scale convection and piles up under up-welling currents (D). Pockets of melt persist today at the edges of piles and are responsible for ultra low velocity zones (D).