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The long-term evolution of the Earth mantle with a basal magma ocean

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The early evolution of the Earth was likely affected by a large scale magma ocean, in particular in the aftermath of the giant impact that formed the Moon. The exact structure and dynamics of the Earth following that event is unknown but several possible scenarios feature the existence of a basal magma ocean (BMO), whose last remaining drops may explain the current seismically detected ultra low velocity zones. The presence of a BMO covering the core carries many implications for the dynamics and evolution of the overlying solid mantle. The phase equilibrium between the magma and the solid mantle allows matter to flow through the boundary by melting and freezing. In practice, convective stresses in the solid create a topography of the interface which displaces the equilibrium. Heat and solute transfer in the liquid acts to erase this topography and, if this process is faster than that the producing topography, the boundary appears effectively permeable to flow. This leads to convective motions much faster than in usual mantle convection. We developed a mantle convection model coupled to a model for the thermal and compositional evolution of the BMO and the core that takes into account the phase equilibrium at the bottom of the solid mantle. It also includes the fractional crystallisation at the interface and net freezing of the magma ocean. Early in the history, convection in the mantle is very fast and dominated by down-welling currents. As fractional crystallisation proceeds, the magma ocean gets enriched in FeO which makes the cumulate to also get richer. Eventually, it becomes too dense to get entrained by mantle convection and starts to pile up at the bottom of the mantle, which inhibits direct mass flow through the phase change boundary. This allows a thermal boundary layer and hot plumes to develop.

This model therefore allows to explain the present existence of both residual partial melt and large scale compositional variations in the lower mantle, as evidenced by seismic velocity anomalies. It also predicts a regime change between early mantle convection dominated by down-welling flow to the onset of hot plumes in the more recent past.