The effects of melt-solid density inversion on the early evolution of the mantle in a planet of the Earth’s size

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The early mantle that contains the magma ocean evolves due to compositional differentiation by melt-solid segregation and stirring by mantle convection. I applied a numerical model of a coupled magmatism-mantle convection system to this problem, taking account of various properties of mantle materials: the post-spinel transition; the garnet-perovskite transition; the temperature-dependence of mantle rheology; the density inversion between magma and the coexisting matrix. When the Rayleigh number is higher than a threshold, the buoyancy of magma generated by decompression melting enhances the upwelling flow that causes the decompression melting itself. This positive feedback, called the magmatism-mantle upwelling (MMU) feedback, strongly stirs the early mantle regardless of the detail of the material properties. At lower Rayleigh number, however, the mantle becomes layered with the Mg-rich upper mantle and Si-rich lower mantle, if a density inversion as large as 100 kg/m^3 occurs just above the post-spinel phase boundary between magma and the coexisting matrix. The threshold value of the Rayleigh number depends on the effective permeability of magma through the solid mantle. As for the Earth, the calculated history of the mantle that follows this layered structure is not compatible with the observed features of the Earth’s mantle. The possibility of early mantle layering in other terrestrial planets of extra-solar system is, however, not ruled out.

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