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The effects of magma oceans and the Moon on the Earth's mantle before plate tectonics

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Studies of magma oceans indicate that planets obtain a gravitationally stable, compositionally differentiated mantle following solidification. This stable mantle results primarily from iron-magnesium partitioning during solidification, producing progressively iron-enriched mantle phases as solidification proceeds. Near the end of solidification, the dense solids will overturn to a stable configuration. The resulting differentiated mantle is stable from compositional density gradients that are significant enough to suppress thermal convection for up to hundreds of millions of years or longer, a scenario that proceeds self-consistently from physical and chemical principals, but is in contradiction with a previous image of a hot, turbulently convecting earliest terrestrial mantle.
The isotopic range found in Martian meteorites indicates that its mantle differentiated in the first tens of millions of years of the solar system and has not been thoroughly remixed since. The specific isotopic range found on Mars is consistent with formation in a magma ocean. Based on the isotopic compositions of magmas, the mantle of the Earth is well mixed in comparison with the mantle of Mars. If the terrestrial planets experienced partial or whole magma oceans and thus began with stable mantles, resisting the onset of thermal convection and subsequent remixing, then why is the mantle of the Earth well mixed? Two processes predicted to occur on the Earth, but not on the smaller Mars, may explain the divergent evolutions of these bodies. Here we will present model calculations for these two processes.
First, we hypothesize that in the brief period that the Moon was very close to the Earth, it may have tidally heated the interior of the Earth sufficiently to overcome its initial compositionally stable mantle, initiate active convection, and set the stage for the well-mixed mantle sampled today. Mars, conversely, may have cooled significantly before thermal convection began, allowing the formation of a thick solid lid and diminished the likelihood of mantle remixing.
Second, on an Earth-sized planet a magma ocean would solidify to produce very dense near-surface solids that also contain the bulk of the water held in the solid state, and the bulk of the incompatible elements. During gravitationally-driven overturn shallow, dense, damp solids carry their water as they sink into the perovskite stability zone and transform the bulk of their mineralogy into perovskite. The last solids that form near the surface exceed the likely water saturation levels of perovskite and will be forced to dewater as they cross the boundary into the lower mantle, leaving water behind in a rapid flux as the dense material sinks.
This event will form a kind of water catastrophe, and would have the potential to partially melt the upper mantle, to produce a damp asthensosphere, and indeed to encourage convection. These results imply that planets in which perovskite is stable, that is, planets that are larger than Mars, are perhaps more likely to have an early initiation of plate tectonics, and that larger planets may have more violent and near-surface mantle volatile releases during any overturn event.

Keywords: Magma ocean, Moon, plate tectonics, mantle, Earth, water