

Why is the basal silicate layer of Mars absent in the Earth?: Insights from magma ocean differentiation modeling

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One of the most recent discoveries about Mars is the existence of a distinct silicate layer between the Mantle and the Core. Its existence is puzzling, but interpreting this silicate layer as a remnant magma ocean is attractive, because the magma ocean scenario readily explains all the layer's features on Mars. Such dense layers have been frequently predicted by previous numerical models of mantle convection. According to these models, fractional crystallization and differentiation enrich the magma ocean in iron. The enrichment will increase the density of the magma ocean, which eventually will lead to an overturn, creating this silicate layer between the mantle and the core. However, this raises the question of why this layer exists in Mars but not in Earth, where it should be detectable by geophysical techniques.

We focus on a process that is missing from current models of magma ocean differentiation: the melting of crystal cumulates (or remelting) that occurs as soon as solid-state convection starts, substantially before the end of magma ocean crystallization. Using boundary layer theory and a binary melting model, we calculate the evolution and differentiation of a magma ocean undergoing crystallization and fed by remelting. Under these conditions, two possibilities appear, depending on the ratio between magma ocean cooling and mantle convection speeds: either (a) the magma ocean cools fast compared to mantle convection, and differentiates steadily, forming a silicate layer; or (b) the composition of the magma ocean is buffered by the remelting incipient mantle, halting differentiation, diluting iron, and precluding the formation of the dense silicate layer. On Earth, the greater planet size fosters fast mantle convection and stronger remelting of the mantle, favoring case b. On Mars, a smaller planet size slows down mantle convection, favoring case a.

We propose that the magma ocean scenario readily explains the discrepancies between the mantles of Earth and Mars. The basal silicate layer on Earth may have never been formed, while on Mars it had no problem forming. A corollary of this work is that initial chemical stratification should be stronger in small rocky planetary bodies than in larger ones.