
Degree one convection pattern during the lunar magma ocean solidification

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Abstract

The classical scenario for the solidification of the lunar magma ocean (LMO) explains the formation of the crust by flotation of anorthite crystals. This model explains many geological features specific to the lunar crust, including its composition, highly enriched in anorthite minerals, and the presence of the Procellarum KREEP terrane, which concentrate incompatible elements. But it does not explain the degree-one variation in thickness of the lunar crust. The lunar crust is indeed significantly thinner on the near side (~23-30 km) than on the far side (~50-60 km).

One proposed hypothesis is that degree-one convection can set up in the solid cumulates before the end of LMO crystallization. The phase-change boundary between the magma ocean and the solid cumulates allows material to flow through the solid-liquid interface by crystallization or melting, and favour the appearance of a degree-one convection pattern in the solid cumulates (Morison et al. 2019).

Here, we develop a model for the solidification of the Moon in its magma ocean stage. This model is based on a simple olivine-pyroxene/anorthite phase diagram with a eutectic. Two stages of crystallization result from this phase diagram. (1) In the first stage, olivine-pyroxene crystallize and settle at the bottom in about a thousand years, forming cumulates. (2) At the eutectic, simultaneous crystallization of anorthite and olivine-pyroxene leads to cumulate growth and to the formation of a flotation crust which insulates the LMO. This insulating crust considerably increases the crystallization time of the magma ocean to about 100 million years.

Using a linear stability study as well as numerical resolutions of the convection equations accounting for a phase change boundary conditions at the interface between the solid cumulates and the magma ocean, we show that convection can take place in the cumulates before complete solidification of the LMO and that a degree-one convection pattern manifests in the solid cumulates.

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