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Rapid destabilization of a magma ocean cumulate due to permeable melting/freezing boundary

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It is commonly accepted that the mantle of terrestrial planets has been formed by crystallization of a magma ocean from the bottom-up. The crystallization of the surface magma ocean is expected to occur on a timescale of the order of 1 Myr. This rather short time has lead several authors to assume convection in the solid part takes place only after the complete solidification of the magma ocean. As the crystallization progresses, due to fractional crystallization, the magma and resulting solid are more and more enriched in FeO, leading to an unstable chemical stratification. This unstable configuration triggers an overturn after which the resulting solid mantle is strongly compositionally stratified.

The present study tests the assumption that solid-state mantle overturn only occurs after complete crystallization of the surface magma ocean. We model convection in the solid part of the mantle and parametrize the presence of a magma ocean with phase change boundary conditions. These boundary conditions allow the matter to cross the boundary between the solid and the magma ocean by melting and freezing.

We performed a linear stability analysis with respect to the temperature and compositional profiles obtained in a growing magma ocean cumulate to assess the destabilization timescale of such profiles as a function of the crystallized thickness. By comparing this timescale with a model of surface magma ocean crystallization, we deduce the time and crystallized thickness at which the convection timescale is comparable to the age of the solid crystallizing mantle. This time is found to be much shorter ($\sim$1 kyr) than the time needed to crystallize the entire surface magma ocean ($\sim$1 Myr).