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The Consequences of Fractional Crystallization for Basal Magma Ocean on the Long-term Planetary Evolution

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Constraining thermo-chemical evolution for the interior of terrestrial planets is substantial to understanding their evolutionary path. Thermo-chemical processes is controlled by stages of large-scale melting, or magma oceans (MO), due to the energy released during accretion, differentiation, radioactive decay of heat-producing elements and crystallization of the melt. Previous work shows that one of the product of considering fractional crystallization (FC) for MO is a FeO-enriched molten layer or basal magma ocean (BMO) which is stabilized at the core-mantle boundary for a few billion years. The BMO is expected to freeze by FC because it cools very slowly. FC always yield a highly iron-enriched BMO and last stage cumulates. Other crystallization mode could be dominated and has not yet been systemically explored – at least for the Earth-like planets.

To explore the fate of the BMO cumulates in the convecting mantle, we explore 2D geodynamic models with a moving-boundary approach. Flow in the mantle is explicitly solved, but the thermal evolution and related crystallization of the BMO are parameterized. The composition of the crystallizing cumulates is self-consistently calculated in the FeO-MgO-SiO_2 ternary system according to Boukaré et al. (2015). In some cases, we also consider the effects of Al_2O_3 on the cumulate density profile. We then investigate the entrainment and mixing of BMO cumulates by solid-state mantle convection over billions of years as a function of BMO initial composition and volume, BMO crystallization timescales, distribution of internal heat sources, and mantle rheological parameters (Ra# and activation energy), . We varied the initial composition of BMO by manipulating the molar fraction of FeO, MgO, and SiO_2 -based on published experiments- to model different BMO-compositions: Pyrolitic composition, After 50% crystallization of Pyrolitic composition *Boukaré et al. (2015),* After 50% crystallization of Pyrolitic composition *Caracas et al. (2019), and* Archean Basalt.

For all our model cases, we find that most of the cumulates (first ~90% by mass) are efficiently entrained and mixed through the mantle. However, the final ~9% of the cumulates are too dense to be entrained by solid-state mantle convection, and rather remain at the base of the mantle as a strongly FeO-enriched solid layer. We conclude that this inevitable outcome of BMO FC – at least for Earth - leads to inconsistent evolutionary path comparing to recent geophysical constraints. FC substantially change the compositional, thermal, and geometrical properties for the lower mantle structures. An alternative mode of crystallization may be driven by an efficient reaction between a highly-enriched last-stage BMO with the overlying mantle due to chemical disequilibrium.