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Deep magma ocean crystallization reconciles the Nb–U and Sm–Nd mantle discrepancy

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Mass-balance approaches using different geochemical tracers yield contrasting and inconsistent estimates of how the present-day mantle compares to the primitive mantle taken as the bulk silicate Earth (BSE). The Sm-Nd isotopic system suggests it represents only ~20-50% of BSE, whereas the Nb/U ratio implies a fraction higher than 60% [1]. To address this discrepancy, we investigated whether the solidification of Earth's magma ocean ~4.5 Ga ago could be a contributing factor.

To quantify this process, the mineral-melt partition coefficient in the deep mantle must be constrained. To this end, we conducted new laser-heated diamond anvil cell (LH-DAC) experiments to determine the partitioning coefficients of key trace elements (Nd, Sm, U, and Nb) between a pyrolytic melt and bridgmanite under lower-mantle conditions. Experiments were performed at deep-mantle pressures and temperatures sufficient to achieve complete melting, followed by controlled fractional crystallization. Quantitative major and trace element concentrations in both solids and melts were measured using scanning transmission electron microscopy (STEM). These experimental constraints allow us to model deep-mantle crystallization dominated by early bridgmanite formation, followed by ferropericlase and calcium perovskite at more advanced stages.

Using these new partitioning data, we calculate the compositions of the crystallized solids and the remnant liquid during magma ocean solidification. The crystallized solids may subsequently be enriched by mixing with a fraction of the remnant liquid to produce a source that would later evolve to generate the Continental Crust (CC) and its residual counterpart, the Present-Day Mantle (PDM). Combining the results of our crystallization model with the known composition of the PDM and CC [1], we identify a range of conditions under which the Sm-Nd and Nb-U systems are consistent with geochemical observables. These two ratios are reconciled for the first time without invoking a hidden or lost reservoir. In our model, the PDM represents between ~70% and ~98% of the BSE.

These results show that magma ocean solidification plays a significant role in establishing primitive mantle reservoirs, and that its geochemical impact on mantle chemistry should be systematically considered in models of Earth's evolution.

[1] Hofmann, Class & Goldstein (2022), *Geochemistry, Geophysics, Geosystems* 23, e2022GC010339.