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Quantitative Modeling of Magma Ocean in the early Earth and its implication for the origin of LLSVPs

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We modeled the evolution of terrestrial Magma Ocean (*MO*) using the short-lived ^{182}Hf-^{182}W isotope system ($t_{1/2}$= 8.9 Myr) in a multi-reservoir Earth evolutionary model (Fig. 1). Model simulates several scenarios of *MO* crystallization. After crystallization, denser magma ocean residue (MO_{RES}) became gravitationally unstable and sank to the core-mantle boundary (CMB). The sequestrated MO_{RES} might represent the present-day seismically identified Large Low-Shear Velocity Provinces (LLSVPs) [1], and material from such a source is argued to have contributed to ocean island basalts (OIBs) [2].

We start with a chondritic Earth (M_E = 5.9×10^{24} kg) at T_0 = 4.56 Ga. Core segregates and attains its present-day mass (1.883×10^{24} kg), W concentration (500±120 ppb), ^{182}W/^{184}W ratio (μ^{182}W$_{\text{Core}}$ of -220; μ^{182}W is ppm deviation in ^{182}W/^{184}W relative to present-day terrestrial standard) at the end of core formation (T_{CF}). The time and rate of core formation constrains the starting composition of the silicate Earth (adopted from [3]) and impose several initialization states for *MO* models. We assume a large *MO* with a composition similar to the silicate Earth was formed soon after core formation, and crystallization of magma ocean, MO_{CX} occurs in time T_{CX}, leaving behind the residue, MO_{RES}; $MO_{CX} + MO_{RES} = M_{MO}$. A series of differential equations describing the changing mass and abundance of ^{182}Hf, ^{182}W and ^{184}W nuclides in each reservoir are solved numerically at 0.1 Myr time steps for the initial 200 Myr of Earth's history. A successful solution reproduces the present-day Hf and W concentrations and ^{182}W/^{182}W ratios in MO_{RES} similar to those constrained from global OIBs, assuming OIBs originate from LLSVPs. Our modeling results constrain: (i) the amount of crystallization in the *MO*, $MO_{CX,}$ (ii) the timing of *MO* crystallization, T_{CX}, and (iii) the depth of *MO*, d_{MO}. The composition of the model-derived MO_{RES} provides significant clues for early-formed distinct geochemical domains in the deep mantle that remained preserved until today and sampled by the deep-rising plumes.

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[3] Kumari, Stracke, & Paul (2022), Chem. Geol. 611, 121104.

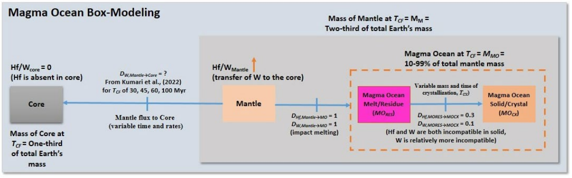

Fig. 1. Model schematics showing the core, mantle, and magma ocean reservoirs in the early Earth. The transfer of mass and species fluxes are shown by arrows, for example, an arrow from the mantle to the core indicates core segregation from the bulk Earth.