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Mantle Processing Rate Controls the Pace of the Silicate Earth Evolution

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The formation and recycling of oceanic crust back into Earth's deeper mantle is the largest material flux on Earth. It determines the outgoing flux of incompatible elements into the oceanic, and ultimately, the continental crust, and thus controls the rate of incompatible element depletion from Earth's mantle. The super-chondritic Hf-Nd isotope ratios of Archean rocks until ~3.8 Ga may reflect high rates of mantle melting during the first few 100 million years of Earth's history [1]. Recent studies have argued, however, that the super-chondritic Hf-Nd isotope ratios of Archean rocks are analytical artifacts [2], and Earth's mantle maintained a chondritic Sm-Nd and Lu-Hf evolution until 3.8 Ga.

We present a multi-reservoir (average mantle, oceanic crust and continental crust) box-model for Sm-Nd and Lu-Hf isotope evolution of the silicate Earth. The model comprises a series of differential equations computing the changing abundance of isotope species in terrestrial reservoirs, from Earth's beginning to the present-day. We varied the rates of oceanic and continental crust formation, the rates of recycling and re-homogenization of the crustal material within the mantle to evaluate the interdependency of these factors on the rate of incompatible element depletion from Earth's mantle. For a given rate of continental crust production [3], extensive mantle depletion is possible within the first few 100 Ma of Earth's history if the rate of oceanic crust production is high (>10^{21} kg.Ma^{-1}), and the isolation times of the recycled (oceanic and continental) crust is at least ~0.2-1 Ga. Subsequently, re-homogenization of recycled crust within the mantle leads to a short pulse of mantle enrichment, followed by progressive incompatible element depletion. On the other hand, moderate rates of oceanic crust formation and/or short isolation time (fast re-homogenization) of recycled crust in the mantle can sustain a chondritic Hf-Nd isotope evolution in the Archean, followed by progressive mantle depletion, whose extent depends on the interplay between the rate of oceanic crust production and crustal recycling.

[1] Vervoort & Blichert-Toft (1999), Geochim. et Cosmochim. Acta 63, 533–556.

[2] Vervoort & Kemp (2024), Annu. Rev. Earth Planet. Sci. 53, 7.1–7.27.

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