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Understanding the chemical differentiation of the Earth using coupled Lu-Hf and Sm-Nd systematics in open system models

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The Lu-Hf isotope system is an important geochronometer and has provided crucial insights for understanding crust-mantle differentiation processes. Hf isotope ratios in zircons that are also precisely dated with the U-Pb method, provide invaluable information about the evolution of the continental crust since the early Hadean. In this study, an open system model was developed to investigate the chemical and isotopic evolution of the silicate Earth in a four-box open transport model comprising continental crust (CC), upper depleted mantle (UM), lower mantle (LM), and a transient isolated mantle reservoir. Our forward model is solved numerically at 1 Ma time step for 4.56 Ga, and thus tracks the chemical and isotopic evolution of various crustal and mantle reservoirs over the entire Earth history. In particular, we have investigated the effect of various proposed crustal growth patterns (such as early vs. late growth, linear vs. non-linear, and episodic growth patterns etc.) on the chemical and isotopic evolution of the bulk continental crust and mantle. We validated the model results using estimates for the present-day chemical and isotopic composition of the upper and lower mantle (UM, LM), and bulk continental crust (CC). Among various crustal growth patterns evaluated in our model, only continuous exponential growth satisfactorily reproduces the majority of the chemical and isotopic constraints. Model simulations suggest a positive ϵ_{Hf} in the mantle during Hadean, an important feature associated with the early crust-mantle differentiation process. Results obtained from short-lived isotope systems (^{146}Sm-^{142}Nd, $t_{1/2}$= 103 Ma; ^{182}Hf-^{182}W, $t_{1/2}$= 8.9 Ma) also suggest the possibility of an early silicate differentiation event around 20-30 Ma leading to the formation of chemically heterogeneous reservoirs in the Hadean. Whether these early formed reservoirs are preserved or subsequently re-homogenized in the mantle, and on what timescales, may have major implications on the isotopic evolution of the present-day crust-mantle system.