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Modeling crust–mantle evolution using radiogenic Sr, Nd, and Pb isotope systematics

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The present–day elemental and isotopic composition of Earth's terrestrial reservoirs can be used as geochemical constraints to study evolution of the crust–mantle system. A flexible open system evolutionary model of the Earth, comprising continental crust (CC), upper depleted mantle (UM) –source of mid–ocean ridge basalts (MORB), and lower mantle (LM) reservoir with a D" layer –source of ocean island basalts (OIB), and incorporating key radioactive isotope systematics (Rb–Sr, Sm–Nd, and U–Th–Pb), is solved numerically at 1 Ma time step for 4.55 Ga, the age of the Earth. The best possible solution is the one that produces the present–day concentrations as well as isotopic ratios in terrestrial reservoirs, compiled from published data. Different crustal growth scenarios (exponential, episodic, early and late growth), proposed in earlier studies, and its effect on the evolution of isotope systematics of terrestrial reservoirs is studied. Model simulations strongly favor a layered mantle structure satisfying majority of the isotopic constraints. In the successful model, which is similar to that proposed by Kellogg et al. (1999), the present–day UM comprises of 60% of mantle mass and extends to a depth 1600 km, whereas the LM becomes non–primitive and more enriched than the bulk silicate Earth, mainly due to addition of recycled crustal material. Modeling suggest that isotopic evolution of reservoirs is affected by the mode of crustal growth. Only two scenarios satisfied majority of the Rb-Sr and Sm-Nd isotopic constraints but failed to reproduce the present-day Pb-isotope systematics; exponential growth of crust (mean age, tc=2.3 Ga) and delayed and episodic growth (no growth for initial 900 Ma, tc=2.05 Ga) proposed by Patchett and Arndt (1986). However, assuming a slightly young Earth (4.45 Ga) better satisfies the Pb-isotope systematics. Although, the delayed crustal growth model satisfied Sr-Nd isotopic constraints, presence of early Hadean crust (4.03 and 4.4 Ga detrital zircon in Acasta gneiss and Yilgarn block, respectively), argues against it. One notable feature of successful models is an early depletion of incompatible elements (as well as Th/U ratio in the UM) by the initial 500 Ma, as a result of early formation of continental crust. Our results strongly favor exponential crustal growth and layered mantle structure.

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