The implications of the Hf and Nd isotopic records for the early history of the silicate Earth

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The Sm-Nd and Lu-Hf isotope systems have been valuable tools in trying to understand the differentiation and evolution of bulk silicate Earth (BSE). Together these systems help constrain evolution of the crust and mantle and provide a basis for quantifying bulk Earth isotopic mass balance. Linking these systems is especially important for constraining the history of the early silicate Earth as they provide independent records in rocks with long and complex tectonothermal histories. Ultimately, the utility of these systems will depend on how well we know the ^{147}Sm and ^{176}Lu decay constants as well as the Lu-Hf and Sm-Nd isotopic composition of BSE.

Recent work on the ^{176}Lu decay constant by cross-calibration of U-Pb and Lu-Hf isotope systems on mineral isochrons in terrestrial rocks [1,2] have determined values ($1.867 \times 10^{-11} y^{-1}$) 3-4% lower than the values in use for the last two decades and ~6% lower than the value determined from meteorites [3]. The terrestrial value, if true, would result in predominantly negative initial ε_{Hf} values for the oldest terrestrial rocks and zircons, indicating they were derived from a source with a prior crustal history. In contrast, a faster decay constant would result in more positive ε_{Hf} values and indicate derivation from a depleted mantle source. The chondritic Lu-Hf parameters, while still a matter of debate [4], will have little effect on ε_{Hf} values in the early Earth because plausible increases in the ^{176}Hf/^{177}Hf BSE value are linked to higher ^{176}Lu/^{177}Hf values, based on Lu-Hf systematics in chondrites.

The Nd isotope record for the early Earth is broadly characterized by positive ε_{Nd} values. Thus, if the terrestrial ^{176}Lu decay constant is correct, there appears to be a fundamental conflict between the Nd and Hf isotopic records for the Earth's oldest rocks with Nd indicating a depleted mantle source and Hf a crustal source. In light of large amounts of new Hf data emerging for early Archean rocks and zircons, and the implications of that data for early crust on the Earth, this apparent conflict between the Nd and Hf isotopic records needs to be resolved.

References

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Early terrestrial mantle dynamics from the ^{143}Nd isotopic record of 3600 Ma to >3850 Ma mafic and felsic rocks

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Mantle isotopic evolution for ^{143}Nd/^{144}Nd is frequently depicted as linearly increasing from a chondritic primitive mantle composition at 4.56 Ga to modern MORB compositions. This implies a progressive depletion of the mantle and a continuity of rates and processes from ancient to modern Earth. The test of these concepts relies on clarifying and extending the isotopic record by finding the oldest, least altered mantle-derived rocks, providing them with age and geologic context and determining accurate initial compositions. Our continuing field and laboratory investigations have identified the islands near Nuuk, SW Greenland, including Qilangarssuit and Innersuartuut, as having the most extensive record of early (3800-3850 Ma) Earth chemistry. Six oldest orthogneisses, with SHRIMP zircon dates of 3850-3840 Ma provide minimum ages for varied mantle derived mafic/ultramafic rock sequences. Initial ε_{Nd}(3850Ma) from >30 mafic samples are in a narrow range of +2 to +4 (±0.5), providing a robust control on early mantle depletion. No negative ε_{Nd} values have been determined. Assuming depletion occurred at 4.56 Ga, these data require a *minimum* average ^{147}Sm/^{144}Nd=0.224 in the pre-3850 Ma upper mantle. The apparent Nd isotopic homogeneity at 3850 Ma contrasts with the more extreme depletion and large range of positive and negative ε_{Hf} measured in >4.0 Ga detrital zircons from Western Australia (Harrison et al., this volume). The oldest felsic suites from SW Greenland provide no evidence for pre-existing felsic crust in the form of either inherited zircons, or Nd and Hf isotopic compositions.

The emerging global Nd and Hf isotopic patterns reveal a increasingly detailed picture of rapid and extreme early planetary differentiation, likely associated with accretionary processes, followed by partial re-homogenisation of the mantle before 3.9 Ga. For at least the next billion years (3.9 Ga to <2.7 Ga) ε_{Nd} and ε_{Hf} isotopic compositions were near constant, indicating rapid crustal recycling timescales (100-300 Myr) and/or reservoir mixing. Long held views of simple, linearly evolving mantle depletion need to be revised in recognition of the isotopic record of punctuated mantle evolution.