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Evolution of the depleted mantle and growth of the continental crust: An early beginning or a slow start?

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A fundamental principle of the geochemical evolution of the Earth holds that continental crust formed by extraction of melts from the mantle leaving part of the mantle depleted in incompatible elements. Nd and Hf isotopes have long been used to show that this process has been an essential feature of the Earth throughout its history, but the details of the record—and its implications for for addressing questions of the mechanisms, timing, and volumes of crustal production—remain hotly debated, particularly for the early Earth. One reason for the uncertainty in the isotopic record is a paucity of Archean rocks > 3.5 Ga and the ones that have survived often have had complex geologic histories, resulting in either compromised isotopic systematics and/or complicated mixtures of components with different ages and isotopic compositions. To address these potential complexities two approaches have been used to constrain the isotopic record: 1) Nd and Hf isotopic compositions of least altered rocks with well-constrained crystallization ages; and 2) Hf isotope composition of zircons in both magmatic rocks and in clastic sediments. The latter approach has found great utility by virtue of coupling U-Pb age constraints with Lu-Hf tracer isotopic information. A further advantage of the integrated U-Pb and Hf approach has been to examine zircons bereft of their corresponding whole rock. This has allowed the extension of the Hf isotopic record to the Hadean by examining detrital zircons from places like the Jack Hills.

One unintended consequence of two different (Nd, Hf) approaches has been the creation of isotopic records not in agreement with each other, resulting in different interpretations. The Nd isotopic record, based solely on whole-rock analyses, shows evidence for the development of a depleted mantle signature in the oldest mantle-derived rocks. These data appear to correlate with positive 142 Nd anomalies, consistent with very early development of depleted and enriched reservoirs. Hf isotopes, on the other hand, indicate derivation of the oldest rocks from chondritic to enriched reservoirs. The Hf isotope record is consistent with evidence from the geological record that suggests that formation of continental crust did not begin in earnest until ca. 3.8 Ga. If both data sets are valid, they indicate a fundamental conflict between the Hf and Nd isotopic records which could only be explained by either inaccuracies in the parameters for these isotopic systems (chondritic/reference values; decay constants) or decoupling of Lu-Hf and Sm-Nd in the earliest Earth.

Regardless of the cause, we need a robust isotopic record to solve this Hf-Nd paradox and answer the enduring questions from the earliest Earth. This is best achieved by integrating zircon U-Pb and Hf and whole-rock Hf and Nd isotope compositions in well age-constrained and least-disturbed magmatic samples. An important part of this approach must be the acknowledgement that not all rock samples (or zircons!) yield useful, unambiguous results. Indiscriminate inclusion of isotope data from disturbed and/or multicomponent rocks and zircons will do more to obscure our understanding of the isotopic evolution of the Earth than to clarify it.