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Evolution of the depleted mantle and growth of the continental crust: improving on the imperfect detrital zircon record

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One of the basic tenets of terrestrial geochemistry is that the continental crust has been extracted from the mantle leaving the latter depleted in incompatible elements. Nd and Hf isotopes have long shown that this process has been an essential feature of the Earth throughout its history. There is wide agreement on the general nature of this process, but the details of the isotopic record—and their implications for the depletion of the mantle and the extraction of continental crust—remain debated. Recently, much attention has been given to detrital zircons in both modern and ancient sediments. An advantage of this approach is the integration of the crystallization history of the zircon from the U-Pb chronometer with its Hf isotopic composition, which can provide important information on whether the zircons have been derived from juvenile or reworked crust. One essential requirement in this approach, however, is to unambiguously determine the crystallization ages of the zircons. We suggest that this represents an important—but generally ignored—source of uncertainty in the Hf isotopic record from detrital zircons.

The quality filter most often used to assess the integrity of zircon U-Pb systematics is concordance; if a zircon is concordant, it is assumed that the U-Pb age is accurate. A concordance filter is less effective in old zircons, however, because ancient Pb loss, viewed today, parallels concordia. Without the benefit from the geological context of the host rock to the zircons, it is impossible to unambiguously determine it true crystallization age. Ancient Pb loss in zircons produces an apparent age less than the true magmatic age. The initial Hf isotopic composition of these zircons, as a result, will be calculated at the wrong age and will be anomalously low (by $\sim$2.2 epsilon Hf units per 0.1 Ga). Hf model ages, calculated from these parameters, will be artificially old and spurious. The combination of unradiogenic Hf and Hf model ages > U-Pb ages in the zircon record are often given as prima facie evidence of crustal reworking and recycling during Earth's early history, and underpin models for large volumes of ancient continental crust. For many of these old zircons it may have nothing to do with crustal reworking, but simply reflect unrecognized ancient Pb loss.

A more robust picture of the isotopic evolution of the Earth can be gained from an integrated approach of Hf and Nd isotopes in well age-constrained magmatic samples: careful U-Pb zircon geochronology to determine the crystallization age of the rock; Hf isotopic composition of the zircons; and Hf and Nd isotopic measurements of the whole-rocks. We demonstrate this with respect to evolution of the depleted mantle, and discuss the implications for the timing of crust formation. An important part of this approach is the realization that not all rock samples (or zircons!) yield useful, unambiguous results. Inclusion of all Hf isotope data from large zircon databases, unscrutinized for quality and lacking in context, will do more to obscure our understanding of the isotopic evolution of the Earth than to clarify it.