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The Nd isotope record from the early Earth is not all right—lessons from accessory minerals

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Long-lived radiogenic isotope systems, particularly Sm-Nd and Lu-Hf, have been widely applied to understanding the early silicate differentiation of the Earth and formation of enriched crustal and depleted mantle reservoirs. The validity of this approach relies on the assumption that samples faithfully retained their initial Nd and Hf isotope information. However, the Nd and Hf isotope records for Earth's oldest rocks do not agree, even when determined on the same samples. Hf isotopes in Paleo-Eoarchean zircon from juvenile, nominally mantle-derived rocks have ~chondritic initial isotope compositions, whereas the Nd isotope record is highly heterogeneous. It should be noted that Hf isotope data are primarily from zircon, whereas Nd isotope data are determined on bulk rocks. The advantage of zircon is directly linking age and Hf isotopes using in-situ analysis. Nd isotopes in whole rocks rely on independent age estimates, something difficult to determine unambiguously in polymetamorphic gneisses. Additionally, the Sm-Nd isotope system is mostly contained in LREE-rich accessory phases (e.g., titanite, apatite, allanite) that are more easily disturbed. These phases, however, can be also be exploited to illustrate post-crystallization Sm-Nd isotope behavior.

The use of LREE-rich accessory phases for Nd isotopes is somewhat different from Hf in zircon. In both, U-Pb ages can be determined on the phases, but zircon have very low Lu/Hf ratios which aid in determining initial ratios but are not capable of producing a Lu-Hf isochron. Sm/Nd in accessory LREE-rich phases are higher and quite variable both between and within different phases, allowing for the determination of Sm-Nd isochron ages, which can indicate if the Sm-Nd isotope system has been re-equilibrated post crystallization. Here, we show several examples where the Sm-Nd system has been disturbed during post crystallization events (e.g., Greenland, Acasta, Wyoming, Brazil) and others where both isotope systems retain their integrity (e.g., Pilbara). This integrated age and multi-system in-situ approach can be used to provide clarity to the Hf-Nd isotope record of early Earth crust-mantle differentiation. In sum, our data demonstrate widespread Sm-Nd disturbances in polymetamorphic gneisses and suggest that much of the heterogeneity in the early-Earth Nd isotope record results from open-system behavior.