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Evaluating the bulk-rock Hf and Nd isotope record: implications for the crust-mantle evolution of the Earth.

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Our understanding of mantle differentiation and crustal evolution in the early Earth relies strongly on the Hf and Nd isotope records from primitive rocks. These global isotopic records have been dominated, particularly for Nd, by bulk-rock analyses. To evaluate the reliability of the bulk-rock isotope record—and to understand the Lu-Hf and Sm-Nd isotope systematics in complex rocks—we use an integrated bulk-rock, mineral-analysis approach. We analyze isotope compositions of bulk-rock samples using traditional dissolution methods and, in parallel, analyze the accessory minerals controlling the elemental budget in these rocks using in-situ LA-MC-ICPMS methods: for Hf we analyze zircon for U-Pb age and Hf isotope composition; for Nd we analyze titanite for U-Pb age and titanite and apatite for Sm-Nd age and Nd isotope composition. With this integrated approach we are investigating Eo-Paleoarchean gneisses from the São Francisco craton. These rocks have two main igneous ages at 3.61-3.59 Ga and at 3.52-3.41 Ga. Apatite and titanite together define Sm-Nd ages at 2.5-2.4 Ga and 2.1-2.0 Ga, the latter within error of titanite U-Pb ages (2.2-2.0 Ga). The mineral phases in the older components have a narrow range of chondritic to sub-chondritic isotope compositions for both Hf and Nd ($\varepsilon_{Hf(3.6Ga)}$ -1.9 to -3.1, $\varepsilon_{Hf(3.5Ga)}$ +0.2 to -3.1, $\varepsilon_{Nd(3.6Ga)}$ +0.9) and strongly sub-chondritic Nd isotope compositions for Paleoproterozoic components ($\varepsilon_{Nd(2.5Ga)}$ -6 to -9; $\varepsilon_{Nd(2.1Ga)}$ -10 to -17). In contrast, bulk-rock isotope compositions, calculated at zircon crystallization ages, exhibit large variations in both Hf and Nd ($\varepsilon_{Hf(i)}$ +2 to -5 with outliers at -8 and -14; $\varepsilon_{Nd(i)}$ from +4 to -12). Variability in bulk-rock isotope compositions reflect open-system behavior due to post-crystallization isotopic disturbances in mineral phases that control the REE+Hf budgets in these rocks. Similar Nd isotopic disturbances have been documented from the Greenland, Superior, and Slave provinces [1-3]. Our findings underscore the importance of examining the Hf and Nd isotope records on the mineral scale to assess open-system behavior at bulk-rock scale. This is necessary to provide more clarity into the isotope record of the early Earth with broad implications for planetary evolution.

[1]Hämmerli et al.,2019

[2]Fisher et al.,2020

[3]Wang et al.,2022