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Combined lunar Lu-Hf and Sm-Nd systematics – beware of neutron capture reactions

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The silicate differentiation history of planetary bodies including the Moon can be constrained by combined Lu-Hf and Sm-Nd studies, [e.g., 1]. Previous Lu-Hf studies on lunar basalts [2-6] yielded results generally consistent with a magma ocean history for the Moon as supported by Sm-Nd systematics [e.g., 7]. However, most KREEP-rich whole-rock samples have initial ^{176}Hf/^{177}Hf values that seem too radiogenic in relation to their unradiogenic initial ^{143}Nd/^{144}Nd values, i.e., they overlap the contemporaneous ^{176}Hf/^{177}Hf of chondrites. This disparity in the Lu-Hf and Sm-Nd systems may reflect a non-chondritic composition of the Moon [8] but could also result from capture of secondary (epi)thermal neutrons (NC) produced during cosmic-ray exposure of the lunar surface [9]. NC reactions can induce positive shifts in measured ^{176}Hf/^{177}Hf [9] and negative shifts in measured ^{143}Nd/^{144}Nd [10]. No previous Lu-Hf study of lunar samples has considered NC effects. To constrain their significance, we obtained Lu-Hf, Sm-Nd, and Hf and Sm isotope data for 20 lunar samples (6 KREEP-rich rocks and 14 mare basalts) having exposure ages between 2 and 500 Ma.

Resolvable, NC-induced ^{180}Hf and ^{149}Sm anomalies were found in 16 lunar samples. Low-Ti mare basalts show the strongest NC effects, with ^{180}Hf/^{177}Hf and ^{149}Sm/^{152}Sm as low as $\sim$820 ppm (μ-value) and $\sim$72 ε-units below those of terrestrial samples, respectively. In μ^{180}Hf vs. ε^{149}Sm space, anomalies define distinct slopes for low- and high-Ti mare basalts, reflecting differences in secondary neutron energy spectra as a function of target composition. The NC effects require correction of measured ^{176}Hf/^{177}Hf (as much as -13 ε-units for the samples investigated here) and of measured ^{143}Nd/^{144}Nd (up to +0.7 ε-units). Two KREEP-rich samples do not have NC-induced Hf or Sm anomalies and yield the lowest initial ^{176}Hf/^{177}Hf yet reported for any KREEP-rich rock. In contrast, the remaining KREEP-rich samples display well-resolved NC effects and initial ^{176}Hf/^{177}Hf values that overlap with that of chondrites. After correction for NC effects following [9], the initial ^{176}Hf/^{177}Hf of all KREEP-rich samples are unradiogenic relative to chondrites, consistent with their unradiogenic initial ^{143}Nd/^{144}Nd. The previously reported radiogenic initial Hf isotope composition of KREEP-rich whole-rock samples [2,3,5,6] can thus be explained fully by unidentified NC effects.

After correction of NC effects, the combined Hf-Nd systematics of the lunar samples investigated here provide internally coherent results for high-Ti mare basalts and KREEP-rich samples, and a highly correlated array of initial Hf-Nd isotope compositions for low-Ti mare basalts. This demonstrates that the correct interpretation of lunar Lu-Hf and Sm-Nd systematics requires careful monitoring and correction of NC effects.

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