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Thermal processing of CAIs revealed by stable isotopes of refractory elements

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Mass-dependent stable isotopic compositions of refractory elements (e.g., Ca, Ti, V, Sr, REEs) provide unique insights into the earliest evaporation and condensation processes in the solar nebula, allowing reconstruction of the physical conditions during CAI formation [1-3]. We studied stable isotopic compositions of Nd and Sr, two refractory elements with Sr having a relatively higher volatility, from Allende CAIs, and investigated their relations to elemental fractionation. All CAIs with non-group-II REE patterns have uniform $\delta^{146/144}$Nd (-0.14 ± 0.24 ‰) unresolved from chondrites, suggesting that Nd in these CAIs has been minimally affected by evaporation, condensation, and melting. Strontium, on the other hand, shows a negative correlation between CI-chondrite-normalized $(Nd/Sr)_N$ ratio and $\delta^{88/86}$Sr, with group-VI CAIs having nearly-chondritic $(Nd/Sr)_N$ and $\delta^{88/86}$Sr (+0.39 ± 0.60 ‰, unresolved from chondrites), and group-(I, V) and group-III CAIs having progressively higher $(Nd/Sr)_N$ and lower $\delta^{88/86}$Sr. This correlation can be explained by kinetic isotope fractionation during condensation with $P_{Sr,sat}/P_{Sr} \approx 0.8$. Despite the limited chemical fractionation between light REEs, the $\delta^{146/144}$Nd of group-II CAIs vary considerably (between +2.0 ‰ and -2.0 ‰), consistent with observations for Ti, another element with similar refractoriness [2]. Compared to non-group-II CAIs, the group-II CAIs show stronger Sr depletions and both more negative (down to -3.6 ‰) and more positive (up to +1.7 ‰) $\delta^{88/86}$Sr uncorrelated to $(Nd/Sr)_N$. Refractory elements in group-II CAIs thus have undergone extensive thermal processing and volatility loss due to both evaporation and condensation. Temperature constraints on the processing of CAIs can be inferred from the element-isotope fractionation patterns. Non-group-II and group-II CAIs have been processed with distinct thermal histories, possibly corresponding to different locations in the protoplanetary disk. We conclude that the fine-grained, group-II CAIs may not represent thermally less-processed materials compared to the coarse-grained, non-group-II CAIs, contributing to the ongoing debates based on CAIs' ^{26}Al-^{26}Mg chronology [4, 5].

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