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Trace element distribution in coarse-grained CAIs by femtosecond LA-ICP-MS: implications for U-Pb chronology

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Calcium-aluminium-rich inclusions (CAIs) in chondrites are among the oldest solids that formed in the Solar System, as established by U-Pb chronometry [1]. After initial condensation, coarse-grained CAIs (Compact Type A, Type B, Type C) experienced melting, resulting in igneous partitioning and spatial redistribution of trace elements among constituent minerals. Understanding these distributions is essential for identifying trace-element host phases and for interpreting U-Pb ages. Rare earth elements (REEs) and the actinides Th and U are particularly informative tracers, yet actinide behaviour in coarse-grained CAIs remains poorly constrained.

Here, we present major- and trace-element distribution maps of six coarse-grained CAIs from CV3 (Vigarano-type) chondrites acquired by femtosecond laser ablation ICP-MS. In CAIs lacking perovskite or hibonite, our results show that Al,Ti-pyroxene is the dominant host of U, Th, and most REEs, with strong enrichments toward grain edges, whereas light REEs reside in melilite. Trace-element zonation reflects igneous fractional crystallization and is overprinted by melt evaporation, which caused depletion of the most volatile REEs (Yb, Eu, Ce) and U in CAI outer regions and Wark-Lovering rims. Using Nd and Th abundances as proxies for Cm distribution [2,3], we model the effects of ^{247}Cm-^{235}U decay on mineral-scale U isotopic compositions. Variable Cm-U partitioning among coexisting minerals is predicted to generate resolvable intermineral ^{235}U/^{238}U variations. The largest ^{235}U/^{238}U excesses are predicted in melilite, which is consistent with recent U isotopic analyses of CAI mineral separates [4]. These intermineral variations can produce apparent U-Pb age offsets of ~0.1-1.0 Myr when U isotopic compositions and radiogenic Pb are derived from isotopically distinct mineral reservoirs, but generally remain smaller (< 0.15 Myr) when bulk U isotopic compositions are used.

Our results demonstrate that fractional crystallization and melt evaporation exert a primary control on U distribution and isotope systematics in igneous CAIs and provide new constraints on the interpretation and robustness of high-precision U-Pb chronology of the earliest Solar System solids.

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