

OXYGEN AND AL–MG ISOTOPE SYSTEMATICS OF A HIBONITE-MELILITE-RICH FINE-GRAINED CAI IN THE REDUCED CV CHONDRITE NORTHWEST AFRICA 8613.

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Introduction: Ca–Al-rich inclusions (CAIs) in meteorites are composed of high-temperature condensates from the solar nebular gas [1]. CAIs in CV chondrites are petrographically divided into the coarse-grained CAIs and fine-grained CAIs (FGIs). Complex layer structures of constituent minerals [2, 3] and volatility-fractionated trace-element patterns [4, 5] of FGIs indicate they are condensates from the solar nebular gas. Igneous CAIs that experienced melting and crystallization have been extensively studied for their formation processes, oxygen isotope compositions of minerals, and formation ages [e.g. 6, 7]. On the other hand, such systematic investigations for the formation of FGIs have been poorly conducted. We investigated oxygen and Al–Mg isotope systematics of a hibonite-melilite-rich FGI from the reduced CV chondrite Northwest Africa 8613 (NWA 8613) as well as detailed petrographic observations, in order to decipher its formation processes, surrounding nebular environment, and formation age.

Experimental: Petrographic observations were conducted using a FE-SEM-EDS-EBSD system (JEOL JSM-7000F + Oxford X-Max 150 + Oxford HKL) at Hokkaido University. Oxygen and Al–Mg isotopic compositions of minerals in the FGI were measured using Cameca ims-1270 and ims-1280HR SIMS instruments at Hokkaido University. The full analytical procedures are reported in [7, 8].

Results and Discussion: The FGI from NWA 8613 named HKD01 has an irregular shape with a size of approximately 10 × 12 mm and composed mainly of melilite, hibonite, and spinel with their crystal sizes of less than ~20 μm. The FGI is petrographically divided into hibonite-rich core, spinel-rich core, melilite-rich inner-mantle, and hibonite-spinel-rich outer mantle. Each petrographic domain contains melilite, hibonite, and spinel with variable proportions of those minerals. The FGI is rimmed by thin spinel and diopside layers. Although hibonite crystals distribute entire the FGI, crystallization experimental work [9] indicate that hibonite cannot be crystallized from a melt with the bulk chemical composition of the FGI HKD01, being consistent with the inferred condensation origin of FGIs [e.g. 3].

Oxygen isotope compositions of the constituent minerals plot along the CCAM line, ranging between $\Delta^{17}\text{O} \sim -23\text{‰}$ and 0‰. Melilite crystals in the core exhibit normal chemical zoning and oxygen isotope compositions from $\Delta^{17}\text{O} \sim -23\text{‰}$ to -10‰ with increasing Åk composition. The melilite crystals in the inner-mantle show chemically complex, oscillatory zoning patterns, but are uniformly ¹⁶O-poor ($\Delta^{17}\text{O} \sim 0\text{‰}$) despite their chemical variations (Åk2–14). Melilite crystals in the outer-mantle exhibit normal chemical zoning and variable oxygen isotope compositions from $\Delta^{17}\text{O} \sim -17\text{‰}$ to 0‰ with increasing Åk composition. The spinel and hibonite grains in the FGI are uniformly ¹⁶O-rich ($\Delta^{17}\text{O} \sim -23\text{‰}$). On the ²⁶Al–²⁶Mg evolutionary diagram, Al–Mg isotope data of the constituent minerals plot on a single straight line within error despite the petrographic structures; the Al–Mg mineral isochron is defined to give an initial ²⁶Al/²⁷Al value of $(4.50 \pm 0.09) \times 10^{-5}$.

Petrography and bulk chemistry suggest that the constituent minerals formed by condensation and were accumulated to form the FGI HKD01. These formation processes occurred within 20 Kyr as inferred from the error of the initial ²⁶Al/²⁷Al ratio. The crystal growth sequences with oxygen isotope variations of the minerals imply that the nebular gas changed its oxygen isotopic composition, at least, from ¹⁶O-rich ($\Delta^{17}\text{O} \sim -23\text{‰}$) to ¹⁶O-poor ($\Delta^{17}\text{O} \sim 0\text{‰}$), and back to ¹⁶O-rich ($\Delta^{17}\text{O} \sim -17\text{‰}$) during the condensation formation. The ²⁶Al–²⁶Mg systematics of the FGI indicate that these formation events occurred at 0.16 ± 0.02 Myr after the formation of so-called canonical CAIs [10, 11], if ²⁶Al was homogeneously distributed. Our combined data infer the presence of the solar nebular gas with variable oxygen isotope compositions 0.16 ± 0.02 Myr after the formation of canonical CAIs. This nebular chemical system is consistent with the observations of coarse-grained CAIs showing the nebular gas with variable oxygen isotope compositions during the first ~0.2 Myr of the Solar System formation [7, 8, 12].

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