O and Al-Mg isotope systematics of a hibonite-melilite-rich fine-grained CAI in the reduced CV chondrite NWA8613

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Ca–Al-rich inclusions (CAIs) in meteorites are composed of high-temperature condensate minerals from the solar nebular gas [1]. CAIs in CV chondrites are petrographically divided into the coarse-grained CAIs and fine-grained CAIs (FG-CAIs). Complex layer structures of constituent minerals and REE patterns of FG-CAIs suggest they are condensates from the nebular gas [2, 3]. Igneous CAIs that experienced melting and crystallization, such as coarse-grained Type B CAIs, have been extensively studied their formation processes, O-isotope compositions of minerals, and formation ages [4, 5]. On the other hand, such systematic investigations for the formation of FG-CAIs have been poorly conducted. Here, we investigated O- and Al–Mg isotope systematics of a hibonite-melilite-rich FG-CAI from the reduced CV chondrite NWA8613 as well as detailed petrographic observations. The O- and Al–Mg isotope measurements were conducted using SIMS instruments of Hokkaido University (Cameca ims-1270 and ims-1280HR).

The FG-CAI has an irregular shape with a size of approximately 10 ×12 mm and composed mainly of melilite, hibonite, and spinel. O-isotope compositions of the constituent minerals plot along the CCAM line, ranging between $\Delta^{17}O$ ˜ −23‰ and 0‰. The FG-CAI is petrographically divided into hibonite-rich core, spinel-rich core, melilite-rich inner-mantle, and hibonite-spinel-rich outer mantle. The CAI is rimmed by thin spinel and diopside layers. Melilite crystals are contained in core and mantle. Melilite crystals in the core exhibit normal chemical zoning and O-isotope compositions from $\Delta^{17}O$ ˜ −23‰ to −10‰ with increasing Åk composition. The melilite crystals in the inner-mantle show chemically complex, oscillatory zoning patterns, but are uniformly ^{16}O-poor ($\Delta^{17}O$ ˜ 0‰) despite their chemical variations (Åk2–14). Melilite crystals in the outer-mantle exhibit normal chemical zoning and variable O-isotope compositions from $\Delta^{17}O$ ˜ −17‰ to 0‰ with increasing Åk composition. The spinel and hibonite grains in the FG-CAI are uniformly ^{16}O-rich ($\Delta^{17}O = -23$‰). Al–Mg isotopic compositions of hibonite in the outer-mantle and in the core and melilite in the inner-mantle plot on a single straight line within error; an Al–Mg mineral isochron can be defined to give an initial $^{26}Al/^{27}Al$ value of $(4.50 \pm 0.09) \times 10^{-5}$. Given that the constituent minerals formed by condensation and were accumulated to form the FG-CAI, the nebular gas, from which they condensed, had variable O-isotope compositions between $\Delta^{17}O$ ˜ −23‰ and 0‰. The Al–Mg systematics of the FG-CAI indicate that these formation events occurred at 0.16 ±0.02 Myr after the formation of canonical CAIs [7], if ^{26}Al was homogeneously distributed. Our data support the presence of the nebular gas with variable O-isotope compositions during the first ˜0.2 Myr of the Solar System formation [8].

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