MINERALOGICAL AND Al-Mg ISOTOPIC STUDY OF FINE-GRAINED Ca-Al-RICH INCLUSIONS.

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Introduction: Fine-grained Ca-Al-rich inclusions (FGIs) in carbonaceous chondrites are interpreted as aggregates of nebular gas-solid condensates that escaped significant melting [1]. Thus far, a small number of FGIs from CV3 chondrites have been analyzed, showing a range of $(^{26}Al/^{27}Al)_0$ = ~5.4×10^{-5} to ~3.4×10^{-5} [2-4]. These values are similar to $(^{26}Al/^{27}Al)_0$ inferred from coarse-grained, igneous CAIs (CGIs) from CV3 chondrites [5]. This observed spread in $(^{26}Al/^{27}Al)_0$ values indicates the CAI formation over an extended time period. However, more analyses are needed to determine if the FGIs formed continuously over a significant time period or by multiple episodic events of nebular condensation. In this study, we present high-precision Al-Mg isotopic data of FGIs from reduced CV3 chondrites to better constrain their formation timescale relative to CGIs in CV3 chondrites, as well as to smaller FGIs in CO3 chondrites [6]. This isotopic study is coordinated with a FIB/TEM study to elucidate the origin and nature of FGIs in the petrologic and mineralogical context [7,8].

Methods: An initial characterization of FGIs from the reduced CV3 chondrites Efremovka and Thiel Mountains (TIL) 07003 was conducted using a FEI Quanta 3D FEG dual beam SEM/FIB and a JEOL JXA-8530F electron microprobe at NASA JSC. Three FGIs (E-A-01, E-A-02, and E-B-01) from Efremovka and one FGI (TIL 003-02) from TIL 07003 were selected for *in situ* Al-Mg isotope analyses performed in high-precision multicollection mode on the CAMECA ims-1290 ion microprobe at UCLA. Hibonite, spinel, melilite, and diopside in the FGIs were sputtered with a 1–2 nA $^{16}O_2^-$ primary ion beam generated by a Hyperion-II oxygen plasma source, as described in [9].

Results and Discussion: The four FGIs from Efremovka and TIL 07003 are irregularly-shaped, often elongated inclusions (up to ~4 mm in size) that contain numerous nodules [7,8]. The individual nodules consist of a spinel ±hibonite ±perovskite core surrounded successively by melilite, anorthite, diopside and ±forsterite. Al,Ti-rich diopside occurs often as a thin layer surrounding the spinel-rich core and, only in TIL 003-02, as an intergrowth with spinel and perovskite below the anorthite and diopside layers. The observed layered structure and fine-grained nature of the FGIs studied and the decrease in volatility (i.e., condensation temperature) through mineral layers in their individual nodules confirm that they formed by condensation [1]. The fine scale layering preserved in individual nodules is likely the result of evolving, but incomplete gas-solid condensation reactions under non-equilibrium conditions [10].

Our high-precision multicollection data of hibonite, spinel, melilite, and diopside in the four FGIs from Efremovka and TIL 07003 yield well-defined isochrons, which show variation in $(^{26}Al/^{27}Al)_0$ values among the different inclusions. The inferred initial $^{26}Al/^{27}Al$ ratios are $(5.59\pm0.25)\times10^{-5}$ for E-A-01, $(4.13\pm0.61)\times10^{-5}$ for E-A-02, $(5.18\pm0.19)\times10^{-5}$ for E-B-01, and $(4.83\pm0.50)\times10^{-5}$ for TIL 003-02 (2σ errors). The FGIs have $\delta^{25}Mg$ <1‰ and do not show any significant isotopic fractionations, supportive of their condensation origin.

The inferred $(^{26}Al/^{27}Al)_0$ values of E-A-01, E-B-01, and TIL 003-02 are broadly consistent with the bulk CAI value of $(5.23\pm0.13)\times10^{-5}$ [11]. A consistent $(^{26}Al/^{27}Al)_0$ value of ~5.2×10^{-5} was also inferred from a majority of FGIs analyzed from Efremovka, Vigarano, Kaba, and Semarkona (LL3.0) [2-4]. This cumulative data set suggests that most pristine, large FGIs condensed over the same short time interval with the canonical value, probably ~40,000 years after primary condensation of small CO3 FGIs (<200 μm in size) characterized by $(^{26}Al/^{27}Al)_0 = 5.4\times10^{-5}$ [6]. In addition, E-A-02 exhibits the lowest $(^{26}Al/^{27}Al)_0$ value of ~4.1×10^{-5}, distinctly lower than the canonical value. Similarly, a range of $(^{26}Al/^{27}Al)_0$ values down to ~3.4×10^{-5} was inferred from several FGIs in Efremovka, Vigarano, and TIL 07007 [4]. The observed spread suggests that multiple condensation events occurred over a time span of at least ~0.4 Ma to form large FGIs found in CV3 chondrites. Importantly, the $(^{26}Al/^{27}Al)_0$ values inferred from FGIs [2-4, this study] overlap those obtained from CGIs [5]. This implies that the CAI formation by condensation and melting occurred repeatedly and contemporaneously in the early solar nebula.

High-precision Al-Mg isotopic analyses of additional FGIs from TIL 07003 and 07007 are underway to evaluate the chronological significance of $(^{26}Al/^{27}Al)_0$ values lower than the canonical value.

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