A RECORD OF NEBULAR AND PARENT BODY PROCESSES OF GROSSITE-BEARING, FINE-GRAINED REFRACTORY INCLUSIONS FROM REDUCED CV3 CHONDRITES.

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Introduction: Grossite ($CaAl_4O_7$) is predicted to condense as the third major phase, after corundum and hibonite, from a cooling gas of solar composition [1] and likely preserves an important record of physico-chemical conditions in the early Solar System. However, this mineral is relatively rare in CAIs from most carbonaceous chondrite groups, except for CH chondrites [2]. In particular, from CV3 chondrites where CAIs are large and abundant, only six grossite-bearing CAIs have been reported and studied, and most of them were coarse-grained Type A inclusions [2-4]. Here, we report the occurrence of grossite-bearing, fine-grained inclusions (FGIs) from reduced CV3 chondrites. We present preliminary results of a FIB/TEM study of one grossite-bearing FGI that provide clues to constrain its formation and alteration history in the solar nebula and on the parent body and to address the overall rarity of grossite in CAIs.

Samples & Methods: Six grossite-bearing FGIs were identified from thin sections of Efremovka, TIL07003, and TIL07007, and their initial characterization was conducted using a FEI Quanta 3D FEG dual beam SEM/FIB and a JEOL JXA-8530F electron microprobe at NASA JSC. All of these FGIs have nodular structures, and individual nodules within the inclusions show successive mineral layers generally consistent with the order of decreasing in condensation temperature [1]. These observations suggest that they represent aggregates of nebular condensates that escaped significant melting [5-7]. For FIB/TEM analyses, we selected one FGI, E-B-01, from Efremovka that was characterized with $(^{26}Al/^{27}Al)_0 = (5.18\pm0.19)\times10^{-5}$, inferred from Al-Mg systematics of hibonite and spinel [7]. One FIB section from each of hibonite-spinel-rich and grossite-rich nodules within the FGI was analyzed using a JEOL 2500SE scanning TEM at NASA JSC.

Results & Discussion: E-B-01 is an irregularly-shaped inclusion (~1.2 mm in size) dominated by numerous hibonite-spinel-rich nodules. The core of these nodules consists of crystallographically oriented hibonite and spinel, surrounded by melilite, anorthite, diopside, and finally forsterite. Rare grossite-rich nodules are observed, but only in the outer margin of the inclusion. These nodules have a core of grossite surrounded by a layer of Fe-rich phase, followed by spinel ± hibonite, melilite, and finally diopside. The Fe-rich phase shares a sharp grain boundary with surrounding spinel, hibonite, or melilite, whereas it often displays a fine-grained, fibrous appearance in contact with grossite. The less refractory grossite-rich nodules formed later and record different condensation conditions compared to the hibonite-spinel-rich nodules, although it is unclear whether they condensed from the same or different gas reservoirs [8]. The condensation of grossite appears kinetically inhibited relative to spinel, due to a structural similarity between hibonite and spinel as evident by common crystallographic orientation relationships between them [9] or disequilibrium conditions in a super-cooled nebular gas [10].

Our FIB/TEM analyses show that the altered Fe-rich phase consists of numerous hercynite laths that are elongated normal to the surface of surrounding Mg-rich spinel and that the tips of these hercynite laths are decorated by euhedral magnetite (Fe_3O_4) nanoparticles. This alteration assemblage shares an irregular boundary with grossite and appears to have grown into grossite. The two spinel-structured phases, hercynite and magnetite, are in crystallographic continuity. Many pores also occur aligned along the elongation direction of the hercynite laths. Hercynite is compositionally close to pure $FeAl_2O_4$, but contains minor Mg, Zn, and Mn. Grossite is nearly stoichiometric $CaAl_4O_7$, but contains detectable Fe and Cl. Combined with the absence of similar alteration assemblage in grossite-bearing CAIs from pristine carbonaceous chondrites of petrologic type 3.0 [2], these observations provide evidence for the mobilization of Fe, Zn, Mn, and Cl during the thermal history on the Efremovka parent body. We therefore conclude that hercynite and magnetite formed as a response of thermal metamorphism by a replacement reaction of grossite with Fe being supplied from the matrix, while Ca was lost [4]. This reaction was crystallographically-controlled and probably aided by fluids [11]. The significant compositional difference between Mg-rich spinel and hercynite and the survival of magnetite nanoparticles indicate that hercynite and magnetite must have formed in the late stages of parent body alteration after peak metamorphic conditions.

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