Grossite and Hibonite Bearing Refractory Inclusions in the CO3.1 Chondrite Miller Range 090019. D. K. Ross[1] and J. I. Simon[2], [1]University of Texas El Paso/Jacobs Technology/NASA-JSC-ARES (2224 Bay Area Blvd. Houston TX 77058, USA (daniel.ross@nasa.gov), [2]NASA-Johnson Space Center-ARES (justin.i.simon@NASA.gov).

Introduction: We have characterized 142 refractory objects by EDS hyperspectral X-ray mapping in the CO3.1 chondrite MIL 090019-13. These include 127 Ca-Al rich inclusions (CAIs), 14 amoeboidal olivine aggregates (AOAs) and one Al-rich chondrule. These data are being used to reveal the mineralogy, texture and bulk composition of these inclusions, and to identify objects that represent endmembers within cogenetic populations of primitive inclusions, which will be further investigated by future isotopic studies. Previous work related to these refractory inclusions in this chondrite also appear in [1] and [2].

Twenty six inclusions are hibonite-bearing, 18 are grossite-bearing and one inclusion is corundum-rich. In seven of these inclusions, grossite and hibonite coexist. Corundum, hibonite, and grossite are predicted to be the earliest condensed phases resulting from cooling of a gas of solar composition [3]. Despite the number of primitive inclusions characterized, the mineral krotite ($CaAl_2O_4$) has not been observed. Thirty per cent of the CAIs in this sample contain corundum, hibonite and/or grossite. These most refractory inclusions are the focus of this abstract.

Methods: Bulk compositions of CAIs are determined by high resolution image analysis by electron mapping techniques at NASA-JSC. X-ray data were extracted from the mapping data set by digitizing the CAIs. Matrix corrections were applied to extracted X-ray spectra to derive the bulk composition. Standard data and Phi-Rho-Z matrix corrections were used to quantify CAI compositions using Thermoelectron NSS software. Representative textures and mineralogy of grossite- and hibonite-bearing CAIs are illustrated in Fig. 1-4.

Population of CAIs: The population of relatively small CAIs (~50-400 microns) in MIL 090019 spans the full range of CAI types, including types A, B and C, as well as more refractory CAI types, such as the grossite and hibonite bearing CAIs illustrated here. Among the CAI populations found in this suite are: 1. Ultrarefractory objects with abundant hibonite and grossite (~30%) 2. Spinel cored spherules (~11 %) 3. Elongated, spinel-cored objects (~12 %) 4. Fine-grained, porous aggregates (~9%) 5. Densified aggregates (15 %) 6. Melilite-rich inclusions (~19 %) and Anorthite-rich inclusions (~11 %). The CAIs in this sample are dominantly condensates and modified condensates, with a low proportion of melted objects. Many consist of aggregates of finer grained particles with substantial porosity. Ongoing reaction with nebular gases produces down-temperature phases partially replacing earlier formed phases and infilling porosity, leading to densified objects. Most CAIs are not fully equilibrated, but exhibit mineralogy reflecting a considerable range of temperature, with relict phases. Hibonite is typically intergrown with, and partially replaced by spinel, violating the predicted crystallization order from thermodynamic calculations[3], in which melilite should precede spinel crystallization.

MIL090019-13-23

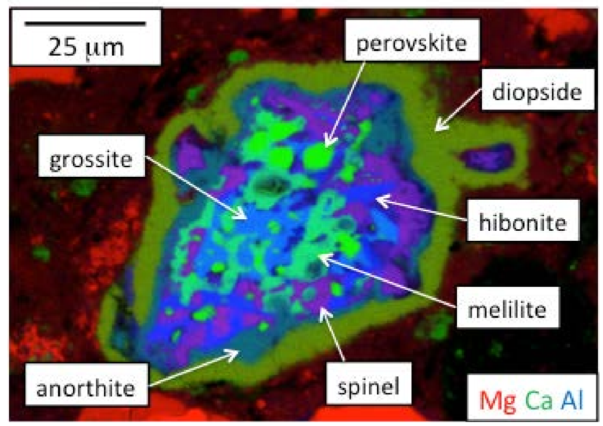

Figure 1. Grossite-cored CAI exhibits the full range of mineralogy that crystallizes by condensation and solid-gas reactions with nebular gases.

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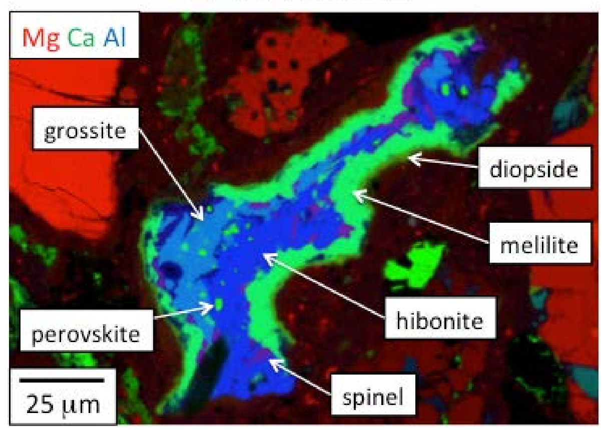

Figure 2. CAI with grossite, perovskite and hibonite in its interior, and rimmed by melilite and a thin layer of diopside.

Bulk compositions of CAIs, projected from spinel, are shown in Fig. 5, the phase diagram Forsterite-Corundum-Larnite. Many of the bulk compositions include considerable FeO (1-6 wt %, but also a few with up to ~14 wt %). In part this reflects the presence of FeO-rich chondrite matrix in interstices of porous objects, and also iron-rich alteration phases locally replacing grossite. Minor FeO (~0.5-1 wt. %) is observed by electron probe spot analyses in various phases in the inclusions, but this accounts for only a small proportion of the FeO in the bulk compositions. In light of these observations, the bulk data were recalculated to reset FeO to 0.5 wt %, and the projected bulk compositions are the corrected, low FeO data.

This is a liquidus phase diagram, and many of these objects were not melted, thus the phase boundaries do not necessarily predict the mineralogy. No glass has been observed in any of the CAIs investigated here. Also, since many of these objects represent crystallization over a considerable range of temperatures during which partial reaction with nebular gas occured, their compositions reflect those processes, and not crystallization from melts.

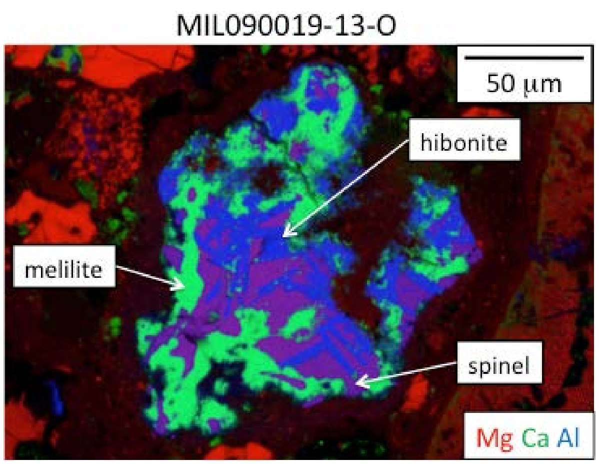

Figure 3. CAI is hibonite, spinel and melilite-rich, with minor preserved, fine-grained perovskite. The CAI is not rimmed, and appears to have been abraded, with rough and irregular margins produced by erosion.

Grossite-rich CAIs exhibit variable alteration, leading to the production of an Fe-Zn-Al oxide phase replacing grossite. This reaction apparently led to Ca loss and Fe and Zn gain, and these modifications must impact the location of the grossite-rich CAIs on the phase diagram in Figure 5, shifting them away from larnite and toward corundum. Sodic alteration is also observed in many of these objects (in all types of CAIs), producing nepheline and sodalite. We are continuing to digitize and extract bulk compositions for the remaining CAIs in this suite.

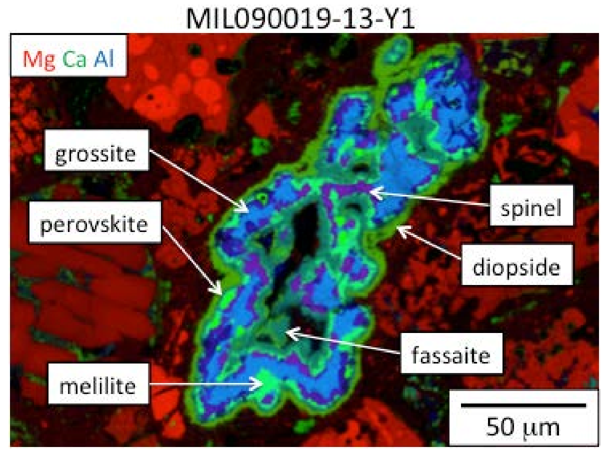

Figure 4. Grossite-rich CAI with textures suggesting replacement by spinel and melilite, with interior fassaite and rimming diopside.

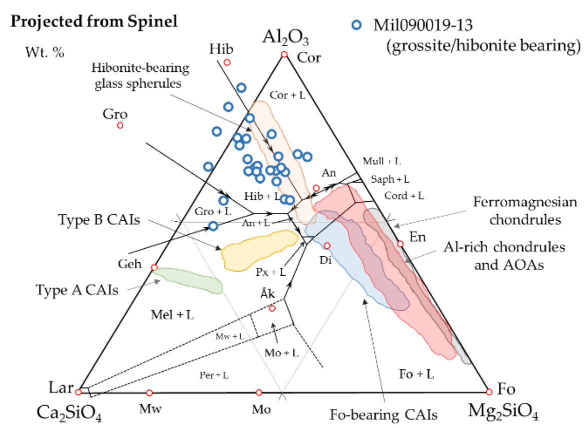

Figure 5. Projected compositions (from spinel) of grossite- and hibonite-bearing CAIs in the system CaO-Al_2O_3-MgO-SiO_2 onto the plane Larnite-Corundum-Forsterite. The projection scheme is described in [4]. Note that all these CAIs are strongly aluminous, and reside in the hibonite + spinel, corundum + spinel or grossite + spinel phase fields. The bulk compositions of these CAIs include, in some cases, rim phases, usually melilite, often diopside and occasionally anorthite. The incorporation of these rim phases shifts their bulk compositions away from Al_2O_3.

References: [1] Simon S. B. (2016) 79th *Met. Soc.*, abstract # 6098. [2] Simon J.I. (2017) *LPS XXVII*, 1344–1345. [3] Ebel D. (2006) in *Meteorites and the Early Solar System II*, Lauretta D. S. and McSween, H. Y., editors., pp 253-278. [4] MacPherson G. J. and Huss, G. R., (2005) *Geochim. Cosmochim. Acta*, 69, 3099-3127.