

### A GROSSITE-RICH REFRACTORY INCLUSION FROM THE MURCHISON (CM) CHONDRITE

L. Kööp<sup>1,2,4</sup>, A. M. Davis<sup>1,2,3,4</sup>, P. R. Heck<sup>1,2,4</sup>, N. T. Kita<sup>5</sup>, D. Nakashima<sup>5,6</sup>, T. J. Tenner<sup>5,7</sup>, A. N. Krot<sup>8</sup>, C. Park<sup>8,9</sup>, and K. Nagashima<sup>7</sup>. <sup>1</sup>Department of the Geophysical Sciences, <sup>2</sup>Chicago Center for Cosmochemistry, <sup>3</sup>Enrico Fermi Institute, University of Chicago, Chicago, IL, <sup>4</sup>Robert A. Pritzker Center for Meteoritics and Polar Studies, Field Museum of Natural History, Chicago, IL, <sup>5</sup>Department of Geoscience, University of Wisconsin, Madison, WI, <sup>6</sup>Tohoku University, Sendai, Japan, <sup>7</sup>Chemistry Division, Nuclear and Radiochemistry, Los Alamos National Laboratory, Los Alamos, NM, <sup>8</sup>HIGP/SOEST, University of Hawai'i at Mānoa, Honolulu, HI, <sup>9</sup>Korea Polar Research Institute, Incheon, Korea. E-mail: koeop@uchicago.edu

**Introduction:** Grossite ( $\text{CaAl}_4\text{O}_7$ ) is among the first minerals predicted to condense from a cooling gas of solar composition [e.g., 1]. Yet, grossite is rare in CAIs except in those from CH chondrites [e.g., 2]. In our study of >200 CAIs recovered from density separates of the CM2 chondrite Murchison, only one grossite-rich CAI, 2-6-1, was found. Here, we present its petrology and isotopic (O, Mg, Ca, and Ti) composition, and discuss its origin.

**Petrology:** 2-6-1 is a CAI fragment (~120  $\mu\text{m}$ ) composed mostly of grossite, and surrounded by a discontinuous rim of FeO-rich silicates (Fig. 1). Set inside the grossite are multiple inclusions, e.g., rounded perovskite grains ( $\leq 10 \mu\text{m}$ ) as well as polymineralic assemblages. Assemblage 1, ~15  $\mu\text{m}$  in diameter, is fully enclosed by grossite (Fig. 1c). Its core consists of hibonite surrounded by an oval band of amoeboid sub- $\mu\text{m}$ -sized Ca-Ti-rich oxide grains (perovskite?), which are set inside hibonite. A larger hexagon (~1  $\mu\text{m}$ ) of the oxide phase is located at the boundary between hibonite and grossite. EDS analyses show that both grossite and the hibonite are stoichiometric and contain no detectable MgO or  $\text{TiO}_2$ . Assemblage 2 occurs close to the edge of 2-6-1, and consists of oxide and silicate mineral layers. The first layer directly adjacent to interior grossite consists of small hibonite platelets (up to ~5  $\mu\text{m}$  across) followed by spinel and anorthite layers.

**Isotope compositions:** The CAI has a high inferred initial  $^{26}\text{Al}/^{27}\text{Al}$  ratio,  $(\sim 4\text{--}5)\times 10^{-5}$ , and has no resolvable nucleosynthetic anomalies in Ca and Ti isotopes. Calcium is isotopically heavy (~16‰/amu); Ti is isotopically normal. The oxygen-isotope composition of 2-6-1 ( $\Delta^{17}\text{O}$  of ~-17‰) is offset from the CCAM line by ~13‰ in  $\delta^{18}\text{O}$ . Note that isotopic values are approximate, as the analyses may be affected by the matrix effect as Madagascar hibonite was used as a standard [3].

**Discussion and conclusion:** The mineralogy of 2-6-1 bears resemblance with the sequence of minerals predicted to condense at high temperatures upon cooling of a solar gas [1], e.g., the hibonite enclosed within grossite and perovskite (assemblage 1) could be understood in the context of grossite and perovskite forming by a reaction of hibonite with the nebular gas. Isotopically heavy Ca in grossite suggests that 2-6-1 may have experienced melt evaporation. If this is the case, CAI 2-6-1 should be devoid of Si- and Mg-bearing phases [5,6]. The presence of anorthite and spinel close to the edge of the CAI (assemblage 2) may thus suggest that the grossite reacted with the solar nebular gas after crystallization. The concave shape of assemblage 2 (Fig. 1a) is supportive of grossite erosion. The presence of extremely Mg- and Ti-poor hibonite in the interior of the CAI (assemblage 1) is unusual. The lack of Ti may be a result of crystallization in a Mg-free melt, as  $\text{Ti}^{4+}$  commonly enters the hibonite lattice in coupled substitution.

Isotopically, CAI 2-6-1 resembles two platy hibonite crystals from Murchison (2-2-1 and 2-8-3), which also show large fractionation effects in Ca, but not in Ti and O [7]. However, 2-6-1 is depleted in  $^{16}\text{O}$  relative to 2-2-1 and 2-8-3. Similar to 2-6-1, postcrystallization reactions with the gas are likely required for 2-2-1 and 2-8-3 to explain the presence of isotopically normal magnesium in these grains. In summary, CAI 2-6-1 is a complex and unique object that likely formed in multiple stages involving melt distillation and reaction with the gas.

**References:** [1] Ebel D.S. (2006) *Meteorites and the Early Solar System II*, 253–277. [2] MacPherson G. J. (2014) *Treatise on Geochemistry*, 139–179. [3] Kööp L. et al. (in press) *Geochimica et Cosmochimica Acta*. [4] Kööp L. et al. (2016) *Geochimica et Cosmochimica Acta* 184:151–172. [5] Simon J. I. & DePaolo D. J. (2010) *Earth and Planetary Science Letters* 289:457–466. [6] Mendybaev R. A et al. (2013) *Geochimica et Cosmochimica Acta* 123:368–384. [7] Kööp et al. (2015) *Lunar & Planetary Science* 46:#2750.

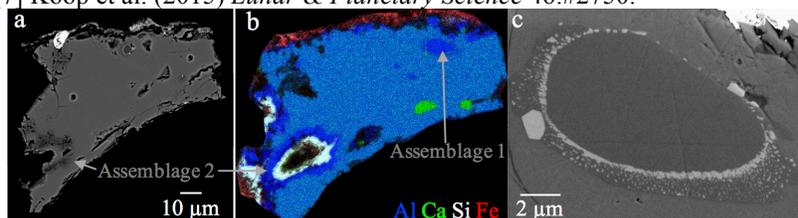


Fig. 1. (a) BSE image of CAI 2-6-1. (b) Layered EDS intensity map (repolished). (c) BSE image of assemblage 1.