CORRELATIONS AMONG MICROSTRUCTURE, MORPHOLOGY, CHEMISTRY, AND ISOTOPIC SYSTEMATICS OF HIBONITE IN CM CHONDRITES.

J. Han[1,2], M.-C. Liu[3], L. Kööp[4,5], L. P. Keller[2], and A. M. Davis[4-6]. [1]Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058, USA (jangmi.han@nasa.gov), [2]ARES, Code XI3, NASA Johnson Space Center, 2101 NASA Road 1, Houston, TX 77058, USA, [3]Department of Earth, Planetary, and Space Sciences, UCLA, Los Angeles, CA 90095, USA, [3]Department of the Geophysical Sciences, [4]Chicago Center for Cosmochemistry, [5]Enrico Fermi Institute, University of Chicago, Chicago, IL 60637, USA.

Introduction: Hibonite is a primary refractory phase occurring in many CAIs, typically with spinel and perovskite [1]. Our microstructural studies of CAIs from carbonaceous chondrites reveal a range of stacking defect densities and correlated non-stoichiometry in hibonite [2,3]. We also conducted a series of annealing experiments, demonstrating that the Mg-Al substitution stabilized the formation of defect-structured hibonite [3-5]. Here, we continue a detailed TEM analysis of hibonite-bearing inclusions from CM chondrites that have been well-characterized isotopically [6-8]. We examine possible correlations of microstructure, morphology, mineralogy, and chemical and isotopic systematics of CM hibonites in order to better understand the formation history of hibonite in the early solar nebula.

Methods: Fifteen hibonite-bearing inclusions from the Paris CM chondrite [8] were analyzed using a JEOL 7600F SEM and a JEOL 8530F electron microprobe. In addition to three hibonite-bearing inclusions from the Murchison CM chondrite previously reported on [3,9], we selected three inclusions from Paris, Pmt1-6, 1-9, and 1-10, representing a range of $^{26}Al/^{27}Al$ ratios and minor element concentrations for a detailed TEM study. We extracted TEM sections from hibonite grains using a FEI Quanta 3D field emission gun SEM/FIB. The sections were then examined using a JEOL 2500SE field-emission scanning TEM equipped with a Thermo-Noran thin window EDX spectrometer.

Results and Discussion: A total of six hibonite-bearing inclusions, including two platy hibonite crystals (PLACs) and four spinel-hibonite inclusions (SHIBs), were studied. There are notable differences in chemical and isotopic compositions between the inclusions (Table 1), indicative of their different formation environment or timing.

Our TEM observations show perfectly-ordered, stoichiometric hibonite crystals without stacking defects in two PLACs, 2-7-1 and 2-8-2, and in three SHIBs, Pmt1-6, 1-9, and 1-10. In contrast, SHIB 1-9-5 hibonite grains contain a low density of stacking defects linked to an increase in MgO contents, indicating complex, disordered intergrowths of stoichiometric and MgO-enriched hibonites. From the data collected to date, we find no clear correlation between the microstructures of hibonite and its morphological and mineralogical types that reflect distinct chemical and isotopic systematics [6-8,10].

Interestingly, the presence of no or few stacking defects in hibonite from the PLACs and SHIBs are in contrast to our experimental studies that produced very high densities of stacking defects in hibonite [3-5]. Unlike our experiments, electron microprobe data from the PLACs and SHIBs hibonite grains show a strong correlation between (Ti^{4+}+Si^{4+}) and Mg^{2+} cations, suggesting that coupled substitutions of (Ti^{4+}+Mg^{2+}) and (Si^{4+}+Mg^{2+}) for $2Al^{3+}$ inhibit the formation of defect-structured hibonite. However, our experimental studies suggest that kinetics (e.g., cooling rate) or other thermal effects also exert a strong control on the microstructures and chemical compositions of hibonite [3-5]. In Pmt1-6, elongated perovskite grains present at the hibonite grain boundaries display (121) twinning, indicative of a fast cooling (>50°C/min) after high-temperature events [11]. Therefore, the nebular microstructural characteristics of hibonite, at least in this inclusion, would not have destroyed by subsequent high-temperature annealing.

Conclusions: Our TEM observations thus far show no clear correlation in microstructures, morphological and mineralogical characteristics, and chemical and isotopic systematics of hibonites from CM chondrites. The observed variation in stacking defect densities in the hibonites may be controlled by thermal processes in the early solar nebula. A detailed TEM analysis of additional CM hibonite samples is underway to evaluate this hypothesis.

Table 1. A summary of inferred $^{26}Al/^{27}Al$ ratios and minor element concentrations from CM hibonite samples studied.

classification	PLAC		SHIB			
inclusion #	2-7-1	2-8-2	Pmt1-6	Pmt1-9	Pmt1-10	1-9-5
$(^{26}Al/^{27}Al)\times10^{-5}$	0.2±0.2	0.0±0.3	2.9±1.4	5.2±1.7	0.66±0.30	not measured
TiO_2 (wt%)	1.9	2.1	1.55–2.05	4.61–5.78	0.79–5.37	3.6–6.7
MgO (wt%)	0.7	0.8	0.76–0.98	2.36–2.96	0.83–2.68	2.0–3.1
stacking defect density	–	–	–	–	–	+

Acknowledgements: This research was supported by NASA grant 14-EW14_2-0122. **References:** [1] MacPherson G. J. (2014) Treatise on Geochemistry II vol.1 pp.139-179. [2] Han J. et al. (2015) MAPS 50:2121-2136. [3] Han J. et al. (2017) 48th LPSC, #2895. [4] Han J. et al. (2016) 47th LPSC, #2848. [5] Han J. et al. (2016) 79th MetSoc, #6534. [6] Kööp L. et al. (2016) GCA 184:151-172. [7] Kööp L. et al. (2016) GCA 189:70-95. [8] Liu M.-C. et al. (2012) EPSL 327-328:75-83. [9] Kööp L. et al. (2016) 47th LPSC, #2005. [10] Ireland T. R. (1988) GCA 52:2827-2839. [11] Keller L. P. and Buseck P. R. (1994) AM 79, 73-79.