

**CONSEQUENCES OF HERCYNITE CRYSTALLIZATION DURING DIFFERENTIATION OF CV CHONDRITE-COMPOSITION PARENT BODIES.** N. G. Lunning, T. J. McCoy, and C. M. Corrigan, Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560-0119, USA. lunningn@si.edu

**Introduction:** Recent findings indicate melting occurred on the CV chondrite parent body. The magnitude of melting ranges from the formation of relatively localized impact melts [1] to the possible formation of a partially differentiated molten interior with a core capable of generating a dipolar magnetic field [2,3]. Previous studies have conducted partial melting experiments on CV chondrite samples, including samples of the Allende meteorite [4]: the aim of these experiments was to examine angrite and eucrite petrogenesis, and thus their primary experimental goal was to produce equilibrium silicate partial melts at varying oxygen fugacities and temperatures. However, to most efficiently achieve silicate equilibrium Jurewicz et al. [4]’s experiments were run for 72-401 hours in a gas-mixing furnace, which lead to complete volatilization/loss of sulfur.

The composition and petrogenetic fate of the opaque components (metals, sulfides, spinel-group minerals) that CV chondrite melts may crystallize remains unexplored. In this work, we present results from preliminary experiments aimed at examining the opaque assemblages in CV chondrite partial melts.

**Methods:** We performed partial melting experiments on chips of the Allende (CV<sub>3oxa</sub> chondrite) and Vigarano (CV<sub>3red</sub> chondrite) meteorites in a Deltech vertical tube furnace at oxygen fugacity of iron-wustite (IW)+1 for 4 hours at 1050, 1100, and 1150 °C. In this abstract, we will focus on the 1150 °C experiments. The durations of the experiments were based on those of [5,6], which retained S.

High-resolution energy dispersive x-ray (EDS) elemental maps and phase data were obtained using the FEI Nova NanoSEM 600 at the Smithsonian Institution. We collected EDS maps using a beam current of 15 kV and 2-3 nA. We used Noran System Six (NSS) software to extract bulk compositional data from select subareas of our EDS maps.

**Results:** Overall, our experiments formed silicate phases similar to those from the 72-hour experiment on Allende powder at 1200 °C and IW+1 by [4] (Table 1).

**Quenched melt:** In our experiments, the quenched silicate melt contains notably higher concentrations of Na<sub>2</sub>O—consistent with better retention of volatile elements compared to Jurewicz et al. [4]’s longer duration experiment. However, in our experimental products the regions dominated by quenched silicate melt have a vesicular texture indicating that some degassing occurred. It is common for these apparent vesicles to be spatially associated with quenched FeNiS liquid (Figure 1), which suggests that S is one of the vesicle-forming volatiles and that S loss remains an issue, even though some S is retained in FeNiS quenched liquids.

**Hercynite (spinel-group minerals):** Both our Allende and Vigarano experiments contain relatively Al-rich spinel-group

minerals (Figures 1-2) which can be broadly described as hercynite FeAl<sub>2</sub>O<sub>4</sub> (more specifically as the hercynite sub-type picotite). The chemistries of these hercynites which crystallized in our experiments are notably different from those of spinel-group minerals found in unmelted CV chondrites, which fall into three main categories: (i) spinel (Mg,Fe)Al<sub>2</sub>O<sub>4</sub> found in refractory inclusions or fragments thereof, (ii) magnetite FeFe<sub>2</sub>O<sub>4</sub> that is thought to have formed during secondary alteration on the CV chondrite parent body, and (iii) chromite (Fe,Mg)Cr<sub>2</sub>O<sub>4</sub> found in chondrules (Figure 3) [7-17].

**Discussion:** Jurewicz et al. [4] posited that the spinel-group minerals crystallizing from CV chondrite melts progressively transition from Cr-rich to more Al-rich in experiments with higher oxygen fugacities through increased activity of FeO resulting from oxidation of the metal. The hercynites in our experiments have a relatively broad chemical range which overlaps the composition of hercynite in the IW+1 experiments of [4] (Figure 3). Additionally, similar hercynitic chromite in CV<sub>ox</sub> chondrite impact melt clasts [1] provide a “ground truth” that the spinel-group minerals in our and previous [4] experiments are relevant to naturally formed CV chondrite melts.

**Implications of hercynite crystallization:** The silicate melt produced at IW+1 in our disequilibrium experiments at 1150 °C and in Jurewicz et al. [4]’s equilibrium experiments at 1200 °C have calculated density ~3 g/cm<sup>3</sup> [method of

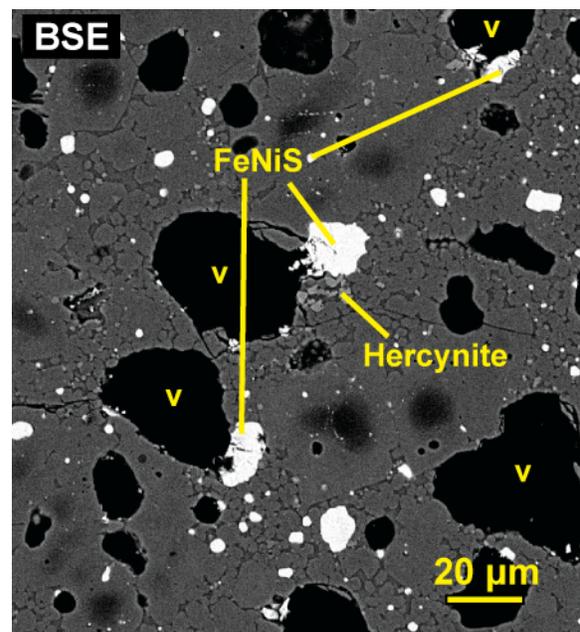


Figure 1: Backscatter electron image (BSE) of charge from this study’s Vigarano 1150 °C at IW+1 experiment. Vesicles (v) are associated with quenched FeNiS liquids.

18,19] (Table 1). In contrast, hercynite is  $4.40 \text{ g/cm}^3$  and for additional context, spinel  $\text{MgAl}_2\text{O}_4$  and chromite  $\text{FeCr}_2\text{O}_4$  are respectively  $3.55 \text{ g/cm}^3$  and  $5.09 \text{ g/cm}^3$  [20]. Even with partial solid solution between spinel and chromite, the hercynites crystallizing in these IW+1 CV chondrite melting experiments have substantially greater density than the silicate melt from which they crystallized. Thus, the hercynite might separate from the less dense silicate melt forming relatively hercynite-rich rock. This scenario provides an alternative petrogenesis for the observed spinel-rich asteroids, which were interpreted as containing higher concentrations of calcium-aluminum-rich inclusions than have been observed in meteorites [21].

Gravitational segregation of hercynite into the lower mantle or outer core during differentiation of a CV chondrite composition planetesimal has interesting potential consequences, which could reconcile some longstanding conundrums of planetesimal differentiation—at least, for differentiation under relatively oxidizing conditions. For one, hercynite potentially sequesters  $^{26}\text{Al}$  (the primary heat source for planetesimal differentiation) in the planetesimal interior to continue driving internal heating. Thus, extraction of partial melts would not carry effectively all of the  $^{26}\text{Al}$  to the exterior of the planetesimal—as is thought to have occurred under more reducing conditions on Vesta [22,23].

**Future Work:** Although some S was retained in the quenched FeNiS liquids in our experiments, textural evidence suggests that S partially degassed. Further experiments are needed to examine the influence S loss has on the activity of Fe and crystallization of hercynite under relatively oxidizing conditions. We plan to conduct additional disequilibrium gas-mixing experiments and equilibrium experiments that will better retain volatiles in sealed vessels (akin to previous experiments at pressures (5-12.5 MPa) consistent with the interiors of 100s-of-km-scale planetesimals [24]).

**References:** [1] Lunning N G et al. (in review) *GCA* [2] Carporzen L et al. (2011) *PNAS*, 108, 6386 [3] Elkins-Tanton et al. L T (2011) *EPSL* 305, 1-10 [4] Jurewicz A J G et al. (1993) *GCA* 57, 2123 [5] Feldstein S N et al. (2001) *MAPS* 36, 1421 [6] McCoy T J et al. (2015) LPS XLVI Abstract #2393 [7] Krot A N et al. (2000) *MAPS* 35, 817 [8] Lee M R. et al. (1996) *MAPS* 31, 477 [9] Murakami T and Ikeda Y (1994) *Meteoritics* 29, 397 [10] Rubin A E (1991) *Am Min* 76, 1356 [11] Allen J M et al. (1978) *Proc Lunar Planet Sci Conf IX*, 1209 [12] Caillet C et al. (1993) *GCA* 57, 4725 [13] Dominik B et al. (1978) *Proc Lunar Planet Sci Conf IX*, 1249 [14] Kracher A et al. (1985) *JGR* 90, D123 [15] Krot A N et al. (2004) *MAPS* 39, 1517 [16] Johnson C A and Prinz M (1991) *GCA* 55, 893 [17] Haggerty S E and McMahon B M (1979) *Proc Lunar Planet Sci Conf X*, 851 [18] Bottinga Y and Weill D F (1970) *Am Jour Sci* 269, 169 [19] McBirney A R (2008) *Igneous Petrology* [20] Deer W A et al. (1992) *The Rock Forming Minerals* [21] Sunshine J M et al. (2008) *Science* 320, 514 [22] McCoy T J et al. (2006) *in Meteorites and the Early Solar System II* pp.733 [23] Yamaguchi A et al. (2009) *GCA* 73, 7162 [24] Singletary S and Grove T L (2006) *GCA* 70, 1291

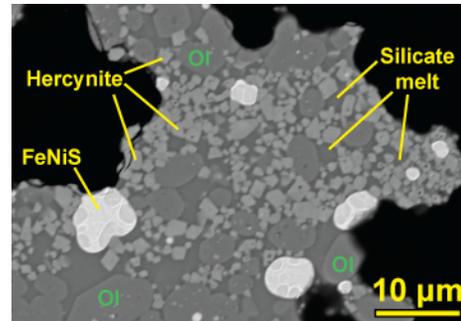


Figure 2: Backscatter electron images (BSE) of the charge from this study's Allende  $1150 \text{ }^\circ\text{C}$  at IW+1 experiment. Images displays a region that is typically hercynite-rich. Olivine microlites (Ol) are present along with the quenched immiscible FeNiS and silicate melts.

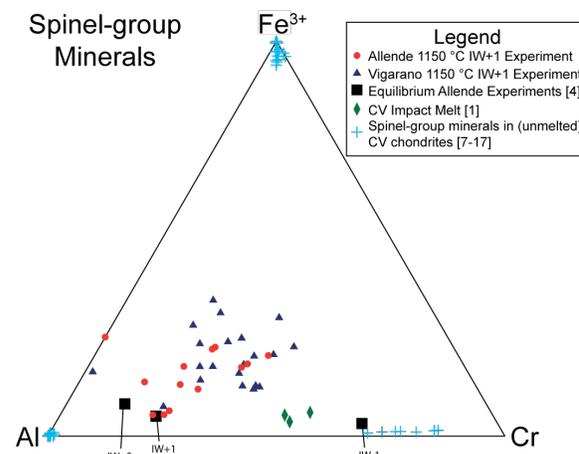


Figure 3: Chemistry of spinel-group minerals. This ternary displays  $\text{Fe}^{3+}$  calculated from chemical analyses based on spinel-group mineral stoichiometry ( $\text{AB}_2\text{O}_4$ ).

Table 1: Composition of quenched melt and olivine microlites. Liquid density calculated using method of [18] updated by [19].

	This work		
	Vigarano	Allende	Allende
$\text{Na}_2\text{O}$	2.08	4.94	0.36
$\text{MgO}$	5.11	3.98	6.08
$\text{Al}_2\text{O}_3$	10.2	12.9	13.1
$\text{SiO}_2$	38.9	39.9	40.1
$\text{P}_2\text{O}_5$	2.00	0.41	0.98
$\text{K}_2\text{O}$	0.12	0.25	n.a.
$\text{CaO}$	14.8	14.9	15.0
$\text{TiO}_2$	1.02	1.11	0.73
$\text{Cr}_2\text{O}_3$	0.13	0.17	n.d.
$\text{MnO}$	0.41	0.24	0.19
$\text{FeO}$	24.3	21.3	22.7
Calculated liquid density at $1150 \text{ }^\circ\text{C}$			
$\text{g/cm}^3$	3.13	2.96	3.07
Olivine microlites from above liquid			
Fo	50-55	55-65	65