

## THE ONSET OF OXIDIZED DIFFERENTIATION: SULFIDE MELTING EXPERIMENTS

S. D. Crossley<sup>1,2</sup>, K. Righter<sup>2</sup>, and J. I. Simon<sup>2</sup> <sup>1</sup>The Lunar and Planetary Institute, USRA-Houston, 3600 Bay Area Blvd, Houston, TX 77058 USA ([scrossley@lpi.usra.edu](mailto:scrossley@lpi.usra.edu), [samuel.crossley@nasa.gov](mailto:samuel.crossley@nasa.gov)), <sup>2</sup>Astromaterials Research Exploration Sciences, NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058 USA.

**Introduction:** The first melts generated at the onset of differentiation in a chondritic asteroid parent body occur within the Fe-Ni-S system [1]. In metal-bearing assemblages (e.g., enstatite, ordinary, and some carbonaceous chondrites), this begins at ~980°C at the FeNi-FeS eutectic [2], but the metal-rich melts produced are physically prohibited from migrating via melt percolation until temperatures exceed the silicate eutectic (>1,050°C) [3]. Consequently, core formation in these asteroidal parent bodies may not occur until extensive silicate melting provides a migratory pathway for immiscible Fe-Ni-S melts [4]. For oxidized chondrites that lack FeNi metal, pyrrhotite (Fe<sub>1-x</sub>Ni<sub>x</sub>S) and pentlandite (FeNiS) dominate the Fe-Ni-S system, but little is known about how these phases begin melting in an asteroidal setting [5]. Previous experimental work has found that sulfide melts with high anion/cation ratios (≥1) are capable of migrating along solid silicate grain boundaries via capillary action [e.g., 6]. If the Fe-Ni-S melts generated within oxidized chondritic asteroids occur under high anion/cation conditions, then oxidized, sulfide-dominated core formation may begin earlier than metal-rich core formation. This sulfur-rich melt would form prior to silicate melting at temperatures as low as 865°C, when pentlandite begins to melt [7]. We are conducting a series of low-pressure melting experiments with Rumuruti (R) chondrite analogues to investigate the melting behaviors of pentlandite-pyrrhotite assemblages in oxidized asteroids.

**Methods:** All experiments and analyses were conducted at JSC ARES, apart from initial SEM/EDS analyses, which were conducted at the LPI SEM Facility. Pentlandite and pyrrhotite were synthesized from metal and S powders in evacuated silica tubes following methods in [8-9]. Synthesized sulfides were mixed with San Carlos olivine to proportions of 90 vol% olivine, 5 vol% pentlandite, and 5 vol% pyrrhotite to approximate the silicate/sulfide ratio of R chondrites [e.g., 10]. Experimental mixtures were placed in an alumina crucible, then sealed in an evacuated silica tube. Oxygen fugacity was constrained using a solid Ni-NiO (NNO) buffer, concordant with the most oxidized R chondrites [e.g., 11]. The experimental assembly was placed into a box furnace and brought to 1,050°C to simulate sulfide melting up to the chondrite silicate eutectic at 1atm. After 48 h, the assembly was removed from the furnace and quenched in water. The alumina crucible containing the experiment was extracted and analyzed with  $\mu$ -XCT to investigate formation of interconnected sulfide melt networks. A separate melting experiment was run at the same conditions with only the two sulfides to investigate diffusion of Ni between liquid and residual sulfides. This experiment was extracted, mounted in epoxy, polished, and then analyzed with EDS and EMPA.

**Preliminary Results & Discussion:** As observed in  $\mu$ -XCT scans, both sulfide phases in the first experiment at 1,050°C and NNO have completely melted. Sulfide melts mantle olivine grains and in some regions form interconnected melt networks. These preliminary results support the potential for transportation of sulfide melt phases prior to the chondritic silicate eutectic. However, the complete melting of sulfides at these conditions was unexpected and requires further investigation. Previous experimental work with terrestrial pentlandite and pyrrhotite have found that residual Ni-poor pyrrhotite would remain extant until ~1,150°C [7]. Preliminary EDS analyses of the separate sulfide melting experiment containing only pentlandite and pyrrhotite found that Ni diffuses into residual pyrrhotite (up to ~5 wt%), which would lower its melting point. Consequently, the complete melting of pyrrhotite in our experiments may be attributable to Ni diffusion from liquid FeNiS into pyrrhotite, oxygen diffusion into sulfides at the imposed NNO oxygen fugacity [6], and/or diffusion of metal cations into San Carlos olivine. These factors will be assessed through subsequent EMPA of the olivine-sulfide melt experiments.

**Ongoing Work:** The current series of experiments includes temperatures down to 900°C, as well as a corresponding series of experiments at lower oxygen fugacity (IW). These findings will be used to determine relevant parameters for siderophile and chalcophile element partitioning experiments for investigating the extent of oxidized, sulfide-dominated core formation among the meteoritic record.

**References:** [1] Mittlefehldt D. W. et al. (1996) *GCA* 60:867-882. [2] Kullerud G. (1963) *Carnegie* 62:175-189. [3] McCoy T. J. (2006) *Meteorites II*, 733-745. [4] Taylor G. J. (1992) *JGR: Planets*, 97:14717-14726. [5] Crossley S. D. et al. (2020) *MAPS*, 55:2021-2043. [6] Gaetani G.A. & Grove T. L. (1999) *EPSL*, 169:147-163. [7] Kitakaze A. et al. (2016) *Canadian Min.*, 54:1175-1186. [8] Ebel D. S. & Naldrett A. J. (1996) *Econ. Geol.*, 3:607-621. [9] Konkana B. et al. (2016) *Nature Comm.*, 7:1-8. [10] Bischoff A. et al. (2011) *Geochemistry*, 71:101-133. [11] McCanta M. C. et al. (2008) *GCA*, 72:5757-5780.