CM2 to CM1 IRON SULFIDES, FROM PRIMARY NEBULAR TO ALTERED ASTEROIDAL

S. A. Singerling[1,*], C. M. Corrigan[2], and A. J. Brearley[1]. [1]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131. [2]Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560-0119, USA. [*]Email: ssingerling@unm.edu.

Introduction: Iron sulfides, minor but ubiquitious phases in carbonaceous chondrites, are often considered to be secondary phases, having formed on asteroidal parent bodies from the interaction of water with primary condensate Fe,Ni metal and/or troilite [e.g., 1-3]. However, recent studies have proposed that a population of sulfide grains in the least-altered CM chondrites are primary, having formed in the solar nebula by sulfidization [4] or crystallization [e.g., 4-8]. This study acts as a capstone, synthesizing our observations of these iron sulfides from their primary characteristics in the least-altered CM2 chondrites to their remnants and alteration products in the heavily-altered CM1 chondrites. These primary iron sulfides and their alteration products provide a link between nebular processes and those operating on parent bodies, shedding new light on solar system formation and evolution.

Methods: The meteorites studied, in order of increasing alteration, include: CM2s QUE 97990, Murchison, Murray, Mighei, CM1/2s ALH 83100, 84029, 84034, 84049, LAP 031166, and CM1 MET 01073. We used the FEI Nova NanoSEM 600 (NMNH) for microscopic-scale imaging, the FEI Quanta 3D Dualbeam® FEGSEM/FIB (UNM) for preparation of FIB sections, the JEOL 8200 EPMA (Institute of Meteoritics) for major/minor element compositional work, and the JEOL 2010F FEGSTEM (UNM) for submicron-scale imaging and X-ray microanalysis and mapping.

Results: The primary iron sulfides observed in the least-altered CM2s include the sulfide-rimmed metal (SRM) grains and the pyrrhotite-pentlandite intergrowth (PPI) grains. The SRM grains are observed only in the matrix and are characterized by an Fe,Ni metal core rimmed by sulfide, sometimes displaying pyrrhotite-pentlandite exsolution. The PPI grains are observed in type IIA chondrules and in the matrix. They are dominated by pyrrhotite with lesser amounts of pentlandite occurring as exsolution textures including patches, blades, lamellae, and submicron rods.

In the more moderately-altered CM2s, the SRM and PPI grains are still observed, but often contain evidence of aqueous alteration. They include the porous, pitted pyrrhotite-pentlandite (4P) grains, PPI altered (alt) grains, and SRM altered (alt) grains. The 4P grains consist of pyrrhotite, containing extensive, sub-micron porosity that appears to be crystallographically-controlled, along with remnant pentlandite exsolution. The PPI alt grains contain pyrrhotite with pentlandite exsolution, where the pyrrhotite shows alteration to magnetite or phyllosilicates. The SRM alt grains consist of Fe,Ni-metal cores rimmed by sulfide, where the metal shows alteration to tochilinite.

In the heavily-altered CM1(/2)s, no remnants of the SRM grains are observed, but several textural groups likely represent the remnants and alteration products of the PPI grains. They include the porous, pitted pentlandite (3P) grains, pyrrhotite+pentlandite+magnetite (PPM) grains, and pentlandite+serpentine (PS) grains. The 3P grains are composed solely of pentlandite with crystallographically-controlled, sub-micron porosity, similar to that in the 4P grains. The PPM grains contain relict primary pyrrhotite with pentlandite exsolution, as well as magnetite veining in the outer portions of the grain with associated secondary pentlandite. The PS grains contain relict pentlandite exsolution as well as serpentine with associated clusters of secondary rod-form pentlandite.

Discussion: Both textural and compositional data support the hypotheses that: 1) the SRM grains formed by sulfidization of Fe,Ni metal by H_2S gas in the solar nebula, and 2) the PPI grains formed by crystallization of sulfide melts produced during the chondrule formation event(s). The Fe,Ni metal of the SRM grains was readily altered to tochilinite, and so, only survived in the least-altered CM2s. The pyrrhotite of the PPI grains was unstable under specific geochemical conditions and altered to magnetite (PPI alt grains), phyllosilicates (PPI alt grains), and secondary pentlandite (4P grains) in the moderately-altered CM2s. At an advanced stage of alteration, such as that experienced by the CM1(/2)s, the pyrrhotite of the PPI grains was unstable under the typical alteration conditions of these meteorites and altered to secondary pentlandite (3P grains) or to magnetite with associated secondary pentlandite (PPM grains). With changes in fluid compositions, the secondary magnetite altered to serpentine (PS grains). It is important to note that our observations do not argue for a link between the CM2 PPI alt grains and the CM1(/2) PPM and PS grains, other than that they all formed from precursor PPI grains. Each of these textural groups records the environmental conditions present during formation. Primary grains (SRM and PPI) provide information pertinent for nebular conditions, such as chondrule cooling rates at sub-silicate solidus temperatures (<600°C) and sulfur fugacity. Altered primary grains (4P, PPI alt, SRM alt, 3P, PPM, and PS) provide information pertinent for asteroidal conditions, such as temperature, pH, fO_2, and fluid compositions.

References: [1] Hanowski N. P. & Brearley A. J. (2001) *GCA*, *65*, 495-518. [2] Zolensky M. & Le L. (2003) *LPS XXXIV*, Abstract #1235. [3] Bullock E. S. et al. (2007) *LPS XXXVIII*, Abstract #2057. [4] Singerling S. A. & Brearley A. J. (2015) *LPS XLVI*, Abstract #1059. [5] Brearley A. J. & Martinez C. (2010) *LPS XLIII*, Abstract #1438. [6] Maldonado E. M. & Brearley A. J. (2011) *LPS XLII*, Abstract #2271. [7] Harries D. & Langenhorst F. (2013) *MAPS*, *48*, 879-903. [8] Schrader D. L. et al. (2016) *GCA*, *189*, 359-76.