# MICROSTRUCTURE OF A PYRRHOTITE-PENTLANDITE INTERGROWTH IN LL6 SAINT-SÉVERIN

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**Introduction:** The compositions, textures, and crystal structures of sulfides can be used to constrain oxygen fugacity, aqueous, thermal, and cooling history [e.g., 1–5]. The most abundant sulfides in extraterrestrial samples are the pyrrhotite group sulfides troilite [FeS] and pyrrhotite [$(Fe,Ni,Co,Cr)_{1-x}S$], which can occur with pentlandite [$(Fe,Ni,Co,Cr)_{9-x}S_8$]. Recent geothermometry of pyrrhotite-pentlandite intergrowths shows that most formed via primary cooling from high temperature or thermal metamorphism [e.g., 6–8].

Sulfides are present in both returned samples and meteorites, and their comparison may yield valuable insights. Analyses of Hayabusa particles have identified asteroid Itokawa as LL5–6 chondrite material [e.g., 9,10], thermally metamorphosed between ~780 and 840°C (via two-pyroxene thermometry; [9]). Sulfides were observed in Hayabusa particles [9], and may record additional information on the formation conditions of asteroid Itokawa. The LL6 chondrite Saint-Séverin was metamorphosed at a temperature similar to that of Hayabusa particles (899±70°C; also via two-pyroxene thermometry [8]) and sulfides in the LL4–6 chondrites equilibrated between 600 and 500°C, consistent with formation during cooling after thermal metamorphism [8]. The equilibrated LL chondrites were heated for 10 to 100 Ma [11], and so low-temperature annealing may also have played a role in their sulfide equilibration. Therefore, to determine microstructural indicators of formation in sulfides from LL chondrites, we studied the microstructure of a pyrrhotite-pentlandite intergrowth in the LL6 chondrite fall Saint-Séverin.

**Samples and Analytical Procedures:** A sulfide grain (dimensions: 81 × 55 µm) consisting of pyrrhotite and pentlandite in Saint-Séverin USNM2608-3 was selected for analysis. Its chemical composition was studied with the Smithsonian Institution JEOL 8900 Superprobe electron probe microanalyzer (EPMA, [8]) and the University of Arizona (UAz) Cameca SX-100 EPMA. X-ray element maps and high-resolution images were obtained with the FEI Helios NanoLab 660 focused-ion-beam scanning-electron microscope (FIB-SEM) at UAz. The FIB-SEM was also used to extract a 10 × 5 µm section transecting the pyrrhotite-pentlandite interface within the sulfide grain, which was thinned to electron transparency (<100 nm). The FIB section was then analyzed using the newly installed 200 keV Hitachi HF5000 transmission electron microscope at UAz.

**Results:** Pyrrhotite composition ranges from 61.8 to 63.7 wt.% Fe, 36.4 to 37.1 wt.% S, and below detection limit (bdl; 0.04) to 0.11 wt.% Ni (n=4). Analyses are Fe deficient compared to stoichiometric FeS, with atomic Fe/S ratios that range from 0.96 to 0.99. In comparison, pentlandite contains 43.0 to 45.1 wt.% Fe, 33.1 to 33.7 wt.% S, 20.5 to 21.0 wt.% Ni, 0.52 to 1.01 wt.% Co, and bdl (0.08) to 0.12 wt.% Cu (n=8) [8, this study].

The FIB section transects the pyrrhotite-pentlandite interface, and contains pyrrhotite and a monocrystaline grain of pentlandite. The pyrrhotite grain is transected by a grain boundary, and selected area electron diffraction (SAED) patterns show the pyrrhotite on either side of this boundary to be very closely oriented. SAED patterns acquired from both regions most closely index to 2C pyrrhotite (hexagonal), also known as troilite [e.g., 12]. Since the pyrrhotite is not stoichiometric FeS, additional SAED patterns at more than one orientation are needed to confirm troilite or another pyrrhotite structure. SAED patterns of the pentlandite grain index to the face-centered cubic structure of pentlandite.

**Discussion:** The sulfide microstructures are consistent with that expected from the equilibration temperature determined by pyrrhotite-pentlandite geothermometry [8]. Terrestrial pyrrhotite occurs in hexagonal or monoclinic crystal structures, while troilite is only present in the hexagonal form [1,4]. At temperatures <584°C, pentlandite adopts a face-centered cubic structure [13], whereas between ~584 and 865°C, it assumes a primitive cubic structure [14]. Therefore, the microstructure of the pyrrhotite-pentlandite intergrowth is consistent with geothermometry [8], and indicates formation during cooling after thermal metamorphism between ~584 and 500°C. Data from more sulfides in Saint-Séverin and additional LL chondrites are underway for comparison to Hayabusa sulfides.

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