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Sulfides in Aqueously Altered Carbonaceous Chondrites: Parent Body vs. Nebula Processes

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CM1 lithologies in the unique Kaidun meteorite contain pentlandite veinlets and masses of euhedral pyrrhotite crystals (Zolensky et al. 1996). The textural relationships among pyrrhotite aggregates and pentlandite veinlets as well as their light sulfur isotopic compositions (McSween et al. 1997) strongly support the formation of these sulfides in a parent body under hydrothermal conditions at up to 450 °C.
On the other hand, typical CM2 chondrites altered below 100 °C contain complex Fe,Ni sulfide grains, which show signs of dissolution, indicating that Fe,Ni sulfides were partially unstable under alteration conditions of the parent body (Maldonado and Brearley 2011). Moreover, exsolution textures of pyrrhotite, troilite, and pentlandite indicate formation temperatures above 300 °C. Therefore, dissolution and microtextures suggest that Fe,Ni sulfides in CM2 chondrites did not form on the parent body but rather in the solar nebula.
In order to elucidate sulfide genesis in hydrous carbonaceous chondrites we conducted FIB-TEM studies of Fe,Ni sulfides in in a CM1 clast of Kaidun (sample 56.01) and in the CM2 chondrite Yamato (Y-)791198.

The Kaidun CM1 clast studied by Zolensky et al. (1996) and McSween et al. (1997) contains lath-shaped Fe,Ni sulfide crystals often enclosed in phyllosilicate sheaths. TEM shows that these 'crystals' consist of nanoscale troilite and pentlandite, exsolved from Fe-rich NC-pyrrhotite (~Fe0.92S). In some parts of the crystals pentlandite did not exsolve and the host pyrrhotite remained Ni-rich (~2.6 wt% Ni).
In Y-791198 two types of Fe,Ni sulfides occur. Common are anhedral grains containing pentlandite and troilite intergrown with Fe-rich NC-pyrrhotite grains (~Fe0.92S). This 'M-type' sulfide represents exsolved, once monocrystalline monosulfide solid solution (MSS) described from other CM chondrites (e.g., Maldonado and Brearley 2011). In addition, we also found polycrystalline, porous, and often concentric sulfide aggregates containing pentlandite, Fe-poor 4C-pyrrhotite (~Fe0.875S), and magnetite as principal phases. This 'P-type' sulfide apparently never existed as a homogeneous MSS phase.

The hydrothermal Kaidun sulfides resemble mineralogically the M-type sulfides of Y-791198, but are morphologically very different. They must have formed above the pentlandite-pyrrhotite solvus at > 300 °C. The same applies to M-type sulfides of Y-791198, but their mineralogical context excludes parent body formation as outlined above. The P-type sulfides of Y-791198 appear texturally compatible with hydrothermal alteration products, but Fe-poor 4C-pyrrhotite requires high sulfur fugacity and temperatures > 400 °C to be stable relative to pyrite and, hence, points to formation in the solar nebula.
Comparison of Kaidun and Y-791198 sulfides shows that defining criteria for sulfide formation may be difficult to establish without contextual information. However, based on phase relations and thermochemical considerations valuable information about settings and conditions of sulfide formation in the early Solar System may be derived.

References:
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