New high-pressure minerals in iron meteorites

K.D. Litasov[1]*, S.N. Teplyakova[2], A. Shatskiy[1]

[1]Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, 630090, Russia
[2] Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Moscow, 119334, Russia

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*e-mail: klitasov@igm.nsc.ru

The shock-melt veins and high-pressure minerals are common in chondritic and rare in other types of meteorites including martian and lunar samples. Shock-induced deformations, melt pockets, and other microstructural features are also common for iron meteorites. However, there were only few finding of high-pressure minerals, including stishovite in IVA iron meteorite Muonionalusta [1], $(Fe,Ni)_2P$-allabogdanite in anomalous Ni-rich ataxites Onello, Santa Catharina and Barbianello [2-3] and tuite in IIE iron Elga [4]. Here we report new evidences for high-pressure microstructures in IIE iron Elga, made of Fe-Ni-P-S aggregates, which could be formed only at high pressures and temperatures according to the experimental phase diagrams.

Elga represents IIE iron meteorite group, which contain 5-20% of silicate inclusions in the metallic matrix [4-5]. The metal part includes kamacite with rare taenite inclusions and abundant zones with plessite textures. Large rounded troilite and irregular schreibersite $(Fe,Ni)_3P$ inclusions are abundant. Rounded or irregular shape silicate inclusions can be divided into three major types: 1) silicate glass with abundant large Cr-diopside and minor small enstatite crystals; 2) silicate glass with tiny quenched crystals of enstatite, plagioclase and silica phases; 3) silicate/phosphate inclusions with liquid immiscibility. Major phases of silicate inclusions are Cr-diopside and enstatite, accessory minerals are represented by chromite, ilmenite, rutile, armalcolite, aenigmatite, and phosphate minerals. Solidified shock melt is represented by immiscible fine-grained mixture of silicate-phosphate and metallic parts. The metal captured to shocked zone appears as Fe-Ni-P or Fe-Ni-P-S-bearing symplectite-like or cryptocrystalline melt pockets. Tuite was identified by Raman spectroscopy in shock-melted zones at the boundary of silicate inclusions [4].

Various Fe-Ni-P-S melt pockets can be subdivided into the following types according to the bulk composition: (a) FN3 – corresponding to stoichiometric $(Fe,Ni)_3(P,S)$; (b) FN2 – corresponding to stoichiometric $(Fe,Ni)_2(P,S)$; (c) FN3-Ox – partially oxidized $(Fe,Ni)_3(P,S)$; (d) FN2-Ox – partially oxidized $(Fe,Ni)_2(P,S)$; (e) FNX – other compositions with the P and S contents deviating from stoichiometric proportions; and (f) FNX-Ox – partially oxidized $(Fe,Ni)_n(P,S)$.

FN3 appears as micro- or nanocrystalline mixture of two or three phases at the boundary between schreibersite and troilite, where melt pockets can form zoned patterns with FN2 near troilite and intermediate compositions between FN2 and FN3. They can also form crystal-like aggregates surrounded by a partially oxidized quenched zone with the same composition. The composition of FN3 varies from $(Fe,Ni)_3P_{0.8}S_{0.2}$ to $(Fe,Ni)_3P_{0.4}S_{0.6}$. The EBSD data on nanocrystalline aggregates of FN3 and on single crystal-like areas of FN3 indicate presence of a phase with $I\bar{4}$ space group. No troilite can be identified in such aggregates strongly indicating the presence of crystalline FN3 or nanocrystalline mixture with the FN3 composition. FN2 form micro- and nanocrystalline mixtures of dendritic crystals and appears near the boundary with troilite along with FN3 aggregates or as interstitial pockets in the non-stoichiometric FNX zones. Its composition varies from $(Fe,Ni)_2P_{0.5}S_{0.5}$ to $(Fe,Ni)_2P_{0.2}S_{0.8}$ and it is easy to identify troilite microcrystals by EBSD measurements.

Fe_3P and Fe_3S are isostructural at high pressure and form complete solid solution at P>20 GPa. This may indicate partial solubility of S in Fe_3P at lower pressures. Recently Gu et al. [6] calibrated the pressure dependence of S solubility in tetragonal Fe_3P and argued that it can be used as a pressure marker for natural Fe-Ni alloys containing P and S. We applied calibration of Gu et al. [6] to Elga aggregates and argued that most FN3 crystals and nanocrystalline aggregates correspond to the pressures of 10-20 GPa.

The origin of FN2 is not clear at present. Gu et al. [6] reported that Fe_2P dissolves S at high pressures. However, quantitative data on the S solubility in Fe_2P as a function of pressure are not yet available. The close textural relations between FN3 and FN2 in Elga meleorites and the lack of stable sulfides with the Fe_2S stoichiometry in the studied pressure range indicate the possibility of high-pressure origin of FN2. In this regards, the stoichiometric composition of these aggregates may not be accidental.

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