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Occurrence of graphite and sinoite in EL6 chondrites Eagle and Pillistfer

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1. Introduction

Enstatite chondrites are meteorites formed under highly reduced conditions and include two chemically distinct groups: EH (high bulk iron) and EL (low bulk iron) with petrological types ranging from 3 to 6 [10]. Classification for petrologic types developed by [9] and modified by later workers can be applied also for enstatite chondrites. Petrologic type 6 underwent high degree of thermal metamorphosis and is characterized beside other by poorly defined chondrules [6]; [7]. The reduced conditions of formation are reflected also in their mineralogy. They contain enstatite, Si bearing kamacite, Ti-Cr-bearing troilite, (Mg,Mn,Fe)-sulfides [solid solution including niningerite (MgS), alabandite (MnS) and keilite ($Fe_{>0.5}Mg_{<0.5}S$)] and oldhamite CaS ([10] and references therein). Recently, the study of enstatite chondrites has been focused on revealing their thermal history; especially on confirmation or disproving of shock melting processes ([1]; [2]; [7] and references therein).

2. Materials and methods

Fragments approximately 13 mm wide and 6 mm high of Eagle and Pillistfer meteorites were embedded into epoxy resin to produce polished sections. These were examined with reflected light microscopy and analytical scanning electron microscopy. Phase identification was performed by Raman microspectroscopy.

3. Results

Mineralogy of both meteorites is similar. No chondrules were observed in samples. Their matrix consists of mainly euhedral or subhedral grains with partially rounded edges of enstatite of almost pure end member composition with small amounts of CaO. Minor phase is plagioclase which occurs as irregular anhedral grains occasionally enclosing rounded grains of enstatite. Chemical composition is close to albite end member. Occasionally, silica-rich phase with minor amounts of Na, Al and Fe occurs along the grain boundaries of euhedral enstatite, plagioclase and/or metal/sulfide aggregates. Small (up to 10 µm) droplets of this silica-rich phase are also associated with metal and sulfide droplets. In addition to that, in Pillistfer, silica-rich phase forms some sort of dendritic structures with metal and schreibersite or sulfides. Silica-rich phases in both meteorites were identified as tridymite and cristobalite. Subhedral grains of sinoite appear in association with dendritic structures. In Eagle, sinoite occurs as subhedral grains in association with plagioclase and enstatite in matrix. Rarely, sinoite also appears as euhedral inclusion in troilite. Metal is Si-bearing kamacite (Si ~ 1 wt %; Ni < 6 wt % for both meteorites). Kamacite particles have irregular shapes partly rounded with embayed rounded enstatite grains in association with schreibersite and sulfides. In Eagle, kamacite rarely contains inclusions of more Ni rich parts (Ni up to 16 wt %). Kamacite in both meteorites contain inclusions of rounded grains of enstatite and graphite of various morphologies (feathery fan-shaped graphite, graphite chaplets or graphite booklets). Kamacite in Eagle contain more graphite inclusions than Pillistfer. In addition, in Eagle, graphite booklets also appear in silicate matrix. Edges of kamacite grains are slightly oxidized (this phenomenon is more obvious in Eagle, in which some thin veins of (Fe,Ni)-sulfate are observed along the grain boundaries of enstatite). Grain of FeSi was observed in kamacite few microns from such oxidized part. Sulfide minerals in both meteorites include Ti-Cr-bearing troilite (Ti < 1 wt % in both meteorites; Cr < 1 wt % in Eagle, Cr ~ 1 wt% in Pillistfer) with daubréelite exsolution lamellae and ferroan alabandite. In Pillistfer, oldhamite grains are also present.

4. Discussion

The presence of graphite and sinoite as well as euhedral enstatite grains have been presented as one of the possible indicators of impact melting ([4]; [5]; [7] and reference therein). However, temperature of formation of sinoite is similar to metamorphic temperatures expected for EL6 chondrites suggesting formation of sinoite over geologic timescale. The latter suggestion is also supported by the fact that sinoite amorphizes in dynamic events as was experimentally demonstrated by [8], which excludes the impact melting formation [1]. The silica-rich phase reported from other EL6 chondrites corresponds to either tridymite and/or cristobalite [3]. Based on very high stability temperature of cristobalite, which is close to temperatures of liquidus of enstatite chondrites, the formation of cristobalite from primordial EL6 material or derivation from chondrules is suggested. Survival of tridymite and/or cristobalite along the grain boundaries suggests crystallization from melt followed by fast cooling; similar textural context was observed in both studied EL6 meteorites. On the other hand, no shock textures were observed in these samples. Missing indication of shock compression may be due to thermal annealing of EL6 chondrites as was suggested already by [6].

5. Summary and Conclusions

Sole presence of sinoite, graphite and silica-rich phases do not provide an unambiguous evidence for any of the proposed mechanisms of the enstatite chondrite formation. The ultimate decision on the origin of these enigmatic meteorites would deserve more detailed study particularly that focused on isotopic character of graphite and sinoite as has already been demonstrated by [1]. Further, more detailed study focused on chemical composition of metal and sulfides should be carried out. The presented data on mineral chemistry does not seem to support the impact melting theory.

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