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Deformational structures in Pułtusk meteorite

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1. Introduction

The Pułtusk meteorite is an H4-5 breccia [1]. Its shock stage was defined as S3 [2] based on deformation of olivine crystals. However, many petrographic indicators [3] like darkening, glassy melt pockets, pervasive metal and sulfide veins, metal-sulfide nodules or native copper occurrences point to higher shock stage (S4–S6) [2,4,5]. Such discrepancies may result from repeated episodes of shock and annealing. It is suggested that ordinary chondrites may have experienced annealing which obliterated some shock effects in silicate minerals, however the mentioned structures are very likely to survive after annealing [6]. An important question is whether all of these features actually indicate shock or only high temperature strain event. It is known that e.g. darkening may result from high strain-rate deformation without passage of any shock wave or shock waste heat [7,8,9].

2. Preliminary results

Two samples of Pułtusk meteorite were investigated using high-resolution microtomographic technique (voxel size: 20 μm). Thin sections and slabs cut from these specimens were analyzed by optical and electron (EMP, EDS) microscopy.

In the investigated specimens, olivine and pyroxene crystals are irregularly fractured and show undulose extinction of light. Generally, small amount of planar fractures occur. Specimens are brecciated and consist of darkened and light clasts. Interestingly, the more equilibrated H5 clasts are elongated and present only inside the darkened parts. At the boundaries of the dark and light clasts, metal veins/sheets or silicate glass with dispersed troilite dendrites occur. Some shear zones in the light parts are very distinct. There are also abundant chromite-plagioclase assemblages which concentrate either near clasts' boundaries or close to the shear zones.

2.1 Darkening, shearing and frictional melting

The darkened clasts make wedge-like structures in the light ones or enclose the rounded light clasts. Boundaries of clasts are sharp and straight. The wedge-like structures fit the definition of pseudotachylites [9]. Their fine-grained, silicate matrix is cataclastic. Chondrules in side of dark clasts are elongated. No difference in chemical composition of olivine and pyroxene grains in the darkened and light parts exists. Some of them form ~200 μm wide glassy sheets of plagioclase–diopside composition (tab. 1) with relict olivine and some orthopyroxene crystals and troilite dendrites (fig. 1a). No FeNi particles are present in them. Very thin troilite veinlets projected into the darkened portions. Moreover, some boundaries are marked by metal-sulfide sheets. In other portions of the studied specimens intergrowths of troilite and FeNi form blebs in small melt pockets, in the vicinity of which mean Ni content in FeNi grains is 32,8–52,2 wt. % (fig. 1b).
In the light parts, distinct shear zones cut through chondrules, silicate and phosphate grains (fig. 1c). Slip surfaces are well-defined and displacement is ~0,1 mm or more. They continue as opaque veins with dispersed blebs of metal and troilite embedded into silicate glass.

Since troilite, plagioclase and diopside are the first phases to melt during friction [7] and olivine is the most resistant phase, it seems very likely that glassy veins on boundaries of clasts come from frictional melting and no eutectic melting of Fe–Ni–S occurred. The cataclastic texture of the darkened clasts is in good agreement with high strain-rate shearing rather than shock processes.

Tab. 1. Mean chemical composition of glass making opaque veins on the boundaries of light and dark clasts

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
56,92±4,63	0,21±0,19	12,16±7,49	0,23±0,22	3,31±1,68	0,19±0,11	7,77±5,21	9,01±8,54	35,37±3,13	0,59±0,38

2.2 Metal nodules and chromite-plagioclase assemblages

Kamacite (6,7±0,2 %wt. Ni) nodules only occur in the darkened clasts. They seem to be plastically elongated along the shear and frictional zones. Metal particles (kamacite and taenite) around the nodules are reduced in grain size but not dispersed in the matrix.

Ubiquitous chromite-plagioclase assemblages (~80–180μm) gather at shear zones in light parts (fig. 1c) or at boundaries of the light and darkened clasts (fig. 1b). Subhedral to anhedral chromite grains (~1–20 μm) are embedded into plagioclase glass. In the chromite grains, varying concentrations of FeO (24,7–29,2 wt. %), MgO (2,4–5,6 wt. %), TiO_2 (1,4–2,7 wt. %) and Al_2O_3 (5,8–7,7 wt.%) suggest that they crystallized from a plagioclase-rich melt.

Since plagioclase has a low impedance to shock compression [10], it is suggested that heat from the plagioclase melt triggers melting of adjacent chromite grains. However, plagioclase melts easily also during friction, so that the heat required to melt chromite may also be due to friction.

3. Conclusions

In the Pułtusk chondrite, darkening, cataclastic textures, frictional melt pockets and shear zones are interpreted as deformational features produced at high strain-rate shearing rather than by shock processes. Metal nodules and chromite-plagioclase assemblages may have also come from shear and friction rather than shock. They are also found in no-shocked or weakly shocked chondrites (S1–S2) [6] which may only have undergone shear deformation at high strain-rate.

Acknowledgements

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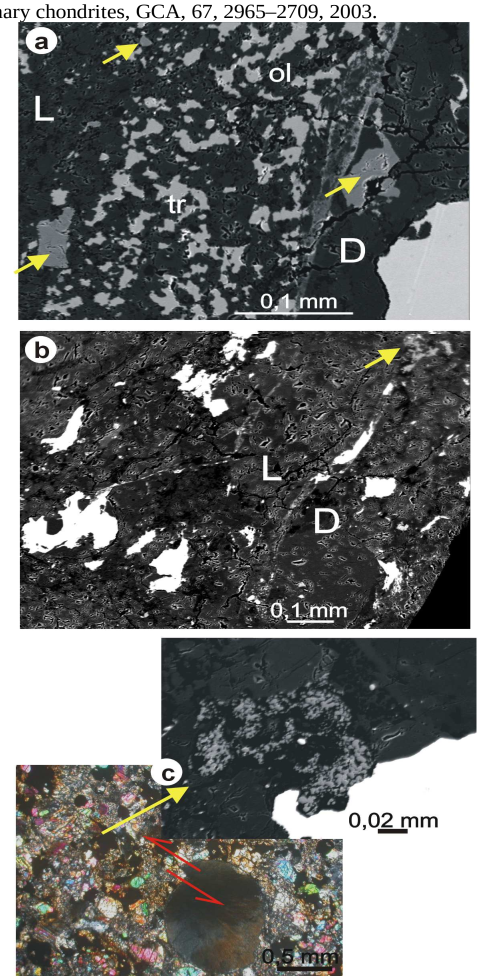

Fig. 1. Frictional boundaries of light (L) and dark (D) clasts, shear zones in light clasts and accompanying structures. (a) Glassy melt sheet with troilite (tr) dendrites and sheared chromite crystal (arrows) at the boundary of darkened and light parts; (b) opaque vein along the boundary of clasts and chromite-plagioclase assemblage (arrow); (c) shear zone in the light part (red arrows) and the chromite-plagioclase surroundings.