OBLIQUE IMPACT–INDUCED (SHOCK–RELATED) SHEARING AND FRICTIONAL MELTING IN PULTUSK (H5) CHONDRITE. A. Krzesinska[1]. [1]Institute of Geological Sciences, Polish Academy of Sciences, Podwale 75, 50–449 Wroclaw, Poland; e-mail: agatakrz@twarda.pan.pl.

Introduction: The Pultusk metorite fell in January 1868 in Poland. It is classified as an H5 ordinary chondrite, however displays a brecciated texture with H4 and H5 clasts [e.g. 1]. It represents shock stage S3 in shock classification [2], based on deformation of olivine crystals, occurrences of opaque veins, and rarely connected melt pockets. Many specimens have discernible dark and light clasts. Darkening may result from dispersion of the metals and sulfides due to shock processes [3] or due to high strain–rate shear deformation [4, 5, 6].

Based on optical microscopy and high–resolution X–ray computed tomographic (CT) images, deformation of meteorite in vicinity of darkened zone was investigated

Description of studied sample: In sample a black vein up to 0,6 mm in width occurs. This vein is pervasive at sample scale and consists of three zones: 1) 10 µm wide domain of <1 µm troilite blebs arranged in net–like manner, embedded in silicate glass 2) 150–200 µm wide zone of ~1µm metal–troilite dendrites and 5–10 µm large, rounded olivine clasts embedded into amorphous glass, 3) 300–500 µm wide zone without chondritic texture, composed mainly of olivine, kamacite and troilite. It has microcrystalline texture with irregular, but elongated metal and sulfide grains. Relicts of larger olivines are visible.
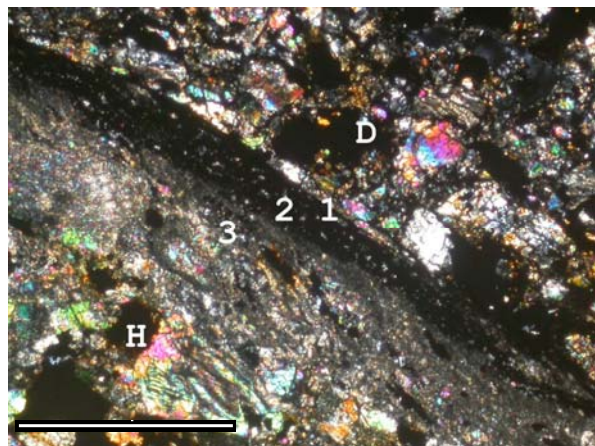

Fig. 1. The boundary of light and dark clasts.
D – darkened zone is; 1– glassy zone with troilite blebs; 2 –melt pocket; 3 – zone of silicate melt; H-light clast (host). Crossed polars, scale bar is 500 µm.

Neither the amorphous glass zone (2) nor zone (3) contain opticaly identifiable high–pressure polymorphs of minerals. Interestingly most of blebs and dendrites in zone (2) are troilitic and metals occur in the achondritic–like zone (3). The two zones continue as a metal–sulfide vein which is visible only on micro–computed tomographic images. All three zones make straight and sharp boundary between light and darkened clasts (fig. 1).

The dark clast makes a wedge in the light one. All boundaries are marked by comminuted metal–sulfides, but only the described boundary shows such a strong deformation. Single chromite grain is cut by amorphous zone and displaced over a distance of 0,1 mm. It is present in darkened clast and in the host, being absent in melt pocket.

The dark clast is composed of olivines, orthopyroxenes, kamacites and troilites, contains relict chondrules and has cataclastic texture. Grains seem to be elongated along the contact with the host. Olivines are mosaic, pyroxenes show undulose extinction, and they have sometimes planar fractures. They have many opaque inclusions. Generally, metal grains are smaller than in the light clast and irregular, but kamacite nodules 1–3 mm large are present. All nodules are also elongated and/or irregular. The matrix is composed of fine–grained silicate grains.

The light clast (host) is typical shock stage 2/3 chondrite. The silicates are moderately shock–deformed. Olivines exhibit undulatory extinction and have a few irregular fractures. Pyroxenes display slightly undulose extinction. Many tiny opaque veins occur. Interestingly, no metal nodules are present in the light clast.
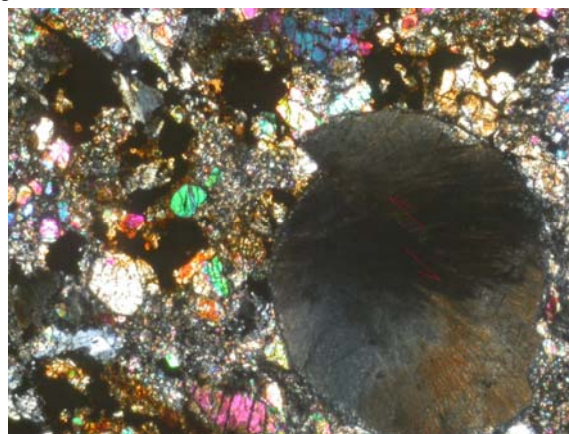

Fig. 2. Radial pyroxene chondrule in the light clast with evidence of shearing. Shear zone cuts across the chondrule displacing also silicate grains in the matrix. Crossed polars, scale bar is 500 µm.

In clast, slip zones occur with dispalcement about 0,1 mm or more. One of these zones cuts a radial pyroxene chondrule and olivine grains (fig. 2). The slip surface is well–defined, however no discontinuity in pyroxene crystals of the chondrule are discernible with the optical microscope. Shear zone is continued in the silicate–metal matrix around the chondrule at a distance of ~0,8 mm. Near this zone olivines may be planarly fractured and are slightly darkened. Beyond chondrule, this zone continues as an ordinary, tiny, black vein. Similar zones are parallel to the one, although less marked. All these zones are parallel to the contact of the light and darkened clasts, and to the elongated melt pocket and achondritic–like zone 3.

Discussion: Pultusk chondrite contains pervasive opaque veins, connected melt–pockets and melted achondritic–like clasts, however its host silicate deformation points at the shock stage S2–S3. In such a case the peak temperature on shocking was insufficient to cause the rock to melt. However melting must have occured as glassy melt pocket and zone with achondritic texture are present. Rubin [7] suggested that ordinary chondrites may have experienced shock deformation followed by annealing, which removed shock features from silicate minerals. The described sample does not exhibit evidence for annealing however.

Similarities between described melt pocket and experimentally generated frictional melts in chondrites [4, 5, 6, 8] suggest that the sample may have undergone high strain–rate deformation and shearing. A cataclastic texture of the darkened clast is consistent with deformation at low–pressure but with high strain–rate. Shearing parallel to the clasts' boundary must have occured in the radial pyroxene chondrule.

The absence of high–pressure polymorphs in melt vein is also consistent with a shear deformation rather than shock. Also, troilite is much more often present in the melt pocket than kamacite. So, in this part the non-eutectic melting must have occurred. During frictional melting, FeS is the first phase to melt [4]. Moreover, it has lower viscosity than FeNi, thus is capable to penetrating into the clasts.

Olivine is also more resistant to frictional melting than pyroxene [9], which would explain why only olivines occur in the melted zones (2) (higher capability of preservation). Taking into account the pressence of the disrupted chromite grain, temperature during frictional melting must have been less than 1600°C, because it was not melted.

Such a texture supports the view that so called shock veins in meteorites may be the results of shear heating rather than of pressure heterogeneites. Of course, shock process seems to be only one probable deformation mechanism on the chondrite parent bodies, so shear deformation must have been a part of these processes. Shearing occurs very likely during oblique impacts [10]. Such oblique collision is favoured in the studied sample, slicate grains are only slightly deformed, which would be consistent with relatively low angle of impact, because pressure decreases with decreasing angle [11]

Conclusions: Pultusk chondrite may be an example of meteorite deformed at high strain–rate impact–related shear deformation not directly associated with a shock wave (without high shock pressures). Melting at the boundary of the clasts was most likely associated with heat resulted from frictional process [8]. This process and cataclastic flow occurred during an oblique collision,

In an ordinary chondrite the presence of melt veins and darkening of clasts do not have to imply severe shock deformation. In fact, high strain–rate deformation at low shock pressures and frictional melting are particularly effective in the formation of opaque veins.

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