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The crust structure of the Morasko meteorite – a preliminary hypothesis

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Abstract

A small piece of the Morasko meteorite, weighing 970 g, yields traces of its journey through the Earth's atmosphere and of its impact into a mineral substrate, such as reflected in the meteorite's crust. This is seen in the crust structure in the form of sintered as well as fusion and semi-fusion layers for which ablative niches are optimum sites. Subsequent weathering processes have resulted in significant mineralogical changes in the crusts. The meteorite crusts originated during polygenetic processes.

Key words: sintered crust, fusion crust, genesis, SEM, EDS

1. Introduction

Meteor fragmentation in the atmosphere results in a number of differently sized objects with a spatially variable surface temperature ranging from very high (in the outermost zone, partly with a fusion film) to extremely low (parts reflecting the temperature of a meteorite's interior). A landed breccia of meteoric matter thermally influenced the sediments at the impact site in very different ways; cold parts even cooled down the surrounding ground. Hot parts were preserved in the form of surviving remnants of the fusion film, generating the fusion layer, while the temperature gradient transmitted to the ground led to the origination of the sintered layer. The potentially optimum places for preservation of the full structure of these impacts, related to ablative niches, were filled with material of the impact site. The secondary explosion on the ground resulted in numerous pieces of shrapnel that were scattered over various distances.

A significant feature of the Morasko iron meteorites is the well-developed, very hard crusts. Usually, their thickness does not exceed several millimetres, but in places it may attain several centimetres. The thickest crusts are found within the deep ablative niches. These very characteristic crusts are usually associated with post-impact weathering processes. In my view, traces of the processes typical of the flight of the meteorite through the atmosphere, and the effects of the impact itself, can be found within the crusts of the Morasko meteorites. The main aim of the present note is to illustrate records of these phenomena.

The very short journey of the meteorite through the atmosphere (a dozen seconds only) caused strong heating of a thin surface layer. Processes of crushing, melting, evaporation and "blow off" of matters particles typically occur here and depressions (referred to as ablative niches; regmaglypts) are generated. An incomplete fusion layer occurs on the surface of the meteorite. This is reflected in a delicate crust as observed, for example, on parts of the Pułtusk stone meteorite, which fell in 1868. Below, part of the description in a bulletin issued by the Warsaw Main School after the event in Pułtusk, is supplied (translated from Polish), "The specimens delivered to the Warsaw Main School were covered with a glassy layer. Each piece was brown and black, and the layer thickness was on average 0.5 mm" (Kamińska, 2009). Pilski (1999) drew attention to the existence of two types of crust in the Pułtusk meteorites, both referred to as fusion crusts. The crust of the first type, black or brown in colour, is slightly matt, its thickness attaining 0.5 mm. The crust of the second type is dark brown to almost black, with a thickness of 0.3 mm. It should be noted that along the line of the crusts and hardly fusible meteoric matter of the Pułtusk meteorites, but also outside it, there is a very thin zone of slightly fused minerals (e.g., pyroxene, olivine). The colour of this zone is brighter than the two previously mentioned types of fusion crusts (Kamińska, 2009). In addition, Pokrzywniki (1972) already noted recognisable envelopes/crusts of meteorites, while analysing meteorites that consisted of matter with varying degrees of fusion. A detailed analysis of the crusts of the Morasko meteorite, mainly of the weathering origin, with a stressed clear fusion layer, was presented by Gurdziel et al. (2012).

As mentioned above, the Morasko meteorites have crusts usually of a few millimetres in thickness, but occasionally they reach several or even a dozen centimetres within the ablative niches. My attempts to determine the age of the crusts meant that not only the entire crusts had to be sampled correctly, but also, and above all, the individual components of the structure. Initial macroscopic observations enabled documentation of the crust's layering structure. A possible record in the crust of the effects of both the flight through the atmosphere (fusion layer) and the thermal effects on the materials of direct impact (sintered layer) is hypothesised. At first, a suitable piece of the meteorite with clearly developed layers of interest could not be acquired. It was only in 2014 when Mateusz Szyszko found a specimen that met these requirements (Fig. 1).

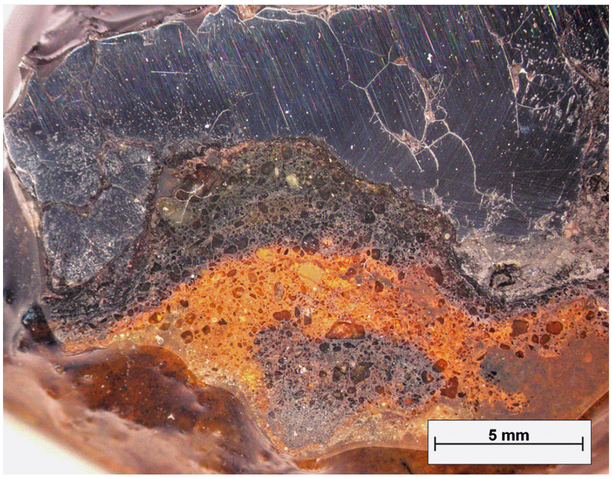

Fig. 1. SEM picture of the 970-g meteorite fragment, with its coating structure (photograph: Dr Monika Nowak).

2. The 970-g-Morasko meteorite

The largest known iron meteorite shower in Europe, observed at Morasko, occurred approximately 5,000 years BP as a result of double fragmentation, i.e., within the atmosphere and after impact on the ground. Craters were created as a result of the explosion (see Pilski & Walton, 1999; Stankowski, 2010; Muszyński et al., 2012; Fedorowicz & Stankowski, 2016). To date, numerous specimens have been documented, with a total weight of approximately 2,000 kg. It is difficult to determine how many fragments of the Morasko meteoric matter have been informally excavated and placed on the international collectors market.

An example of the shrapnel with preserved layers (fusion and sintered) is a part of the meteorite crust with a weight of approximately 970 g, found in 2014 (co-ordinates 52º29.21′ N, 16º53.66′ E, at a depth of 40 cm). I should add that, after meteorite stabilisation on the ground, weathering processes were initiated that continue to the present day. Therefore, existing crusts are characterised by spatially diversified polygenesis.

A macroscopic analysis of the crust structure was the starting point for the interpretation of this shrapnel specimen (Figs 1, 2). First of all, there is a marked spatial variability, revealing its great origin dynamics in the form of areas with a disordered or an ordered structure. The disordered crust structure shows small oval packages and streaks of iron-nickel alloy, non-adherent to the basic mass of meteorite matter. The ordered part reveals the layered character more clearly. It is justified to distinguish a thin fusion layer (2a in Fig. 2), on the surface of iron-nickel alloy (1 in Fig. 2). Outside, there is matter that appears to be connected to the wider fusion zone (2b in Fig. 2). Theoretically, this is an area of spatially small penetration of the molten meteorite matter to sediments at the impact site ("coating"/ flooding of grains). In this case, one can use the term semi-fusion zone. The dynamics of the processes occurring within the "ordered structure" of the crust are proved by the torn-off packages of this specific matter (2c in Fig. 2), also present in the outer layer and referred to as sintered (3 in Fig. 2). The genesis of the unit referred to as sintered is

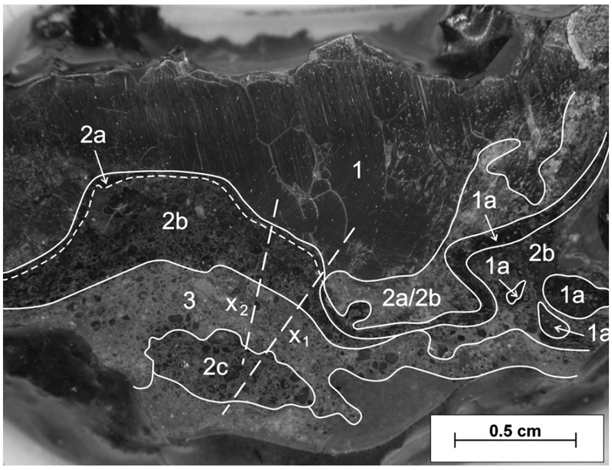

Fig. 2. SEM picture of the 970-g meteorite, with macroscopic interpretation of its coating structure. A portion of this photograph was published in Fedorowicz & Stankowski (2016).
1 – iron-nickel alloy, 1a – destabilised "strand streak" and "packages" of iron-nickel alloy within meteorite coating, 2a – remaining molten area – thin melting/fusion layer, 2b – zone of interaction of molten meteorite matter ("matrix") and material of fall site (grains) = semi-molten layer, 2c – destabilised packages of material 2b in the sintered layer, 3 – sintered layer, x_1 and x_2 – strings of EDS linear measures.

characterised by the thermal gradient of the meteorite impact.

The macroscopic interpretation of the crust structure presented here requires confirmation or rejection of instrumental proceedings. The preliminary EDS chemical analyses were executed at the Scientific-Didactic Scanning Microscopy and Microanalysis Laboratory of Adam Mickiewicz University, using scanning microscopy equipped with a Noran SIX energy dispersive X-ray spectrometer (EDS) microanalyser. For 23 measurements, data on the chemical composition of sub-/semi-quantity percentages, expressed in oxides, were obtained. Six measurements were executed within iron-nickel alloy, four for a clearly emergent thin fusion layer, nine within the semi-fusion zone (six of which related to the observable mineral grains), three to the intergranular matter (specific matrix) and finally four measurements were executed for the sintered layer. The averaged analytical results documented existing real differences between the chosen meteorite crust layers; these are listed in Table 1.

Results of laboratory measurements show geochemical similarities of fusion/molten layer and the "matrix" of semi-molten layer. They are characterised by a predominance of Fe_2O_3 (>81% in average) and considerable or noticeable content of NiO. Moreover, a significant percentage of SiO_3 in the molten layer and in the "matrix" of the semi-molten layer seems to be surprising. However, grains of the semi-molten layer and material of the sintered layer exhibit distinctly different chemical composition. SiO_3 predominates here (>68% on average), with a relatively high (up to 20%) content of CaO and a considerable admixture of Al_2O_3. The mentioned characteristics seem to confirm the former macroscopic identification of a crust-layered structure (Fig. 1). Current research permits hypotheses as to the complex origin of the meteorite crust, where melting and heating processes played a role. The melting process of parent iron-nickel alloy was the most important in the formation of the fusion and semi-fusion layers. Not only was a very thin fusion layer created, but also shallow penetration of molten matter into mineral material of the place of landing occurred ("matrix" in the semi-molten layer). The mineral grains in the semi-molten layer, as well as the outer mineral material were heated. This led to formation of the sinter layer.

Table 1. Chemical composition of the 970-g meteorite – mean indexes, EDS semi-quantitative wt. % data in oxides. tr. – traces.

Sample no.	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Fe_2O_3	NiO	Ta_2O_5	C
nickel–iron alloy (no. 1 on Fig. 2)														
6	–	–	0.4	0.6	0.1	0.1	tr.	–	tr.	–	87.4	11.3	0.1	–
fusion, nickel–iron melt zone (no. 2a on Fig. 2)														
4	–	0.6	1.9	12.6	0.1	–	0.8	0.4	1.2	–	80.0	3.2	0.2	–
'semi–melting' zone (no. 2b on Fig. 2)														
'matrix'														
3	0.3	–	0.6	10.4	–	–	tr.	tr.	0.4	–	85.6	2.2	0.5	–
grains														
6	–	tr.	0.7	75.8	–	1.1	0.6	0.7	15.4	0.1	–	–	–	~5
sinter crust (no. 3 on Fig. 2)														
4	3.2	0.2	11.4	62.2	–	0.5	–	3.8	18.7	–	–	–	–	–

In specific places of the meteoric crusts, it is possible to find records of phenomena associated with the flight and impact of this extra-terrestrial matter. Subsequent weathering processes have undoubtedly led to contamination and modified the output that sintered and fusion structures developed during the impact.

The present study is of a preliminary nature, and certainly requires further detailed research, allowing for a full documentation of existing records of sintered and fusion layers within the crusts of the Morasko meteorite. A presentation of all data will be included in multi-authored papers that contain also detailed microscopic and mineralogical analyses, currently under way (Duczmal & Michalska, in prep.; Stankowski et al., in prep.).

3. Conclusions

The 970-g shrapnel of meteorite matter found in the vicinity of Poznań in 2014 resulted from the Morasko Meteorite fall that become fragmented in an explosion on the ground. Around the iron-nickel alloy, the meteorite crust was formed. The first step involved temperature impact, which makes luminescence dating of the time of the fall possible (Fedorowicz & Stankowski, 2016). The main results of recent research are as follows:

- The shrapnel provides evidence of the meteor's flight through the atmosphere and its impact into a mineral substrate.
- Amongst crust structures, sintered and fusion and semi-fusion layers can be differentiated on the basis of macroscopic analysis.
- Macroscopic distinction of layers is confirmed in EDS analysis as semi-quantitative data of chemical composition. Laboratory results permit the hypothesis that chemical differences between the outer zones of the meteorite reflect preservation of initial crust layers: fusion/molten and sintered ones.
- Post-impact weathering processes resulted in significant mineralogical changes, complicating the identification of layers directly associated with the impact.
- Crusts of the Morasko meteorite are characterised by polygenesis.

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