Magnetic Properties of Impact UHPHT Glasses, Melt Rocks, Suevitic Breccia and Target Rocks of the Giant Kara Meteorite Crater (Pay-Khoy, Arctic Seashore, Russia)

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Abstract. The shock waves can strongly change the physical properties of the target rock minerals including their density and magnetism which determine petrochemical properties of impactites finely as a rule are resulted in astrobleses contours on geophysical maps. Following to the aero-magnetic mapping data the non-magnetic sedimentary rocks of the Kara target create a zero and negative magnetic field with an average intensity of -1 nT, against the background the southwestern region of the Kara astrolsme provides the positive magnetic anomalies with an intensity of 1 to 3 nT which are in a good correspondence with the Pay-Khoy ridge structure general orientation. The Kara dome is characterised with an isometric negative anomaly of intensity -5 nT. Here we present the magnetic properties of the different kinds of the Kara impactites including impact ultra-high pressure high temperature (UHPHT) melt glasses, melt rocks and suevitic breccia compare to sedimentary target rocks. The petrophysical measurements presented the specific magnetic susceptibility of the impactites in the range of 8 to 48×10⁻⁸ SI units, where the UHPHT glasses have the limits from 9 to 38×10⁻⁸ SI units (15×10⁻⁸ SI units, in average). The sedimentary target is characterised with essentially lower level of magnetic susceptibility – no higher than 15×10⁻⁸ SI units, where limestone has it about zero. Following to the similar level of the iron content within the impactites and target rocks the magnetism of the Kara impact melts is explained rather by changing of magnetic properties by the impact process. One of the possible source of magnetism can be partially an iron-containing matter of the asteroid component in the form of pyrrhotine accompanied with Ni and Co impurities. Also, we cannot exclude partial presence of magnetic iron component directly within the quenched impact glasses including UHPHT variety.

1. Introduction

Large impacts provide shock ultra-high high pressure conditions resulted in high temperature melted material partly saved as a melt pull at a crater bottom, partly ejected with back-fall material forming breccia impactites with clastic impact glasses named by suevites, some melted material is spread away from the crater and quenched as natural glasses – tectites forming wide strewnfields to the distance up to several thousand kilometres [1-3]. The impact glasses have specific features including composition and physical properties compare to volcanic glasses [4-7]. Among their characteristics the magnetic properties are the most important for geological mapping of the impact structures [8-13] and can be interesting for specific magnetic materials from impact glasses especially interesting in the context of the recently discovered unusual UHPHT impact melt glasses [5-7]. The Kara astrosme has been studied by industrial geologists at geological mapping and scientific studies [8, 15-19] and it was found
that the impact crater is quite good recognisable by the geophysical data. At the same time, the detailed studies of magnetic properties of the Kara impactites have not been provided except some short preliminary works [20, 21]. The first our petrophysical measurements demonstrate high magnetic properties of the Kara impactites compare to the sedimentary rock target. Here we demonstrate our preliminary results of magnetic studies of the different kinds of target rocks and impactites including impact UHPHT glasses, melt rocks and suevitic breccia. Also, we combine the measurements of magnetic properties with high resolution microscopic observations and petrochemical composition studies for more complex data and analysis.

2. Materials and methods
The material was sampled in 2015 and 2017 at the southern part of the Kara astrobleme (Kara River basin, Pay-Khoy Ridge, Russia, Figure 1, 2). For the studies all general types of the impactites (impact UHPHT glasses, melt rocks and suevitic breccia) and the sedimentary target rocks (aleurolite, limestone, sandstone) have been sampled and crushed to the fraction -2 mm for the specific magnetic susceptibility measurements. The UHPHT glasses preliminary have been selected manually from the host suevitic mass before the crushing to the specimens for the magnetic measurements.

![Figure 1. Geographic position of the Kara astrobleme (red point) on the Google map.](image)

The spatial magnetic features at the territory of the Kara meteorite crater have been created (Figure 2b) on the basis of the air-geophysical magnetic mapping data at the scale 1:200000.

The magnetic measurements were produced with the use of the KAPPABRIDGE KLY-2 facility (Czech Republic), the analysis was provided at the room conditions with the accuracy 2%. Every powder specimen was measured three times for definition of an average value which then was used for the calculation of the specific magnetic susceptibility by the formula (1):

\[ \chi = K \times X \times 10^{-8}/m, \]

where: \( K \) – coefficient to the measurement range; \( X \) – equipment display data; \( m \) – specimen mass, kg. In total more than 200 specimens of the Kara melt and suevitic impactites and the sedimentary target rocks have been measured.
The analysis of probable mineral composition resulting the magnetic properties of impactites has been provided by a complex mineral study. The preliminary research by optical microscopy has been performed using POLAM R-312 polarization microscope (LOMO, Russia) in combination of transparent and reflected light. The used analytical methods included scanning electron microscopy (SEM), electron microprobe analysis (EMPA) and Raman spectroscopy (RS) which have been performed at the Center of collective use of the Institute of Geology of Komi Scientific Center UB RAS (IG FRC Komi SC UB RAS, Syktyvkar, Russia). The bulk chemical composition of the rocks has been measured with wet chemistry analysis. For the detail elemental composition, mineral microparticles presence and spatial relations of mineral phases a scanning electron microscope TESCAN VEGA3 (Czech Republic) equipped by energy dispersive device (Oxford instruments X-Max) has been used. For the SEM and microprobe study we used the large square thin polished sections with the size of 3 cm × 4 cm covered by a conductive carbon layer.

3. Results and discussion

The magnetic properties map of the Kara astrobleme region has been reconstructed on the basis of industrial air-geophysical magnetic mapping data. The characteristic of the magnetic anomalies allows to conditionally divide the research area into two parts – the northeastern higher and southwestern lower values of the magnetic field (Figure 2). At the same time, the magnetic anomalies (Figure 2) have different morphology and chaotic distribution within the impact structure. In the central uplift of the Kara crater, over the cataclized Paleozoic rocks of the basement complex, an isometric negative anomaly of intensity up to -5 nT is observed. The positive magnetic anomalies are shifted to the southwest and northeast and therefore their boundaries do not coincide with the central uplift of the studied Kara impact structure, represented by the fractured rocks of the basement having evidently negative anomaly. Two positive anomalies stand out to the northeast and southwest of the mentioned center of the astrobleme. The southwestern positive anomaly of up to 3 nT intensity is observed over block breccias, megabreccias, clippen breccias and suevites. At the northeast from the crater center, a second positive magnetic anomaly is set having a lower intensity (up to 1 nT) with a smaller area of the anomaly. The latter is located at the area of a negative magnetic field of psammite-aleurite allogeneic breccias – coptoclastites. The both positive magnetic anomalies have a noticeable northwestern orientation (Figure 2b).

The provided studies of measurements of the specific magnetic susceptibility of the Kara impactites and the target rocks have demonstrated observable difference in magnetic properties among the analyzed rocks varieties as for impactites and sedimentary rocks and between their varieties (Figure 3). On the basis of the wide range of the measured specimens (over 200 powder samples) we have constructed the statistical diagram pointing to the specific magnetic susceptibility ranges for the every rock variety. The diagram allows watching the observable magnetic properties difference between the sedimentary rocks of the Kara target and the impactites varieties.

The analyzed sedimentary target rocks have the low level of the range of the specific magnetic susceptibility (Figure 3) getting just 15×10⁻⁸ SI units in the maximum data (and no higher than 10×10⁻⁸ SI units in overage) and around 0 level from the other range side.

The highest level of the specific magnetic susceptibility belongs to the bulk clast-poor impact melt rocks getting up to 50×10⁻⁸ SI units (28×10⁻⁸ SI units in overage) (Figure 3). Such a high level of the magnetic properties could be explained with changing of the magnetic properties of the Fe-containing minerals including newly formed minerals, for example, formation of the Fe-Ti micro-phases spread through the bulk impact melt rock (Figure 4), and, probably magnetic Fe within the general melt rock matter, which is a subject for the future high resolution microscopic and spectroscopic studies.
Figure 2. The geological position of the Kara Meteorite Crater on the Geological Map of the Russian Federation, R-41, Amderma, scale 1:1000000 [18] (a). Magnetic field intensity of the Kara astrobleme region (b). Legend: general structural boundaries at the Kara astrobleme: Kara crater boundary (1), central uplift (2), redeposited impactites (3); characteristics of the magnetic field by the intensity levels of $\Delta T$, anomalies – negative (4), neutral (5), positive (6).

Figure 3. Specific magnetic susceptibility of the Kara impactites and the target rocks: 1 – UHPHT impact melt glass, 2 – suevitic breccia, 3 – bulk melt rock, 4 – mega-breccia, 5 – aleurolite, 6 – limestone, 7 – marble-like carbonate rock, 8 – sandstone.
Figure 4. FeTi phase (white elongated microcrystals) within the bulk impact melt rock. Polished melt rock specimen, SEM image in BSE mode.

The UHPHT impact melt glasses have the wide range of the specific magnetic susceptibility, also getting high data up to $37 \times 10^8$ SI units ($15 \times 10^8$ SI units in average). The latter points to the irregular specific magnetic susceptibility of the UHPHT impact melt glasses, probably connected with their different conditions of their PT-conditions quenching with varying level of liquation and crystallization differentiation of the impact melt.

Within the UHPHT impact melt glasses of the vein-like morphology described in detail in (Shumilova et al., 2018, 2019, 2020) we have found numerous particles of pyrrhotite (Figure 5) usually enriched in Ni and Co impurities up to the first percents. The provided in-situ diffraction measurement with electron backscatter diffraction (EBSD) allowed recognize a magnetic variety of the pyrrhotite particles. Thus, for the UHPHT impact melt glasses we propose possible input of the magnetic pyrrhotite to the measured specific magnetic susceptibility of the UHPHT melt glasses.

4. Conclusions
By the provided studies of petrophysical properties of the Kara impact melt varieties we have found that they are characterised with higher magnetic properties compare to the sedimentary rock target presented with aleurolites, limestones, marble-like carbonate rocks and sandstone. The magnetic features of the impact rocks can be explained by partial participation of the asteroid input with the additional portion of magnetic iron in the pyrrhotite mineral form and some newly formed Fe-containing phases such as FeTi alloy spread through the bulk melt impact rocks. At the same time, it is evidently need to continue the started magnetic studies for more full information about the giant impact effect to changing of the magnetic properties of the sedimentary target rocks including possibility of large-scale mapping in the magnetic properties mode. The latter will be informative for better understanding of the impactites
varieties distribution through the giant Kara astrobleme including recently discovered bottom flow suevites with the large portion the UHPHT impact melt glasses with coesite.

Figure 5. Pyrrhotite (light particles) in the UHPHT impact melt glass. Polished thin section. SEM data: BSE image (left), SE image (right).

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