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Comparative Characteristics of Structural-Textural, **Mineralogical and Petrochemical Features of Melt Rock** Impactites of the Kara Astrobleme. Preliminary Data (Pay-Khoy, Russia)

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Abstract. The Kara astrobleme is one of the largest astroblemes known on land. Its diameter is \sim 65 km, the age is about 70 million years. The astrobleme is located at the northeastern part of the Pay-Khoy anticlinorium at the Kara River mouth region (Kara Sea coast, Russia). It is a unique object of impact genesis due to the presence of a variety of suevites and melt impactites. Melt rocks are products of the highest degree of impact transformation of target rocks. The diversity of melt rock impactites of the Kara astrobleme and obtaining their complex comparative mineralogical and petrochemical characteristics are important for solving the fundamental problem for studying of the typomorphism of the impactitogenesis products of melt rocks both - the impactites of the Kara astrobleme and other astroblemes in general. In the Kara astrobleme region there are at list two different types of massive melt rocks bodies - a cover melt rock at the Anaroga River (I) studied by previous researchers and an unexplored body of melt rock impactite at the Kara River (II) spatially connected with ultrahigh-pressure high-temperature (UHPHT) glasses just recently discovered. Our preliminary data indicate that the melt rock varieties of the Kara astrobleme have significant differences in texture and structure. The considered melt rocks are mostly composed of a matrix represented by a "mixture" of amorphous and cryptocrystalline masses of predominantly feldspar composition with a subordinate SiO₂ content. According to the data of energy dispersive analysis the compositions of the studied melt rocks are similar and have minor deviations within the first percent. The difference in the shape of silicate segregations in melt rocks may indicate that the impact melt could have a high temperature with a shorter time interval for the solidification of melt rock II on the Kara River, in contrast to the massive melt rock I on the Anaroga River, where the impact melt had large volume and, accordingly, was cooled longer at lower temperatures. The data obtained complement the specificity of the Kara melt impactites, which may play a role in complementing the geological model of the Kara astrobleme. The reported study was funded by RFBR, project number 20-35-90065; the analytical equipment has been used at the Center for Collective Use "Geonauka" (IG Komi FRC SC UB RAS, Syktyvkar, Russia); the author expresses his gratitude to Isaenko S.I. for analytical work using Raman spectroscopy; Tropnikov E.M. for help in performing microprobe studies.

1. Introduction

The Kara astrobleme is one of the largest astroblemes known on land. It is located on the northeastern side of the Pay-Khoy anticlinorium at the Kara River mouth region (The Kara Sea coast, Russia). Its diameter is ~65 km, the age is about 70 million years [1].

The Kara astrobleme is a unique and complex object of impact genesis due to a variety of suevite breccia and melt impactite varieties [2]. The astrobleme was formed after sedimentary rock target of the Paleozoic from the Ordovician to the Permian deposits [3]. The Kara impact rocks were formed by crushing, melting, mixing and redeposition of the target rocks complex and are called coptogenic [4]. The rocks of the Kara coptogenic complex of are overlain by Quaternary deposits. The structure of the

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complex contains mainly of breccias, suevites and rare by melt rock impactites. The latter are of particular interest being a product of the highest degree of impact transformation of the target rocks [5]. According to the modern foreign classification of impactites, melt rocks are subdivided into clastic, poor, and clasts-rich melt rocks [5]. Their diversity, features of distribution, conditions of formation, material composition and phase state remain insufficiently understood. At the moment, we are interested in detail studies of melt rock varieties among the Kara astrobleme impactites.

2. Materials and methods

The material was sampled and described in natural outcrops at the Kara and Anaroga rivers in 2017. The detailed studies of the impactites have been provided by methods in 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 samples of impact melt rocks were analyzed by optical microscopy, scanning electron microscopy (SEM) and Raman spectroscopy. The optical study has been performed using Nikon Eclipse E400 polarization microscope. For the detail information about fine structure a scanning electron microscope TESCAN VEGA3 (Czech Republic) equipped by energy dispersive device (Oxford instruments X-Max) was used. For the SEM and microprobe analysis of the melt rocks thin polished sections of the large square $\sim 4\times 5$ cm covered with a conductive thin carbon layer were studied. For the phase state diagnostics of mineral substances a high-resolution Raman spectrometer LabRam HR 800 (Horiba Jobin Yvon) was attracted. The Raman spectra had been recorded at room temperature with He-Ne laser (632 nm) excitation.

3. Results and discussion

On the territory of the Kara astrobleme, there are several bodies of the massive melt rocks. The melt rock I at the Anaroga River (Figure 1a) had been described by previous researchers [6, 7]. A batholith-like body of melt rock II just has been found at the left bank of the Kara River near the Togorey mouth stream (Figure 1b) [8]. This melt body has been mentioned by previous researchers, but till present there are no any detail data on the melt variety. The latter has a tight spatial relation with just discovered ultrahigh-pressure high-temperature impact melt glasses. At the macro-level, both impact melt varieties (I and II) differ in texture.



Figure 1. Outcrops of melt rock impactites: **A** – massive melt rock I at the Anaroga River, **B** – melt rock II on the left bank of the Kara River (upper part of the outcrop, brown color). Photo **A** by Shumilova T.G. Photo **B** by Maksimenko N.I.

3.1 Melt rock I

Melt rock I at the Anaroga River has a massive texture. Selected from the bedrock outcrop melt rock is characterized by the dark brown color of the groundmass, which is caused by the presence of iron hydroxide. The fractures are conchoidal uneven. The melt rock ground mass has a fine-grain structure and optically is very weakly distinguishable (Figure 2). The matrix is represented mainly by a mixture of amorphous and crystalline components, that is confirmed by X-ray diffraction analysis (the content of the crystalline component is ~90%). The crystallized component of the main mass of the studied melt rock is represented mainly by feldspar-quartz microgranular aggregates with grain sizes of up to 15 μ m. The fragments of

lithoclasts are represented by thermally altered sandstones, siltstones, and shales, are ubiquitous. The size of the fragments varies strongly - from microscopic to essentially large, up to visible in outcrops (within half a meter). But, generally, most of the fragments are less than 2 cm in size. Based on the data of microprobe studies, it can be assumed that the fluid texture of melt rock is caused by the presence of accumulations of disintegrated minerals of the target rocks involved in the flow of the impact melt. Microprobe mapping of the samples made it possible to reveal only insignificant differences in their compositions, confirming the very weak differentiation of the composition of massive melt rock I (Figure 3A). According to SEM data, the following minerals have been found in the samples: titanite, ilmenite, apatite and pyrite. All of the listed minerals are finely dispersed in the matrix. The debris of the target rocks contains rare relics of zircons (Figure 4a). According to the Raman spectroscopy data, the melt rock groundmass is presented by feldspar (bytownite) with rare presence of cristobalite. The aggregate size of christobalite is less than 30 µm.

3.2 Melt rock II

Melt rock II from the left side of the Kara River has a lighter brown color than the melt rock I. It is located in the upper part of the outcrop (Figure 1B, upper part), being in close spatial relationship with suevite and vein bodies of UHPHT impact glasses. The impact melt variety II is characterized by a fluid texture that is clearly identified by optical microscopy. The scanning electron microscopy data indicate that the fluidity is expressed due to SiO2 segregations. Within the melt rock II the segregations have a more complex structure, reminiscent of the liquation pattern of SiO₂ droplets in the UHPHT vein glasses that have been widely studied earlier in general [9-12] and spectroscopically [13]. However, it is likely that these SiO₂ structures have been formed as a result of incomplete melting of mineral fragments of the target rocks. The clastic component within the melt rock II is weakly expressed and is represented by single fragments of the target rocks (siltstones, sandstones, shales), the groundmass is represented by feldspar. A more accurate determination of the species by the Raman spectroscopy was not possible due to high noise in the spectra by a high level of luminescence. The most common phase among the mineral excretions is pyrite, the others are essentially rare and presented with barite, sphalerite, titanite, pyrrhotine, apatite dispersed within the melt rock matrix. Some christobalite occurrences were also found.



Figure 2. The optical images of the groundmass of melt impactites (transmitted light, with analyzer): A – melt rock I (Q – quart grains), B – melt rock II.



Figure 3. SEM images of relatively homogeneous melt rocks (BSE mode images): **A** – Melt rock I, **B** – Melt rock II (more details in Figure 4b).



Figure 4. Details of the melt rocks features (BSE mode images): **A** - image of a disintegrated (partially melted) zircon grain within the relict target fragment in the melt rock I. **B** - SEM image SiO₂ component within the melt rock II matrix (Py – pyrite, Ap – apatite, AlSi – aluminosilicate matrix).

3.3 Petrochemical composition

The elemental composition was analyzed by the "area" microprobe analysis. Both varieties of the melt rocks have similar chemical composition of the groundmass (Table 1). They are represented by quartz-feldspar mass, which corresponds to the general petrochemical specificity of these formations (they bear the average composition of the target rocks). There is only a difference in the content of Cr_2O_3 .

Table 1. "Area" microprobe analysis data (size ~2 mm × 2 mm) obtained from different regions on the surface of polished thin sections. The low total mass is explained with presence of water within the impact melt rocks and by the roughness at the large area sizes of the analyzed regions.

	Melt rock I			Melt rock II		
	S1	S2	S3	S1	S2	S3
SiO ₂	52,39	56,1	52,28	54,1	53,22	53,05
TiO2	0,81	0,88	0,78	0,78	0,96	0,84
Al ₂ O ₃	14,81	16,84	14,87	15,39	17,33	15,67
CaO	3,82	4,24	3,76	4,29	4,46	3,71
MgO	3,45	2,89	3,01	4,52	4,03	3,41
K ₂ O	2,8	3,42	3,01	1,32	2,09	2,21
Na ₂ O	2,99	3,33	3,06	2,94	3,37	3,03
FeO	3,75	3,61	3,95	6,45	6,33	5,16
Cr ₂ O ₃	0,16	0,24	0,22	0	0	0
Total	84,97	91,55	84,92	89,79	91,79	87,09

4. Conclusions

Summarizing, by the moment, the provided preliminary data of the Kara impactites allow conclude about at list two varieties of the impact melt rocks of different textural features and bodies morphology. Both varieties demonstrate the significant difference the rocks structure at micro-level. The considered melt rocks optically are composed mostly of a matrix represented by a "mixture" of amorphous and cryptocrystalline masses of predominantly feldspar composition with a subordinate SiO_2 content. According to the data of "area" microprobe analysis the studied melt rocks have similar composition with minor deviations within the first percent. The difference in the shape of silicate segregations in melt rocks may indicate that at the Kara River the impact melt could have a high temperature with a shorter time

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interval for the solidification of melt rock II, in contrast to the massive melt rock I at the Anaroga River. For the latter the melt bodies had larger volumes and, accordingly, should be cooled during longer period.

Acknowledgments

The reported study was funded by RFBR, project number 20-35-90065; the analytical equipment has been used at the Center for Collective Use "Geonauka" (IG Komi FRC SC UB RAS, Syktyvkar, Russia); the author expresses his gratitude to the scientific advisor Shumilova T.G. for consultations; Isaenko S.I. for analytical work using Raman spectroscopy; Tropnikov E.M. for help in performing microprobe studies.

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