Preliminary Petrological and Geochemical Studies of Dolerite Dikes at the Kara Astrobleme Central Uplift, Comparison with UHPHT Impact Melt Glasses (Pay-Khoy, Russia)

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Abstract. Recent find of the ultra-high pressure high-temperature (UHPHT) impact melt glasses among the impactites of the Kara astrobleme has a high interest in nicely preserved 70 Ma glass with potentially unusual structure and properties. By the moment, it is important to understand about the substance source for the UHPHT glasses. The Kara target is characterized with complicated rock material preferably presented with Paleozoic sedimentary units. At the same time, the target has in a sequence Devonian sills and dikes of gabbro-dolerites. The latter appear on the surface at the Kara dome being a material which probably have been affected by the most strong impact. Here we for the first time describe the results of preliminary analysis of petrological and geochemical features of the magmatic dikes of the central uplift with the aim to understand their probable genetic source for the UHPHT impact melt veins matter. The provided studies point to essential difference between the compared materials, that means the UHPHT impact melts do not correspond to the magmatic material of the Khengursky complex of gabbro-dolerites of the Pay-Khoy Ridge (Russia).

1. Introduction
The Kara astrobleme is set on the northeast edge of the Pay-Khoy Ridge at the Kara sea coast of the European Arctic zone of Russia (Figure 1), it is estimated by the recent measurements by the age of about 70 Ma [1]. Being one of the biggest meteorite craters with the diameter about 65 km the astrobleme has the central uplift with the size about 6x9 km (Figure 1b, c) well recognized in geophysical methods by anomaly in gravitic and magnetic fields [2-7] that is a classic structural feature of a complicated large meteorite crater [8-10]. Following to the known impact craters the central point of a large crater should be affected with the most intensive changes with target rock melting. By the moment the recently found UHPHT impact melt veins among the Kara impactites do not have recognized certain target source. As the UHPHT glasses keep the relic features of the most high pressure, presented with high pressure silica polymorph – melt crystallized coesite, theoretically they might be a result of the most high impact affect from the central point of the Kara event with possible relation to the matter from the dome. The idea is also supported by high fluidal property of the UHPHT melt to move out far from the center and intrude suevites at the edge of the Kara rim having immiscibility with the host bulk melt rock matter at the left bank of the Kara river. The latter can be probably explained by the specific chemical composition of the melt. Thus, in this work we tried to compare the chemical and geochemical composition of the
UHPHT impact glasses and the matter of the dolerites of the Khengursky complex of the Pay-Khoy structure. Also, it this work the petrological features of the Kara dome dikes have been preliminary described for the first time.

2. Materials and methods
The dike dolerite material for the study has been sampled at Kara dome from the natural outcrops at the banks of the Sopchau river. The UHPHT impact melt glasses have been sampled at the southern part of the Kara astrobleme from natural outcrop of the UHPHT glasses within the host suevitic breccia at the right bank of the Kara river described earlier in [11-14]. The petrological study has been performed in standard thin sections by optical microscopy using polarization microscope POLAM R-312 (LOMO, Russia). For the chemical composition the bulk dolerite samples have been crushed to a powder. The UHPHT glasses preliminary have been separated under binocular microscope for mono-fractions, then have been milled to powder specimens for the chemical composition analysis. The elemental composition of the rocks has been measured with wet chemistry analysis (silicate analysis for 14 components); the geochemical studies have been performed by ICP-MS analysis at the chemical laboratory of the Institute of Geology of Komi Scientific Center UB RAS (IG FRC Komi SC UB RAS, Syktyvkar, Russia). For mineralogical specification some of the analytical methods have been used such as scanning electron microscopy (SEM), electron microprobe analysis (EMPA) and Raman spectroscopy (RS) 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).

![Figure 1](image_url)

**Figure 1.** Geographic position of the Kara astrobleme (red point) on the Google map (a) and on the fragment of the Geological Map of the Russian Federation, R-41, Amderma, scale 1:1000000 [5] (b); overview geological cross-section through the center of the Kara astrobleme from the Geological map of the Ust’-Kara region, the map scale 1:200000, after Zarkhidze et al. [6].
3. Results and discussion

The Kara astrobleme central uplift is characterized with rare bodies of the magmatic dikes/sills of the Khengursky complex of gabbro-dolerites on the modern dome surface [5, 6]. Here we present for the first time the preliminary petrological description of the magmatites. Among the studied material the dikes are presented preferably by quartz-containing dolerites having the quartz content from several percent to 20 % and even more (Figure 2a). The other wide spread variety is characterized with amphibolitic dolerite (Figure 2b), in a single specimen we observe gabbro (Figure 2c). The dolerites are cut by quartz veins (Figure 2d). The all magmatic varieties are characterized with high contamination by secondary mineralization, in some cases the active impact influence have been signed in deformation features such as PDF structures, essentially spread in hard minerals especially in quartz (Figure 2d) and pyroxene. Also, quartz exhibits strong fibrous darkening. The latter changes are the results of initial stage deformation and post-impact hydrothermal activity.

![Figure 2](image_url)

**Figure 2.** The optical images of the gabbro-dolerites of the Khengursky complex from Kara astrobleme central uplift in transmitted light: a – quartz-containing dolerite with quartz grains in the center (grey); b – amphibolitic dolerite with needle-like amphibole microcrystals; c – gabbro with quartz granophyric structures; d – bulk quartz in quartz-containing dolerite with numerous PDF structures (a–c – crossed polarizes; d – parallel polarizes).

3.1. Quartz-containing dolerites

They are the most spread in the Kara dome according to the present geological data. They have different varieties with middle- and micrograin rock with allotriomorphic structure and different quartz content 10-30%. The quartz is characterized with irregular, isometric shapes, fills mineral intergrain space and
exhibits micrograin aggregates getting sizes up to 3 mm. The latter can include amphibolite microcrystals. Large-sized quartz grains usually surrounded by tiny-crystalline, micro-plated and radially-textured aggregates of chlorite. Usually quartz has strong deformation features, such as fibrous darkening and PDF structures (Figure 2a, d), the real evidence of impact treatment. The other minerals are presented with rock-forming minerals in different relation from sample to sample – plagioclase (0-35%), pyroxene (15-30%), amphibole (5-20%), chlorite (10-15%), titanite (5%) and ore minerals (5%). The pyroxene is presented by shapeless grains with sizes up to 0.2 mm, has poor optical transparency, strong cracking and secondary changes by amphibole. Sometimes altered plagioclase micrograins can be included within the pyroxene grains. Amphibole is widely spread through the rock and presented with needle-like crystals with different orientations.

The mineral accessories are presented with single grains of zoisite, talc and epidote. Secondary mineralization within the quartz-containing dolerites is presented with chlorite and sossurite. Chloritic alteration developed in plagioclase intergrain space and within microcracks at the time the sossurite replace plagioclase inside. The chlorite spatially often correlates with ore mineralization.

3.2. Amphibolitic dolerite
Amphibolitic dolerite is presented with micrograin composition with ophitic microstructure. Among the rock-forming minerals are plagioclase (50%), pyroxene (30%), amphibole and hornblende (15%) and ore minerals (5%). Chlorite, titanite, zoisite and quartz can be met as rare accessory grains. From the above described dolerite variety it differ generally by lower acidity and corresponded by almost quartz absence and micrograin structure.

3.3. Gabbro
Gabbro at the Kara central uplift is rare quartz-containing rock having large-sized hipidiomorphic structure composed of plagioclase (35%), pyroxene (25%), quartz (20%), titanite (5%), chlorite (5%) and ore minerals (10%). As rare grains amphibole and zoisite can be met among the accessories. The plagioclase exhibits isometric sub-prismatic crystals with sizes 0.2-0.5 mm, often altered with sossurite and sericite. The pyroxene is presented by cub-idiomorphic prismatic crystals and irregular-shaped forms with size up to 0.7 mm with different level of chloritization. The quartz often presents clear granophyric structures (Figure 2c), grain sizes up to 0.2 mm, has angular and irregular grain shapes, fulfills the intergrain space between plagioclase and pyroxene. The ore minerals are presented either by quite large grains up to 0.1 mm or by tiny powder grains within pyroxene.

As a whole, the dolerite varieties at the Kara dome exhibit initial different magmatic differentiation that is a characteristic of the Khengursky Pay-Khoy complex. At the same time the dikes have essential deformation features signed in some minerals such as PDF structures and cracking. Also, it is clear that hydrothermal alteration is widely developed through the dikes material that can be a result of the after-impact activity.

3.4. Petrochemical and geochemical composition of the Kara dome dolerites and UHPHT impact melt veins
According to our provided preliminary petrochemical and geochemical studies it is following that the the Kara dome dolerites and UHPHT impact melt veins have the most close petrochemical composition compare to the other impact melts in the Kara impactites (Table 1, figure 3). At the same time we can see that the UHPHT impact melt glasses form independent region on the TAS diagram (Figure 3).

The more tiny geochemical analysis also exhibits different elemental features between the dome dolerites and the UHPHT glasses (Figure 4). The UHPHT glasses are characterized with essentially higher content of the light REE and by absence of the Eu minimum that is a general characteristic of the
Khengursky of the Pay-Khoy. Also, it is evidently that the UHPHT glasses have very low level of REE differentiation as a whole at the REE spider-diagram normalized by chondrite.

**Table 1.** Petrochemical components (overage) of the vein UHPHT impact glasses and the magmatic dikes of the Kara central uplift (wt.%)

| Component | Rock type | UHPHT glasses | Uplift dikes |
|-----------|-----------|---------------|--------------|
| SiO$_2$   |           | 57.77         | 48.24        |
| TiO$_2$   |           | 0.81          | 1.11         |
| Al$_2$O$_3$|           | 15.18         | 12.67        |
| Fe$_2$O$_3$|           | 6.96          | 3.00         |
| FeO       |           | 3.87          | 7.75         |
| MnO       |           | 0.08          | 0.20         |
| CaO       |           | 3.04          | 10.99        |
| MgO       |           | 5.13          | 9.03         |
| K$_2$O    |           | 1.91          | 0.61         |
| Na$_2$O   |           | 2.54          | 1.57         |
| P$_2$O$_5$|           | 0.16          | 0.08         |
| L.O.I     |           | 6.63          | 4.73         |
| H$_2$O    |           | 2.58          | 0.74         |
| CO$_2$    |           | 0.56          | 0.57         |

**Figure 3.** The TAS diagram with the pointed impact melts and the magmatic rocks of the Kara astrobleme target from the central uplift: 1 – 4 clastic fragments of impact melts from suevites from different Kara crater sectors, 1 – Anaroga sector, 2 – Togorey sector, 3, 4 – Sopchau sector; 5 – gabbro-dolerites from the central uplift; 6 – UHPHT impact melt veins in suevite complex at the Togorey sector.
4. Conclusions
Here the preliminary petrological characteristics of the dikes of the Kara central uplift have been presented. The dikes are characterised by the preserved initial different magmatic differentiation that is a characteristic of the Khengursky complex of the Pay-Khoy Ridge. While, the uplift dikes have strong deformation features such as PDF structures and cracking in rock-forming minerals. The described widely developed hydrothermal alteration in the dikes can be initiated by after-impact activity of the Kara meteorite event. The provided preliminary studies by petrochemical and geochemical analyses in a complex allow conclude that the UHPHT impact melt glasses should have another source for their formation than the Khengursky dikes. The different composition of the UHPHT impact melt glasses might be explained by other target rock source and with probable participation of the Kara asteroid material that is a subject for future studies.

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