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Varieties of Impactites and Impact Diamonds of the Kara Meteorite Crater (Pay-Khoy, Russia)

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Abstract. Impact diamonds are technical material with valuable mechanical properties. Despite of a quite long story from their discovery and huge diamond storages at the Popigai astrobleme (Siberia, Russia) they were not involved into industrial production, first of all because of remoteness of objects, complexity of extraction and economically more favourable synthesis of technical diamonds in the seventies of the past century. However, due to the high hardness of impact diamonds and also to the high demand of new carbon materials, including nanomaterials, the interest towards this type of natural diamonds is significantly increased in the recent years. Although the mentioned Popigai astrobleme is situated in a remote part of Russia it has been studied in more details. At the same time, the less known Kara giant meteorite crater (Pay-Khoy, Russia) is situated essentially closer to the industrial infrastructure of the European part of Russia. This astrobleme, similarly to Popigai, is enriched in impact diamonds as well. But, till recent years it was not deeply studied using modern analytical methods. During our studies in 2015 and 2017 at the territory of the Kara meteorite crater we have distinguished and described 5 varieties of impactites – bulk melt impactites which form cover-like and thick dike bodies; melt ultrahigh-pressure vein bodies and at least 3 types of suevites formed after specific sedimentary target rocks. These varieties have typomorphic features regarding the crystallinity and mineral composition. It was found that all of them have high concentration of microdiamonds formed by high-pressure high temperature pyrolysis mechanism from precursor materials like coal and organic relicts. Using a set of modern mineralogical methods we have found two principal types of diamond morphologies within the Kara impactites – sugar-like after coal diamonds and diamond paramorphs after organic relicts. The Kara diamonds have several accompanying carbon substances including newly formed graphite, glass-like carbon and probably carbyne. The studied diamondiferous Kara impactites provide an essentially novel knowledge of impact processes in sedimentary targets.

1. Introduction

Impactites are intensively studied objects around the world, as meteorite cratering is one of the crucial geological processes of the formation of Earth crust and mineral deposits [1-6]. There are about 190 proven meteoritic craters on the Earth, among them the diamondiferous astroblemes attract especial attention as significant reservoirs of high quality technical diamonds [6].

Three large diamondiferus astroblemes are known in Russia – Popigai (diameter 100 km), Puchezh-Katunki (diameter 80 km) and Kara (diameter 60 km) meteoritic craters [6]. At the territory of the Popigai impact crater 2 deposits with estimated huge diamond resources are known – Udarnoe and Skal`noye. Despite of their quite old story dating back to pioneer studies of the diamond objects in the in the seventies of the past century , they were not involved into industrial production mainly due to the remoteness of these objects, the complexity of their extraction and on the other hand, the economically more favorable synthesis of technical diamonds.

However, because of the unique technical characteristics of the lonsdaleite-containing impact diamonds and also the high demand of new carbon materials, the interest towards the impact diamonds has significantly increased. At the same time, it should be noted that the Popigi astrobleme, although is in a remote part of Russia, is more extensively studied [6]. The Kara crater and the closely located Ust`-Kara crater with a diameter of 25 km are situated closer to the industrial regions which, together with the better transportation facilities make them easily accessible for potential exploration. At the same time these craters, which provided the first unusual after-coal impact diamonds [8, 9], are significantly less studied [7]. The impact nature of the crater had been proven in the seventies and supported by later studies [7, 10], and the age of the impact event was supposed to be ca. 70 Ma [11]. According to earlier estimations the diamond concentration within the impactites is about 17 carat per ton for grain size larger than 0.5 mm [12]. During our studies of impactites from the Kara astrobleme we have revealed new types of impactites and impact diamonds, including a new variety of impact diamond – diamond fossils in very high concentrations [13, 14].

Earlier the varieties of the impactites (suevites and tagamites) were distinguished based on the relation of impact glass and detrital material [6, 7], while petrological approach was used for impactites by V. Feldman [15]. At the same time it was noted [16, 17] that the petrographic structure of suevites from certain localities strongly differs even within the same outcrop. However, previously detailed petrographic and geochemical characteristics [16, 17] of the Kara suevites were not reported and systematized.

2. Materials and methods

The material was sampled in 2015 and 2017 at the Kara astrobleme (Russia). The astrobleme is located in the Kara sea coast at the Northern-East edge of the Pay-Khoy ridge. The suevites and melt impactites were described in natural outcrops by geomorphological, textural-structural and color features, and porosity. Impact diamonds had been enriched from impactites by thermochemical dissolution at the Laboratory of Diamond Mineralogy (IG Komi SC UB RAS).

Detailed investigation of the impactites and impact diamonds were done using mineralogical, petrological and geochemical methods in the Center of collective use of the Institute of Geology of Komi Scientific Center UB RAS (Syktyvkar, Russia) including optical microscopy, Raman spectroscopy (RS), scanning electron microscopy (SEM), and electron microprobe analysis (EMPA), X-Ray diffraction (XRD), thermal analysis, fluid chromatography, chemical analysis and others. Transmission electron microscopy with focused ion beam preparation has been done at the Thin Film Physics Group of the Institute for Technical Physics and Materials Science, Centre for Energy Research, Hungarian Academy of Sciences (Budapest, Hungary) and at the Jena University (Jena, Germany).

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3. Results

On the basis of our field observations, an subsequent mineralogical, petrological and geochemical characterization we have distinguished at least 3 types of suevites which were formed by the transformation of different prevailing types of sedimentary target rocks [18].

We have studied Kara impactites at several stages. First in the field we have analyzed geomorphological features of suevites bodies (Figure 1), their relationship with host sedimentary rocks, together with structural and textural features (Figures 2), and the mineralogical and petrological composition of fragments within suevites.

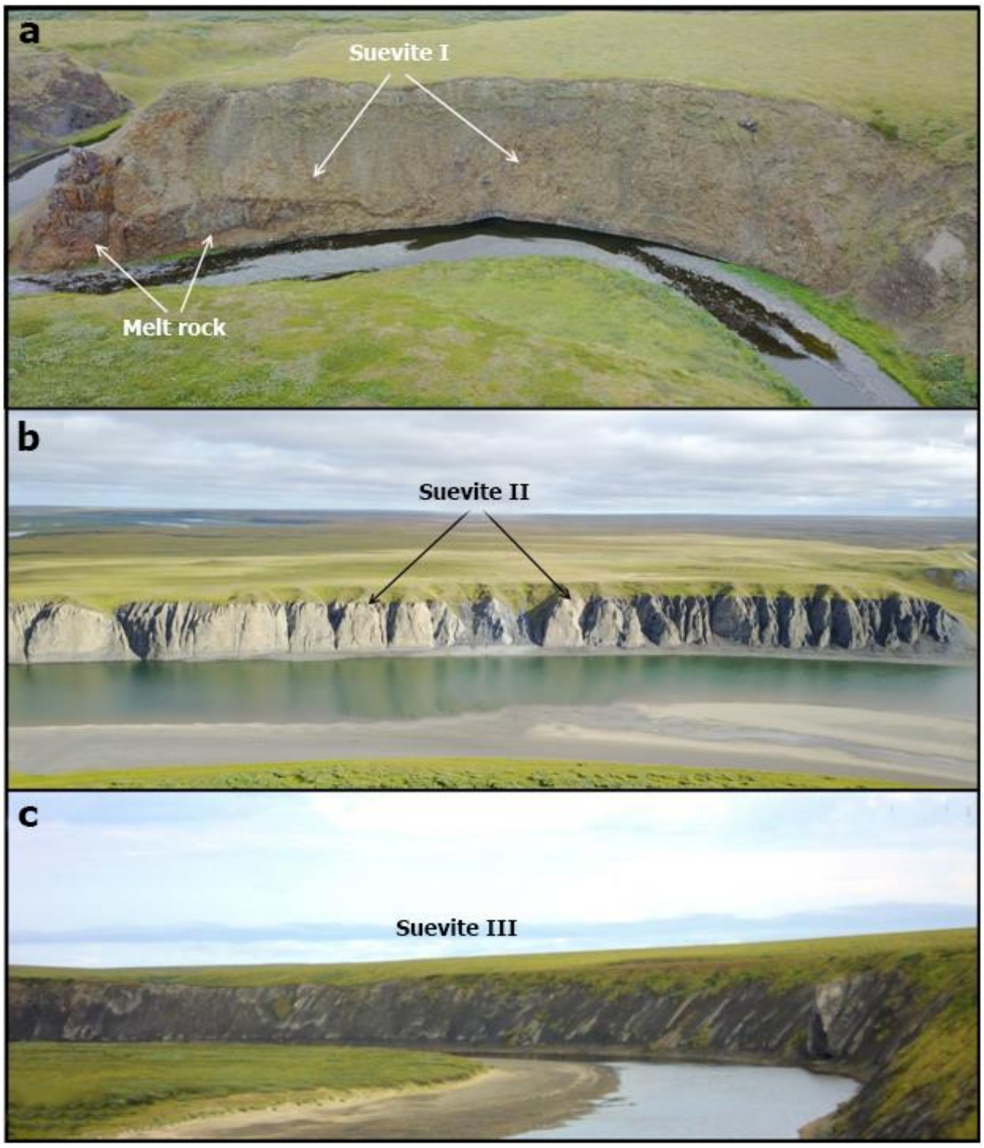


Figure 1. Natural outcrops of impactites varieties of the Kara impact crater: a – melt variety and type I suevite, the visible outcrop prolongation is about 400 m; b – type II suevite, the visible prolongation is about 1 km; c – type III suevite, the visible prolongation is about 800 m.

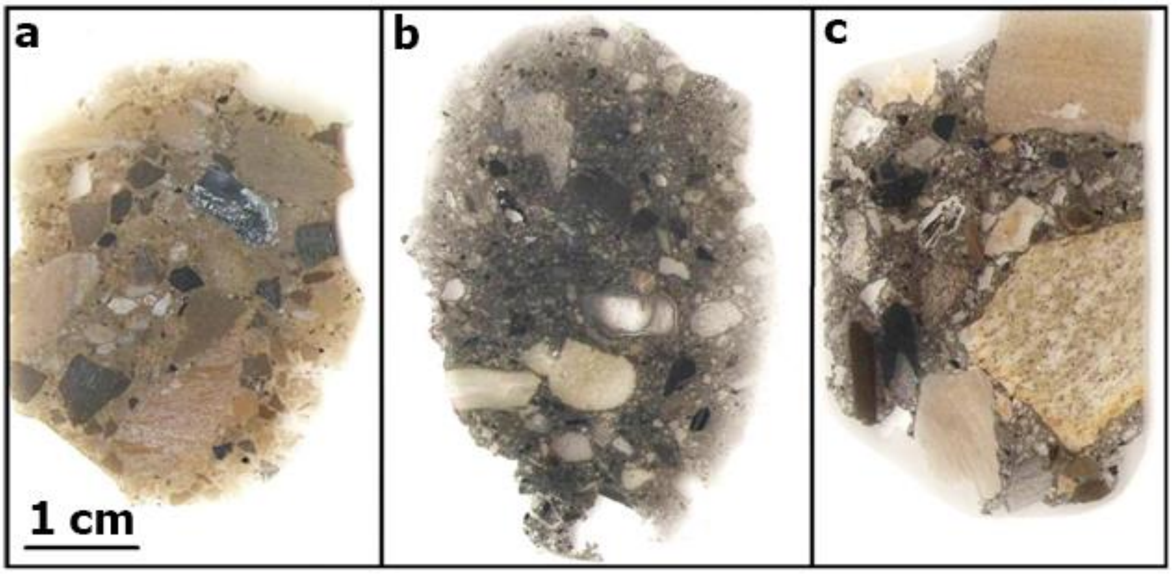


Figure 2. Varieties of suevites of the Kara impact crater, typical thin sections in transparent non-polarized light: a – type I suevite; b – type II suevite; c – type III suevite.

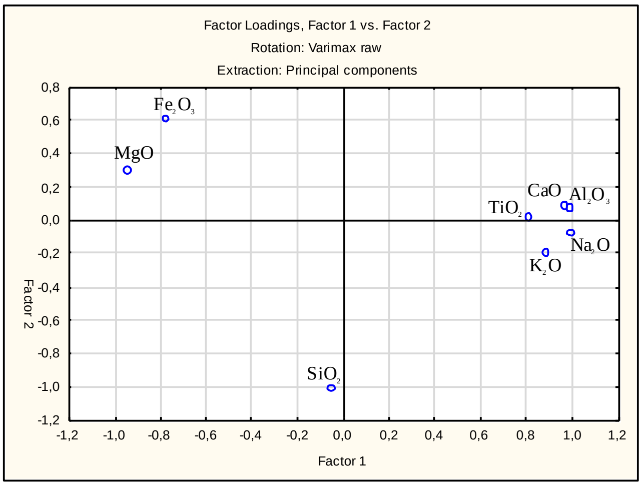
From the first stage we have distinguished directly in field conditions 3 types of suevites and also melt impactites. At the next stage we have applied a new approach to study the petrochemical features of the suevites on the basis of cementing matrix analysis and structure of impact glasses according to square microprobe analyses described in [18]. The results of the statistical analysis are presented on the Figure 3, indicating some essential compositional differences between the distinguished suevites varieties.

On the basis of a deep complex study of impact carbon material enriched from the Kara impactites, including modern high resolution methods, we have described the typomorphic features of the after-coal diamonds first reported by V.A. Yezerskiy [8, 9]. We have distinguished two essentially different varieties of Kara impact diamonds – 1) sugar-like after-coal diamonds (figure 4, a, b), and 2) a newly discovered variety, diamond pseudomorphs after organic relicts (diamond fossils) (figure 4 c, d) [13, 19, 20].

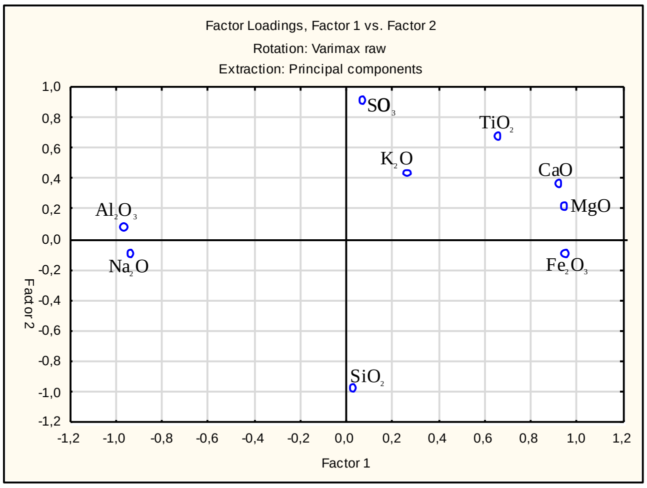
The diamond fossils are characterized by the specific spectroscopic features which demonstrate that the diamond nanocrystals are in an ultra-nanocrystalline-amorphous diamond-like matrix (figure 5). This variety is widespread through the whole astrobleme and locally can accumulate concentrations as huge as thousand carats per ton.

As the result of a detailed analysis of the impact carbon materials, the coexistence of after-coal diamonds in form of sugar-like units of white colour, exhibiting gray and brown shades with different degree of crystallinity is proven. According to the complex high resolution studies the after-coal diamonds represent micro- and nanoporous polycrystalline nanostructure with diamond crystallites 20-30 nm (figure 6a). At the same time the diamond fossils have brown colour, their morphology clearly indicates the organic precursor and they are characterized by an overall homogeneous ultra-nanocrystalline structure with crystallite sizes about 2-5 nm (figure 6b). Both varieties are characterised by the absence of stress texture and lonsdaleite. The latter clearly distinguishes them from after-graphitic impact diamonds [21].

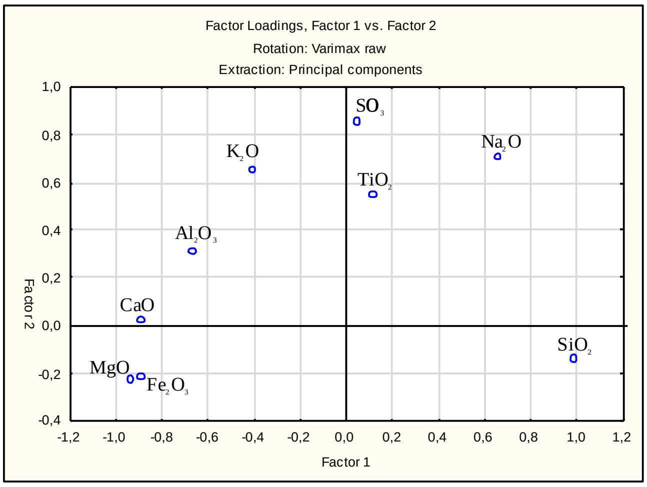
Among the accompanying carbon phases we have analysed newly formed nanocrystalline graphite, glass-like carbon, holey onion-like carbon, amorphous carbon and carbyne (probably) [19, 20].



a



b



c

Figure 3. Factor analysis diagrams for petrochemical components of the suvites varieties: a – type I suevite; b – type II suevite; c – type III suevite

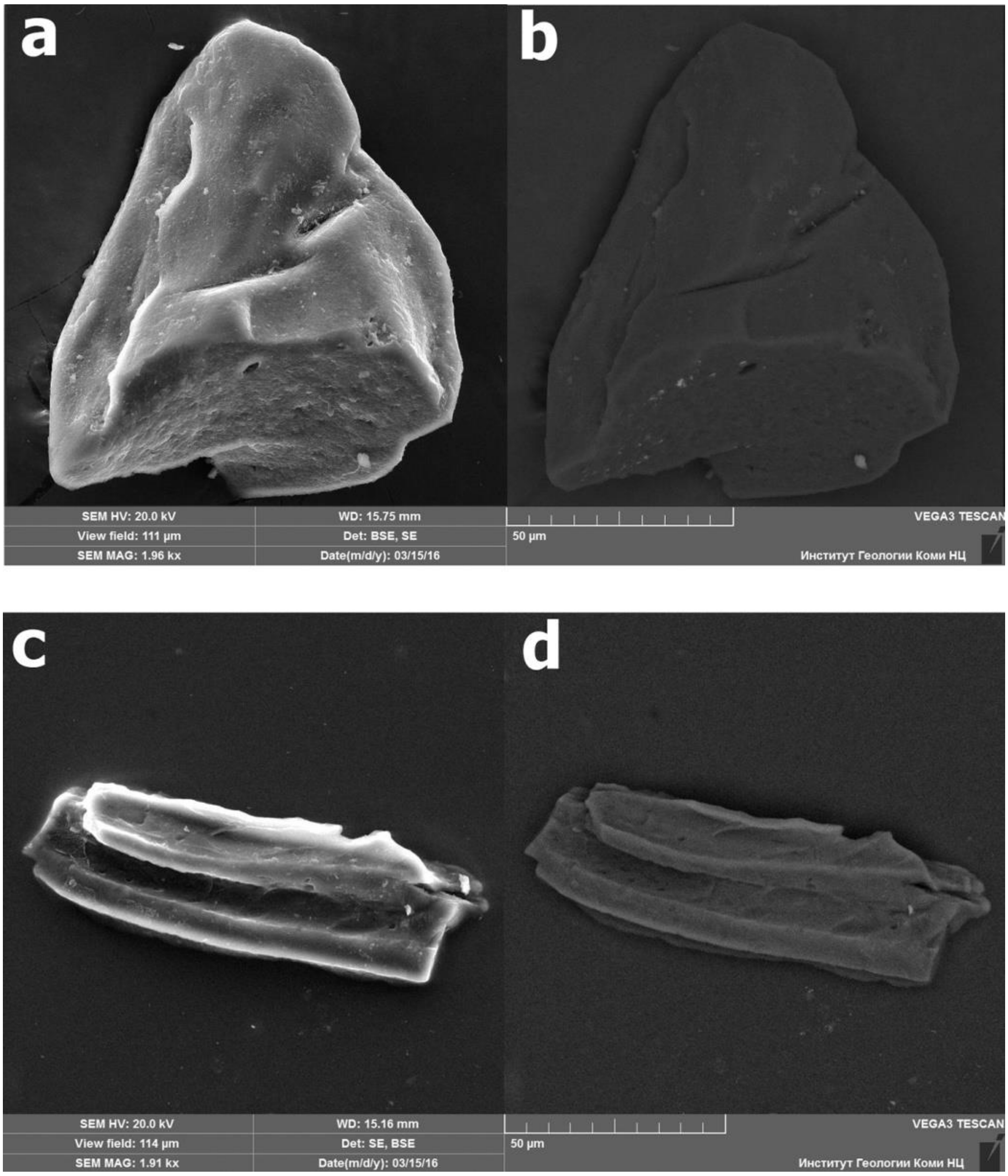


Figure 4. Typical diamond grains, SEM images: a, b – sugar-like diamond, c, d – diamond fossil, morphology clearly indicates the organic relict precursor. a, c – images in secondary electrons mode; b, d – in back scattered electron mode.

4. Discussion

The presented data obviously demonstrate difference between the distinguished varieties of the Kara suevites and impact diamonds. The mineralogical and geochemical properties of suevites are in quite good agreement with the regionally located sedimentary target rocks [18]. The morphological and structral features of the diamond varieties allow to conclude their different carbon precursors – carbonaceous matter from black shales for the for the sugar-like variety and wood relicts for the diamond fossils. According to the well preserved micro-morphological features of the pseudomorphs [19] we conclude slightly changed organic material as a precursor (before the stage of gelification). Also, we cannot exclude the possibility of diamond formation from fresh wood as proven by the partial preservation of cellulose [19].

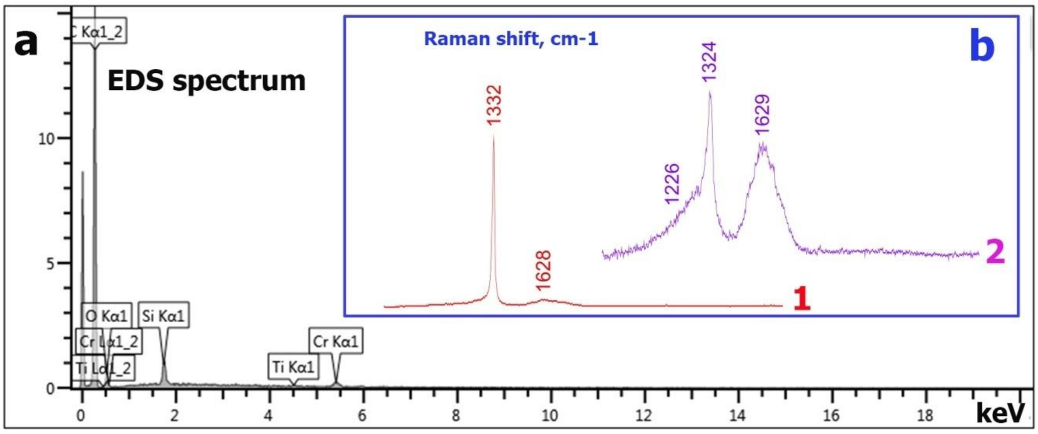


Figure. 5. Spectroscopic data of the general Kara impact diamond varieties: a – typical chemical composition for sugar-like diamond, energy dispersive spectrum; Raman spectra – 1 sugar-like diamond, 2 – diamond fossil

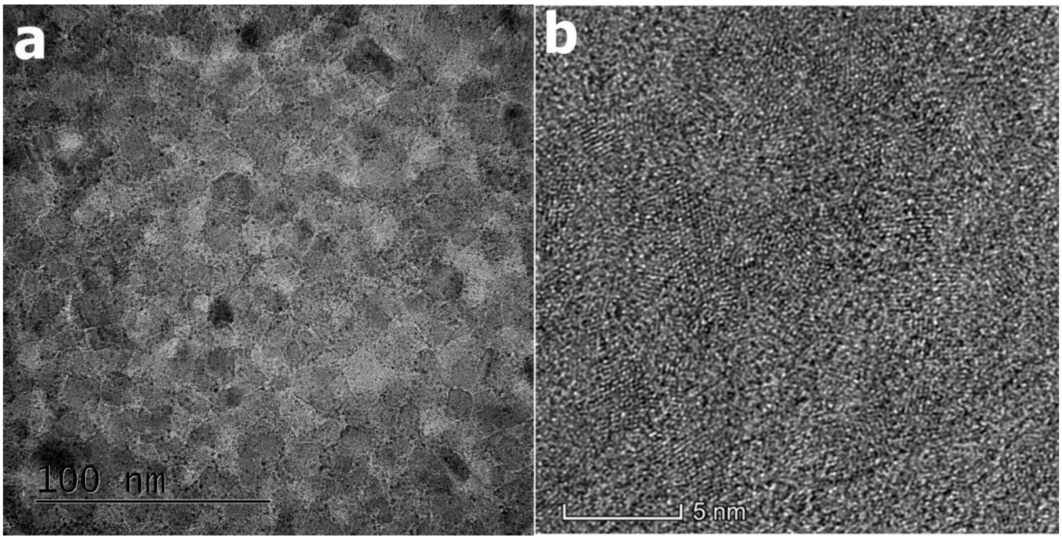


Figure. 6. (HR)TEM images of Kara impact diamond varieties: a – sugar-like diamond with 20-30 nm crystallites, diamond fossil with ultra-nanocrystalline structure.

5. Conclusion

Our studies provide essentially new information on suevites and impact diamond varieties raising the need of a deeper investigation of the impact processes and products. The discovery of a new variety of impact diamond, namely diamond fossil, demonstrates the possibility of the formation of ultra-nanocrystalline diamonds in the nature. Ultra-nanocrystalline diamond is a novel valuable carbon matter that can be an intriguing new natural nanomaterial for potential technological developments.

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References

[1] Stoffler, D. Hamann, C., Metzler, K. Shock metamorphism of planetary silicate rocks and sediments: Proposal for an updated classification system. Invited Review. Meteoritics & Planetary Science, 1–45, 2017.
[2] Kenkmann, T., Poelchau, M. H., Wulf, G. Structural geology of impact craters. Journal of Structural Geology, 62, 156–182, 2014.
[3] Koeberl, C. The geochemistry and cosmochemistry of impacts. In: Holland H.D. and Turekian K.K. (eds.) Treatise on Geochemistry, Second Edition, vol. 2, pp. 73-118. Oxford: Elsevier, 2014.
[4] Melosh, H.J. Impact Cratering: A Geologic Process. Oxford University Press, New York. 245 pp Melosh HJ (2003) Shock viscosity and rise time of explosion waves in geologic media. Journal of Applied Physics, 94, 4320–4325, 1989.
[5] Reimold, W.U., Koeberl, C., Impact structures in Africa: A Review, African Earth Sciences, DOI: http://dx.doi.org/10.1016/j.jafrearsci.2014.01.008, 2014.
[6] Masaitis, V.L., Mashchak, M.S., Raikhlin, A.I., Shafranovsky, G.I., Selivanovskaya, T.V. Diamondiferous impactites of Popigai astrobleme. VSEGEI Press, 1998, 169 p. (in Russian), 1998.
[7] Mashchak, M. S. Morphology and structure of the Kara and Ust`-Kara astroblemes. International Geology Review. 33(5), 433–447, https://doi.org/10.1080/00206819109465701, 1991.
[8] Yezerskiy, V. A. High pressure polymorphs produced by the shock transformation of coals. International Geology Review. 28:2, 221-228, 10.1080/00206818609466264, 1986.
[9] Yezerskiy, V.A. Impactly metamorphosed coal substance in impactites. Meteoritika, 41, 134–140 (in Russian), 1982.
[10] Udoratin, V.V., Konanova, N.V., Popov, I.V. Deep composition of Kara ring structure. Proceedings of Komi SC UB RAS, 4, 47–51 (in Russian), 2010.
[11] Trieloff, M., Deutsch, A., Jessberger, E.K. The age of the Kara impact structure, Russia. Meteoritics & Planetary Science, 33, 361–372, 1998.
[12] Shishkin, M. A. et al. State Geological Map. Scale 1:1000000 (3rd editing). South-Karskaya series. R-41 – Amderma. Report. Saint-Petersburg, VSEGEI, 383 p. (in Russian), 2012.
[13] Shumilova, T.G., Isaenko, S.I., Ulyashev, V.V., Kazakov, V.A., Makeev, B.A. Aftercoal diamonds: enigmatic type of impact diamonds. European Journal of Mineralogy. Volume 30, Number 1, February 2018, pp. 61-76(16). DOI: 10.1127/ejm/2018/0030-2715, 2018.
[14] Shumilova, T., Isaenko, S. Nanoporous nanocrystalline impact diamonds. Mineralogy and Petrology. https://doi.org/10.1007/s00710-019-00671-1, 2019.
[15] Feldman, V. Petrology of impactites. Moscow, Moscow University Press, 299 p. (in Russian), 1990.
[16] Masaytis, V. L. (Ed.) Structures and Textures of Explosion Breccias and Impactites: Trudy VSEGEI, Vol.316, 159 p. (in Russian), 1983.
[17] Mashchak, M. S., Selivanovskaya, T. V., Masaytis, V. L. Structure of the suevites and allogenic breccias of the Kara astrobleme and dynamics of the distribution of fragmental material in them: Meteoritika, 42, 149-157, 1983.
[18] Shumilova, T.G., Kovalchuk, N.S., Makeev, B.A. Geochemical features of Diamond-bearing suevites of the Kara astrobleme (Pay-Khoy). Doklady Earth Sciences, 486(1), 545–548, 2019.
[19] Shumilova, T.G., Ulyashev, V.V., Kazakov, V.A., Isaenko, S.I., Svetov, S.A., Chazhengina, S.Yu., Kovalchuk, N.S. Karite – diamond fossil: a new type of natural diamond. Geoscience Frontiers (in press), 2019.
[20] Ulyashev, V. V., Shumilova, T.G., Kulnitskiy, B.A., Perezhogin, I.A., Blank, V.D. Nanostructured features of carbon polyphase aggregates of after-coal impact metamorphism products. Vestnik IG Komi SC UB RAS, 8, 26–33 (in Russian), 2018.
[21] Kvasnytsya, V.,Wirth, R. Micromorphology and internal structure of apographitic impact diamonds: SEM and TEM study. Diam. Relat. Mater., 32, 7–16, 2013.