ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 409, No. 5, pp. 779–783. © Pleiades Publishing, Inc., 2006.
Original Russian Text © Z.V. Spetsius, A.S. Ivanov, S.I. Mityukhin, 2006, published in Doklady Akademii Nauk, 2006, Vol. 408, No. 6, pp. 810–814.

GEOCHEMISTRY

Diamondiferous Xenoliths and Megacrysts from the Nyurbinskaya Kimberlite Pipe (Nakynsky Field, Yakutia)

Z. V. Spetsius[a], A. S. Ivanov[b], and S. I. Mityukhin[c]

Presented by Academician I.D. Ryabchikov August 20, 2005

Received October 30, 2005

DOI: 10.1134/S1028334X06050230

Paragenetic associations with diamond in kimberlites can be subdivided into three main types: (1) inclusions of various minerals in diamond crystals, (2) mineral intergrowths with diamonds, and (3) xenoliths of diamondiferous mantle rocks. These types are found in different proportions in all the kimberlite pipes with commercial diamond contents. Such rocks have always attracted attention of researchers, since they bear the most reliable information on natural formation environments of diamonds and their peculiarities, i.e., petrological features of the upper mantle in the region.

Like any new object, kimberlites from the recently discovered Botuobinskaya and Nyurbinskaya pipes (Nakynsky kimberlite field) became a target for intense research. Despite the relatively short (less than 10 yr) history of their study, several publications have been dedicated to the geology, kimberlite mineralogy, and other compositional features of these pipes [1–10]. These works demonstrate that kimberlites from the new field are unique in terms of their isotopic signatures, which are similar to those of kimberlites of the second group, and compositional features of associated minerals (primarily, garnets and chrome spinels). It is also established that the lithospheric mantle under the Nakynsky field differs (with respect to petrography of rocks and tectonomagmatic evolution) from the neighboring Malaya Botuobinskaya and Daldyn-Alakitsky fields [5, 9].

Already, first data on the external morphology demonstrated that diamonds from kimberlites of this field differ (in terms of the spectrum and proportions of various morphological groups) from diamonds of other kimberlite pipes of the Yakutian province [1, 3]. The diamond population from kimberlites of the Nakynsky field contains a higher content of rounded and enveloped (or rimmed) crystals. Crystals with caverns, etching channels, and other signs of natural dissolution and resorption are also present [3, 5]. The visual study of mineral inclusions in diamonds from kimberlites of this field revealed the elevated content of orange garnets and other minerals of presumably eclogitic association, which points to wide distribution of eclogitic mineral inclusions among diamonds from these pipes [1, 3]. This inference has been supported by the microprobe studies of inclusions in diamonds from the Botuobinskaya Pipe, which demonstrated that over 50% of crystals belong to the eclogitic association [10]. All these facts indicate that the new diamondiferous area is unique and it is important to study specific features of mantle xenoliths, particularly those with diamonds.

We studied mantle rocks and monomineral garnet megacrysts containing single diamond ingrowths or occasional crystals at their surface. The diamondiferous xenoliths and megacrysts (more than 130 samples) were taken from kimberlite ore in the course of its concentration by X-ray luminescence separators. Since the samples are represented by diamondiferous xenoliths (with only garnet preserved as the primary mineral) or nearly monomineral garnet megacrysts, we mainly studied garnets and diamonds. In all samples, we carried out the microprobe analysis of garnets and the morphological study of diamonds.

The garnet composition was examined under standard conditions using a Superprobe JXA-8800R X-ray microanalyzer in the Central Analytical Laboratory of

[a] *Yakutian Research and Design Institute of Diamond Mining Industry, ALROSA Joint-Stock Company, ul. Lenina 39, Mirnyi, Yakutia, 678170 Russia; e-mail: Spetsius@yna.alrosa-mir.ru*

[b] *Central Analytical Laboratory, Botuobinskaya Geological–Prospecting Expedition, ALROSA Joint-Stock Company, ul. Pyat'desyat et oktyabrya, Mirnyi, Yakutia, 678170 Russia; e-mail: Asivan@mail.ru*

[c] *ALROSA Joint-Stock Company, ul. Lenina 6, Mirnyi, Yakutia, 678170 Russia; e-mail: SSSergey@yahoo.com*

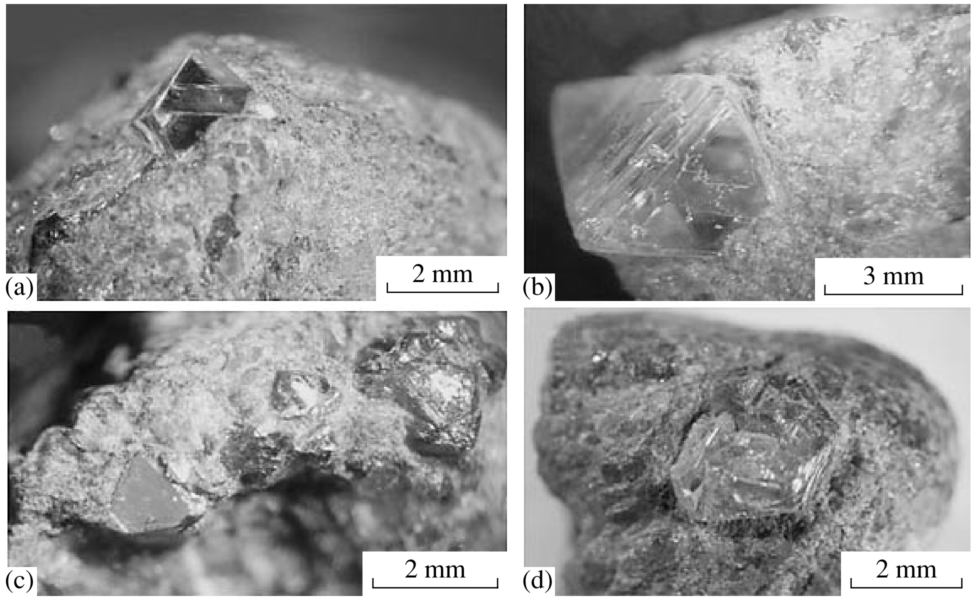

Fig. 1. Diamondiferous xenoliths from the Nyurbinskaya Pipe. (a) Sample N-6 corresponds to magnesian eclogite in terms of garnet composition, diamond (2.4 × 8 mm) is represented by the colorless octahedron with smooth facets; (b) Sample N-47 corresponds to garnet websterite in terms of garnet composition, diamond (3 × 2 mm) is represented by the colorless octahedron with polycentric structure of facets; (c) Sample N-17 corresponds to high-alumina eclogite in terms of garnet composition, diamonds are represented by the five linearly arranged octahedral crystals 2–3 mm across; (d) Sample N-20 corresponds to ferruginous eclogite in terms of garnet composition, diamond (3.5 × 2.5 mm) is represented by the gray intensely corroded irregular in size crystal; one can clearly see leaching channels crosscutting the crystal and rim composed of entirely chloritized phlogopite.

the ALROSA Joint-Stock Company. Some minerals were analyzed using a Link ISIS-300 device (resolution, 133 eV; accelerating voltage, 20 kV; current, 10 nA; and beam diameter, 1–2 μm). Natural minerals certified at the Institute of Geology and Geophysics (Novosibirsk) were used as standards.

The representative collection (163 samples) includes rounded xenoliths (with visible diamonds) or monomineral garnet nodules (with diamond ingrowths). Some samples contain two or more diamond crystals. The collection is unique because of its numerous samples of diamondiferous xenoliths and megacrysts found in kimberlites of the recently discovered pipe. Despite the long history of development of the well-known kimberlite deposits, such as the Mir and Udachnaya pipes, the total quantity of diamondiferous xenoliths found in them usually does not exceed 100 specimens in each pipe. This statement is at least valid for xenolith collections from well-studied kimberlite pipes in both Yakutia and South Africa [11, 12].

Leaving aside the detailed characteristics of diamonds enclosed in xenoliths, let us note that most of them are represented by octahedral crystals (Fig. 1). In general, the collection shows the following proportions between morphological groups of diamonds (%): octahedrons 65, transitional forms 22, intergrowths 8, and various twin types 5. Figures 1a and 1b demonstrate two xenoliths with relatively close composition of the major mineral (garnet) represented by octahedron with the polycentric structure of facets or octahedron with acute edges, respectively. It should be noted that diamonds are deeply submerged into the garnet matrix in both cases and enveloped by entirely chloritized monomineral phlogopite. Such an envelope is particularly well developed around the corroded irregular crystal (Fig. 1d). Several examined samples contain up to five or more diamond crystals. Some xenoliths enclose accumulations of diamonds, which form chains and veinlets (Fig. 1c). In some samples, diamonds are represented by crystals with usually yellow-green rims. The size of diamond crystals ranges from 0.5 to 4–5 mm along the long axis. It is remarkable that many diamonds demonstrate leeching channels and other corrosion signs (Fig. 1d). Such crystals constitute approximately 30% of the collection.

As was noted above, garnet grains from all the xenoliths were analyzed to determine the major components. Particular attention was paid to central and peripheral zones of garnets in order to define any zoning. It was established that approximately 10% of examined garnets show zoning with respect to the distribution of major elements, such as Ca, Mg, and Fe. Factor analysis of the data on the mineral composition of xenoliths revealed eight groups of garnets, which are readily distinguishable in terms of certain major components. The table presents average garnet compositions in defined cluster groups, the number of examined samples, and percentage of separate groups in analyzed xenoliths. The defined garnet groups correspond compositionally to different garnet types in certain mantle

Average contents of garnet cluster groups in diamondiferous xenoliths from the Nyurbinskaya kimberlite pipe, wt %

Component	G1	G2	G3	G4	G5	G6	G7	G8
SiO_2	39.26 (0.73)	39.73 (0.53)	40.05 (0.44)	40.48 (1.42)	40.23 (0.43)	40.62 (0.08)	40.52 (4.01)	40.72 (0.37)
TiO_2	0.27 (0.09)	0.45 (0.22)	0.29 (0.06)	0.38 (0.14)	0.4 (0.11)	0.3 (0.1)	0.37 (0.17)	0.15 (0.11)
Al_2O_3	21.22 (0.32)	21.28 (0.45)	21.75 (0.32)	21.96 (0.97)	21.85 (0.31)	22.05 (0.37)	21.98 (1.8)	15.39 (1.26)
Cr_2O_3	0.07 (0.05)	0.08 (0.05)	0.08 (0.06)	0.1 (0.07)	0.1 (0.05)	0.11 (0.06)	0.17 (0.27)	9.87 (1.56)
MgO	9.38 (2.01)	10.23 (1.41)	12.43 (0.35)	14.1 (1.16)	9 (1.32)	15.53 (0.94)	20.59 (3.32)	19.09 (0.92)
CaO	5.09 (1.0)	8.27 (1.44)	5.05 (0.79)	10.2 (2.2)	16.33 (1.51)	3.82 (0.83)	3.37 (1.57)	6.12 (1.08)
MnO	0.48 (0.12)	0.39 (0.07)	0.38 (0.06)	0.19 (0.07)	0.14 (0.04)	0.37 (0.08)	0.34 (0.12)	0.47 (0.09)
FeO	23.07 (2.13)	18.22 (1.48)	18.83 (0.91)	10.76 (1.76)	11.03 (1.16)	16.26 (1.28)	10.65 (3.7)	7.46 (0.42)
Na_2O	0.1 (0.04)	0.16 (0.06)	0.12 (0.02)	0.22 (0.26)	0.17 (0.03)	0.12 (0.02)	0.12 (0.05)	0.04 (0.02)
NiO	0.01 (0.003)	0.01 (0.03)	0.01 (0.002)	0.01 (0.003)	0.01 (0.002)	0.01 (0.002)	0.01 (0.009)	0.01 (0.003)
Total	98.94	98.83	99.00	98.41	99.26	99.19	98.12	99.31

Number of samples and relative content, %

	G1	G2	G3	G4	G5	G6	G7	G8
Number of samples	10	17	51	8	13	40	10	12
%	6.2	10.6	31.7	5.0	8.1	24.8	6.2	7.5

Note: Standard deviations are shown in parentheses.

xenoliths of the mafic or ultramafic composition. For example, in terms of the high Cr content (>8.0 wt % Cr_2O_3) and magnesian index, group G8 corresponds to garnets of the dunite–harzburgite association. Garnets of group G7 are also characterized by the similarly high magnesian index, but they have lower Cr_2O_3 and CaO contents. Therefore, they are similar to garnets from lherzolites and wehrlites. Garnets of group G6 correspond to those from garnet websterites characterized by the lower magnesian index (as compared with groups G8 and G7) and the low CaO content. It is conceivable that some samples from this group of xenoliths belong to magnesian eclogites. Garnets of group G5 are similar to those from high-alumina eclogites that include grospydite, kyanite, and coesite, as well as corundum-bearing varieties. This is also confirmed by the detection of separate corundum grains found in samples of group G5. The CaO content in garnets is a criterion for defining xenoliths of this group [13]. In terms of the magnesian index, garnets of group G4 are close to those from group G5, but they have a lower CaO content and can belong to various ferromagnesian eclogites.

Groups G1–G3 are depleted in Cr, enriched in Fe, and variable in terms of CaO content. They correspond to garnets from different magnesian and ferromagnesian eclogites. It should be noted that garnets of group G6 with the high magnesian index and lower CaO content can belong to either magnesian eclogite xenoliths or garnet websterites. Garnets with similar composition of major oxides are also recorded in the megacrysts from kimberlites [12]. The position of garnets from group G7, which are characterized by the elevated Cr and Mg contents and a lower CaO content, is somewhat uncertain. Similar garnets occur in lherzolite and pyroxenite xenoliths. At the same time, they can be attributed to garnets from the megacryst association. Therefore, it is probably reasonable to define them as a transitional group.

In any case, the first five cluster groups, which unite garnets with the medium magnesian index, elevated mafic index, and low Cr content, correspond most likely to eclogitic varieties of mantle rocks. They account for more than 60% of the examined xenolith samples. It should be emphasized that samples of undoubtedly dunite–harzburgite association constitute <10% of the studied diamondiferous xenoliths (table).

The analysis of inclusions in diamonds from the Botuobinskaya Pipe of the Nakynsky field revealed that the eclogitic association constitutes no less than 50% of all the inclusions recorded in diamonds from this pipe [10]. Such a high share of the eclogitic association was not noted among diamond-hosted inclusions from any kimberlite pipes of the Yakutian province. These data are substantiated by data on the Nyurbinskaya Pipe. As was shown above, the examined samples of diamondiferous rocks are largely represented by xenoliths that correspond to different eclogite varieties or, less commonly, garnet websterites in terms of garnet composition. The share of samples of the ultramafic association of the dunite–harzburgite and, less commonly, lherzolite or pyroxenite composition approximates 10%. The percentage of diamondiferous associations of the eclogitic composition could even be higher since the examined collection virtually lacks xenoliths with

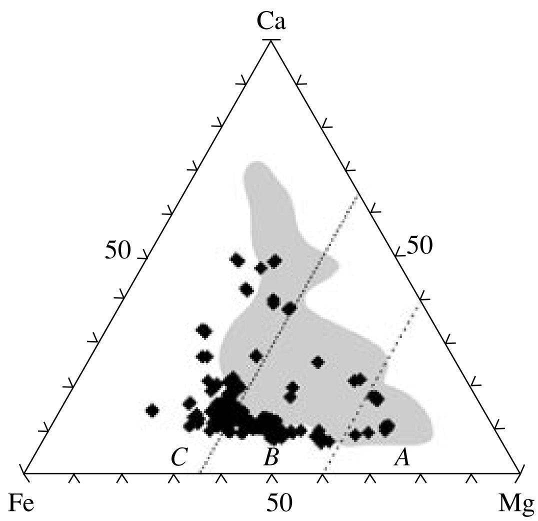

Fig. 2. Diagram illustrating the composition of garnets in diamondiferous xenoliths and megacrysts from kimberlites of the Nyurbinskaya Pipe. For comparison, the field of garnets from diamondiferous eclogites of the Udachnaya Pipe is shown. Fields of garnets (*A, B, C*) from different types of eclogites are shown after [14].

cubic diamonds. Judging from our collections, the share of similar diamonds in populations from both pipes is no less than 5%. Inasmuch as all xenoliths were taken after visual examination of the concentrate yielded by luminescence separators, it is natural that xenoliths with cubic diamonds, which are characterized by low X-ray luminescence, could have been missed. At the same time, kyanite and, less commonly, two-mineral eclogites are parental rocks of such diamonds [11]. Thus, it is conceivable that the share of the eclogitic substrate, which represents substrate for diamonds in the lithospheric mantle beneath the studied kimberlite field, was even higher. The results obtained will probably be refined after subsequent studies. However, it is clear already now that diamonds from the Botuobinskaya and Nyurbinskaya pipes are characterized by an unusual paragenetic composition, an elevated role of the eclogitic substrate in their formation, and a high contribution to the formation of the lithosphere beneath the Nyurbinskaya kimberlite field.

The data on the content of major oxides in garnets from examined diamondiferous xenoliths and monomineral nodules are plotted in the Mg–Ca–Fe ternary diagram (Fig. 2). One can see that garnets from diamondiferous xenoliths of the Nyurbinskaya Pipe are characterized by a wide range of all main components. Moreover, the compositional spectrum of garnets from the diamondiferous xenoliths and nodules exceeds the field of diamondiferous rocks from the Udachnaya and Mir pipes. Variations in the CaO content in garnets associated with diamonds from the Nyurbinskaya Pipe are wider than in xenoliths of the Mir Pipe. The comparison between compositions of garnets from the concentrate and diamondiferous associations of mantle rocks shows that the composition field of the second variety, which served as the substrate for the diamonds and is an undoubted associated mineral of diamonds, is slightly wider than that of the field of garnets from the concentrate. It means that more thorough garnet sampling is needed during prospecting works, primarily in the Nakynsky kimberlite field. Orange eclogite-type garnets are sometimes similar in appearance to almandine garnets from metamorphic rocks and might be rejected by the quality controller, thus, being excluded from the selection of indicator minerals associated with diamonds.

The data obtained suggest the specific composition of the diamond-forming medium and, correspondingly, mantle in the Nakynsky kimberlite field. The specific composition is probably responsible for the anomalously high diamond potential of kimberlites from both pipes. The high diamond content is mainly related to the capture of high-productive mantle xenoliths primarily of the eclogitic composition. It is unclear whether this fact is related to the selective capture or the anomalous composition of the mantle in the study area. However, data on the Nyurbinskaya Pipe testify to the abundance of diamondiferous xenoliths of the eclogite and, partially, pyroxenite composition in relevant kimberlites. This implies the elevated proportion of the eclogitic substrate in the lithospheric mantle beneath the Nakynsky kimberlite field. In addition, some other indirect indications, such as wide distribution of rounded diamonds, as well as crystals with etching channels and other signs of corrosion, point to the substantial role of metasomatism and partial melting in the formation of diamonds [15]. These processes presumably governed the presence of certain types of crystals and specific mode of diamond population but also provided the supply of sufficient carbon owing to intense percolation of fluids. The contribution of metasomatic processes and associated fluid components to the formation of diamonds is emphasized by both the style of zoning in garnets from diamondiferous xenoliths and the presence of chloritized phlogopite rim around diamond crystals in xenoliths from these pipes.

The largely eclogitic composition of the diamond-forming substrate and specific composition of the lithosphere mantle suggest that some methodical approaches to prospecting in the study area and, probably, some other fields of the Yakutian kimberlite province should be revised. For example, special attention should be paid to eclogite-type garnets during sampling and field works, in addition to high-Cr garnets of the dunite–harzburgite association. Such garnets are similar to their orange and pink counterparts from metamorphic rocks or crustal xenoliths. Therefore, they can be ignored during prospecting works.

ACKNOWLEDGMENTS

We are grateful to V.I. Banzeruk for assistance in sampling diamondiferous xenoliths and to N.N. Merkulova and S.V. Banzeruk for assistance in the selection of garnet crystals and the preparation of samples for the microprobe analysis.

REFERENCES

1. V. I. Koptil, V. I. Banzeruk, and A. N. Lipashova, in *Geology, Distribution Regularities, and Methods of Prediction and Prospecting for Diamond Deposits* (Mirnyi, 1998), pp. 183–184 [in Russian].
2. S. D. Chernyi, A. S. Fomin, Yu. T. Yanygin, and G. V. Kolesnikov, in *Geology, Distribution Regularities, and Methods of Prediction and Prospecting for Diamond Deposits* (Mirnyi, 1998), pp. 157–159 [in Russian].
3. A. M. Agashev, A. S. Fomin, T. Watanabe, and N. P. Pokhilenko, in *Extended Abstracts. 7th Int. Kimberlite Conf.* (Cape Town, 1998), pp. 9–10.
4. S. D. Chernyi, A. S. Fomin, Yu. T. Yanygin, et al., in *Extended Abstracts. 7th Int. Kimberlite Conf.* (Cape Town, 1998), pp. 147–148.
5. Z. V. Spetsius and V. P. Serenko, in *Geology and Tectonics of Platforms and Orogenic Regions of Northeastern Asia* (YaNTs SO RAN, Yakutsk, 1999), Vol. 2, pp. 104–108 (in Russian].
6. N. P. Pokhilenko, N. V. Sobolev, S. D. Chernyi, et al., Dokl. Akad. Nauk **372**, 356 (2000) [Dokl. Earth Sci. **372**, 638 (2000)].
7. V. P. Kornilova, A. S. Fomin, and A. I. Zaitsev, Region. Geol. Metallog., Nos. 13/14, 105 (2001).
8. Z. V. Spetsius, S. I. Mityukhin, and A. S. Ivanov, Dokl. Akad. Nauk **390**, 681 (2003) [Dokl. Earth Sci. **391**, 703 (2003)].
9. Z. V. Spetsius and V. P. Serenko, in *Geological Aspects of the Raw Mineral Base of the ALROSA Joint-Stock Company* (Mirnyi, 2003), pp. 191–196 [in Russian].
10. Z. V. Spetsius, S. I. Mityukhin, A. S. Ivanov, and S. V. Banzeruk, Dokl. Akad. Nauk **403**, 248 (2005) [Dokl. Earth Sci. **403**, 808 (2005)].
11. Z. V. Spetsius, J. Geochem. Explor. **53**, 25 (1995).
12. J. J. Gurney, J. Geol. **93**, 423 (1990).
13. Z. V. Spetsius, Lithos **48**, 525 (2004).
14. L. A. Taylor and C. R. Neal, J. Geol. **97**, 551 (1989).
15. Z. V. Spetsius and L. A. Taylor, Int. Geol. Rev. **44**, 973 (2002).