10IKC-149

SUTURES IN THE EARLY PRECAMBRIAN CRUST AS A FACTOR RESPONSIBLE FOR LOCALIZATION OF DIAMONDIFEROUS KIMBERLITES IN THE NORTHERN EAST EUROPEAN PLATFORM

Samsonov*AV[1], Tretyachenko VV[2], Nosova AA[1], Larionova YuO[1], Lepekhina EN[3], Larionov AN[3], Ipatieva IS[4]
[1]IGEM RAS, Moscow, Russia; [2]NIGP AC "ALROSA", Arkhangelsk, Russia; [3]VSEGEI, St.-Petersburg, Russia; [4]GIN RAS, Moscow, Russia

INTRODUCTION

The study of regularities in localization of kimberlites and lamproites in the Early Precambrian crustal structures represents one of the main tasks in geology of these rocks. Long-term studies revealed that commercial diamond-bearing kimberlites and lamproites are usually confined to the oldest Archean blocks lacking signs of subsequent plume magmatism, rifting, and collision, i.e., endogenic processes that could destroy lithospheric roots and enclosed diamonds (Clifford, 1966; Helmstaedt & Gurney, 1995). This hypothesis of the preserved Archean lithosphere known as "Clifford's rule" serves as the main criterion for forecasting and prospecting diamond-bearing kimberlites and lamproites, on the one hand, and as a constituent of the basic problem: the origin and preservation of deep diamond sources, on the other (Stachel et al., 2005). In most of the recent models, diamonds are considered as xenocrysts transported by kimberlites and lamproites from deep (>150 km) levels of the lithospheric mantle, where they were formed, according to geochronological data on minerals trapped in diamonds, in the Archean and avoided subsequent tectono-magmatic transformation (review in Stachel et al., 2005).

Studies of the past few decades have revealed, however, facts that are inconsistent with these empirical regularities. The South African Craton, which represents a cradle of the kimberlite geology and testing area for development of "Clifford's rule" (Clifford, 1966) is the best example illustrating these facts. First, this region demonstrates numerous (from the Paleoproterozoic to Phanerozoic) stages of intraplate magmatic activity(Cawthorn, 2005), which preceded intrusion of diamond-bearing kimberlites and should partly destroy corresponding lithospheric roots (Helmstaedt & Gurney, 1995). Second, the commercial Neoproterozoic Venetia diamond-bearing kimberlite pipe is localized in the Neoarchean Limpopo mobile belt, a relatively young structure of the South African Craton (Deines et al., 2001). The Kimberly Craton, where the commercial Argail diamond-bearing lamproite pipe is localized in the Paleoproterozoic Halls Creak mobile zone (~ 2200 Ma old), which separates the Archean Kimberly and Steart blocks (Jaques et al., 1986), is another example of deviation from "Clifford's rule."

KIMBERLITE POSITION IN A BASEMENT OF THE NORTHERN EAST EUROPEAN PLATFORM (EEP)

The northern East European Platform is an additional region where the tectonic position of diamond bearing kimberlites differs from that following from "Clifford's rule." This region hosts diamond-bearing kimberlites of three generations (Fig. 1): (1) Paleoproterozoic (~ 1.98 Ga) kimberlites of the Kimozero area in central Karelia (Ushkov et al., 2008; Samsonov et al., 2009); (2) Vendian (589–626 Ma) Kaavi-Kuopio kimberlites of eastern Finland (O'Brien et al., 2005), and (3) Devonian (367–380 Ma) kimberlites of the Terskii Bereg area in the Kola Peninsula (Arzamastsev et al., 2001) and Zimnii Bereg area in the Arkhangelsk diamondiferous province (ADP) (Larchenko et al., 2005). Among them, the Vendian kimberlites of eastern Finland (O'Brien et al., 2005) and Devonian kimberlites of the Terskii Bereg area (Daly et al., 2006) are confined to Paleoproterozoic collisional zones (Fig. 1). The position of the largest and commercially most significant Arkhangelsk diamondiferous province relative to old crustal structures remained unclear for a long time, since data on the structure, composition, and age of the Early Precambrian crystalline basement buried under the platform cover were very ambiguous. Inasmuch as direct geochronological data were unavailable, it was considered to represent the eastern continuation of the Archean Belomorian block of the Baltic Shield or the autonomous Archean Kuloi granulite–gneiss block (White et al., 1995). Such interpretation, however, was disagreement with chronological data on Paleoproterozoic age of xenoliths (Markwick, Downes,

2000) and zircon xenocrysts (Lepekhina et al., 2004) from kimberlitic pipes of the ADP. New evidences for Paleoproterozoic age of the ADP crystalline basement were obtained when we undertake special geochemical, isotopic, and geochronological investigations on crustal xenoliths and zircon xenocrysts from kimberlitic pipes.

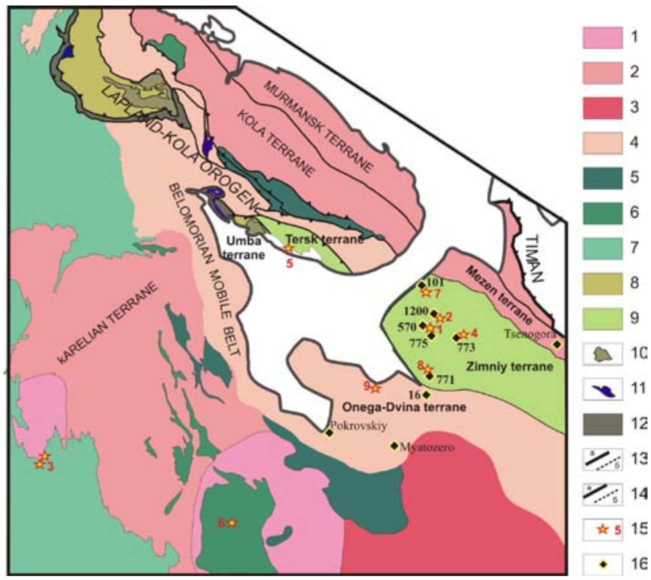

Fig. 1. The schematic tectonic map of the northern East European Platform. Compiled using materials from (Pogrebitskii et al., 1993; Kostinen et al., 2001; Daly et al., 2006).
(*1–3*) Archean blocks: (*1*) Mesoarchean, (*2*) Neoarchean, (*3*) undefined; (*4*) Belomorian mobile belt; (*5–12*) Paleoproterozoic structures: (*5*) initial Paleoproterozoic (2.45 Ga), (*6*) with established multistage development (2.45–1.75 Ga), (*7*) Svecofennian domain (2.0–1.7 Ga), (*8-12*) Lapland–Kola and Zimniy suture zone: (*8*) metasediments (2.0 Ga), (*9*) tonalite–trondhjemite–granodiorite orthogneisses, granitoids (2.0–1.8 Ga), (*10*) enderbites, charnokites (1.91–1.94 Ga), (*11*) anorthosites (2.45 and 1.9 Ga), (*12*) collisional melange; (*13*, *14*) tectonic fractures: (*13*) thrusts: (*a*) proven, (*b*) assumed, (*14*) others: (*a*) proven, (*b*) assumed; (*15*) occurrences(fields) of kimberlite and related magmatism: (1) Zolotitskoe, (2) V. Grib Pipe, (3) Kaavi–Kuopio, (4) Kepa, (5) Ermakovskaya Pipe, (6) Kimozero, (7) Mela, (8) Chidviya–Izhmozero, (9) Nenokskoe; (*16*) sampling sites (boreholes and their numbers, quarries).

COMPOSITION AND AGE OF THE ADP CRYSTALLINE BASEMENT

On regional magnetic and gravity maps structures of crystalline basement of the ADP can be regarded as a southeastern continuation of the Lapland–Kola Orogen, a large Paleoproterozoic collisional belt between the Karelia and Kola-Murmansk Archean composite terranes (Daly et al., 2006) (Fig. 1). Based on geophysical data ADP crystalline basement consists of three main domains. Central part of the province which hosts all the diamond-bearing kimberlites is the Zimniy Bereg (Zimniy) terrane that separates southern Onega-Dvina and northern Mezen terranes (fig. 1).

The basement rocks of the Zimniy terrane, central part of the ADP, were studied in cores from several deep boreholes located on a meridian profile (Fig. 1).

Northern boreholes number 101, 1200, 570, 773, and 775 dissected crystalline basement of Verkhota, Zolotitskoe and Kepa kimberlitic fields. In the cores of these boreholes there are tectonized metamorphosed (epidote–amphibolite facies) calc-alkaline gabbroids, quartz diorites, granodiorites, and granites with geochemical characteristics typical of postcollisional settings: enriched in P_2O_5, TiO_2, Zr, Rb, Sr, Ba, and light REE. U-Pb SHRIMP dating of magmatic zircons from two samples of granodiorites from the 570 and 773 boreholes give the same age of ca 1980 Ma (fig. 2). The studied zircons contain few cores with age ~2.1 Ga, which were probably inherited from the crustal protolith of these granodiorites.

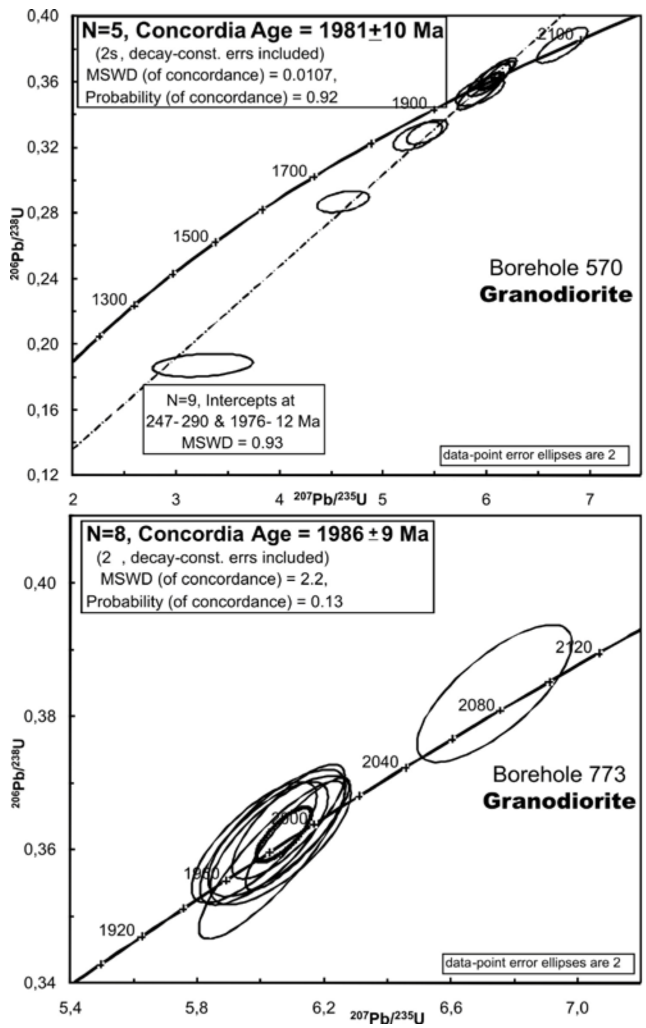

Fig. 2. U-Pb Concordia plots with result of SHRIMP II dating of zircons from granodiorites of Zimniy terrane

On the Sm–Nd isochron diagram, all the basement rocks from the northern boreholes from the Zimniy terrane can be approximated by the line that corresponds to the age of 2.0 Ga and have local variation of εNd(1980) values from + 1.8 to +3.5 (fig. 3). These data indicate that the crust of the Zimniy terrane was formed in the course of the Paleoproterozoic crust-forming episode under the leading role of mantle and juvenile crustal sources. By age and composition, the rocks of the Zimniy terrane are correlative with the juvenile Paleoproterozoic granitoid complexes of the Tersk terrane which form an axial part of the Lapland–Kola orogen on the Baltic Shield.

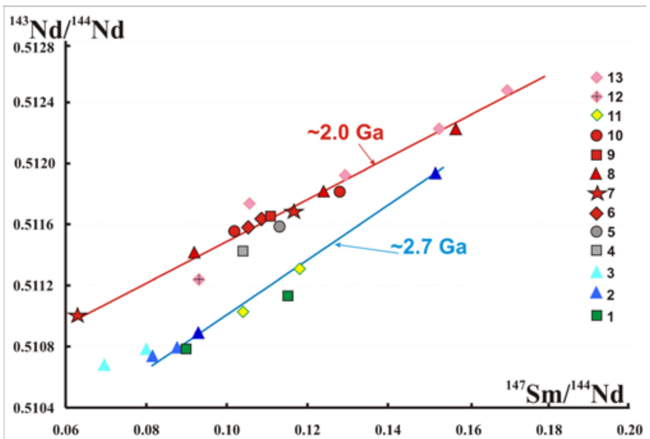

Fig. 3. Sm-Nd isochron diagram for rocks from the crystalline basement of the Arkhangelsk diamondiferous province.
1 - Mezen terrane: gneiss and granite of the Tsenogora borehole; ***2-3 - Onega-Dvina terrane:*** 2 – gneisses and amphibolites of Myatozero boreholes and Pokrovskiy quarry; 3 – granite and pegmatite of the Myatozero boreholes; ***4-5 – southern part of the Zimniy terrane***, gneisses: 4 –16 borehole; 5 –771 borehole; ***6-10 – northern part of the Zimniy terrane***: 6 – quartz diorite and granodiorite of the 773 borehole; 7 - quartz diorite and granodiorite of the 775 borehole; 8 – metagabbro, quartz diorite, granodiorite and granite of the 570 borehole; 9 - granite of the 1200 borehole; 10 –granodiorites of the 101 borehole; ***11-13 – xenolithes from kimberlite pipes***: 11 – middle crustal xenoliths from V.Griba pipe; 12 – lower crustal xenolith from V.Griba pipe; 13 – lower crustal xenoliths from 688 pipe (Markwick, Downes, 2000).

Basement of the southern part of the Zimniy terrane under the Izhmozero kimberlitic field, recovered by boreholes 771 and 16 (fig. 1), consists of cordierite-sillimanite-biotite–garnet gneisses, probably metasedimentary, and granitic migmatites. As compared with granitoids of the Zimniy terrane these rocks have lower εNd (1980) from +1 to 0 (fig. 3) which imply some input of an older Archaen crustal rocks into their sedimentfry protolith. These gneisses are comparable with Paleoproterozoic kondalites – metasedimentary rocks of the Umba terrane of the Lapland–Kola orogen on the Baltic Shield

The basement rocks of the Onega-Dvina terrane, southern part of the ADP, were sampled from the Pokrovskiy Quarry and Myatozero boreholes (Fig. 1). The studied samples are represented by felsic and mafic granulites, granites and pegmatites of Archean ages (T_{Nd} (DM) ~2.6-2.8 Ga, Fig. 3) that are analogous to complexes of the Belomorian terrane.

The basement rocks of the Mezen terrane, northern part of the ADP, were sampled from the Tsenogora borehole from the basement of Mezen rift. In the basement cross-section of the borehole gneisses and granites are predominated. Two studied samples have Mesoarchaen model ages of T_{Nd} (DM) ~2.9-3.1 Ga which are similar to those for the granitoids of the adjacent Murmansk terrane.

The crustal xenoliths from diamond-bearing kimberlites in pipe 688 (Markwick, Downes, 2000) and V. Grib Pipe (original data) reveals that the crust section of the Zimniy terrane is composed of Paleoproterozoic metamorphosed igneous complexes. By their geochemical properties, xenoliths characterizing the middle crust (based on mineral geobarometers, P is approximately 5 kbar) correspond to Mg and Fe–Ti basalts, the geochemical and isotopic analogues of which are known among Early Paleoproterozoic intraplate volcanic and plutonic complexes of the Baltic Shield (Puchtel et al., 1997). It is remarkable that, similar to Paleoproterozoic intraplate volcanics of the Baltic Shield, these middle crust xenoliths are characterized by Archean Sm–Nd model ages (fig. 3), which reflects, probably, contamination of mantle magmas with Archean crust material at the initial stage of Paleoproterozoic rifting 2.4–2.5 Ga ago. Xenoliths transported from the lower crust (P ranging from 10 to 14 kbar) correspond compositionally to tholeiitic and calc-alkali basalts and adakites and are characterized by island-arc geochemical features representing juvenile Paleoproterozoic metamagmatic material with a variable, although insignificant, contribution of Archean material (T_{Nd}(DM) from 2.0 to 2.4 Ga, fig. 3).

U–Pb isotopic dating of captured zircons was carried out for three kimberlitic samples from V.Grib, Pionerskaya and Vesennaya pipes (fig. 4).

In the zircon population from porphyric kimberlite of the V.Grib pipe 1.8–2.0 Ga old grains strongly predominant. The ages of the remaining grains fall into Archean and Riphean intervals of ~2.7 Ga, 1.5 Ga and 1.2 Ga. Zircon population from the porphyric kimberlite of the Pionerskaya pipe mainly consists of Riphean grains 1.0 Ga, 1.2 Ga and 1.5 Ga with a few grains of Paleoproterozoic age. No Archean zircon was found in this pipe. We believe that xenocryst zircon age distribution from the porphyric kimberlite probably reflects the age of crustal rocks along the migration path of kimberlite magma. Thus the differences in zircon ages suggest the Paleoproterozoic crust under the Pionerskaya pipe was more juvenile and underwent stronger Rhiphean reworking in compare with crust under the V.Griba pipe. Zircons, separated from the tuff-breccia of the Vesennaya pipe, show five age groups: ca 2.8, 2.4, 1.8, 1.5 and 1.2 Ga. This is probably result of mixture of sedimentary zircon provinces and zircons that came from a deep level of the crust underlying the pipe.

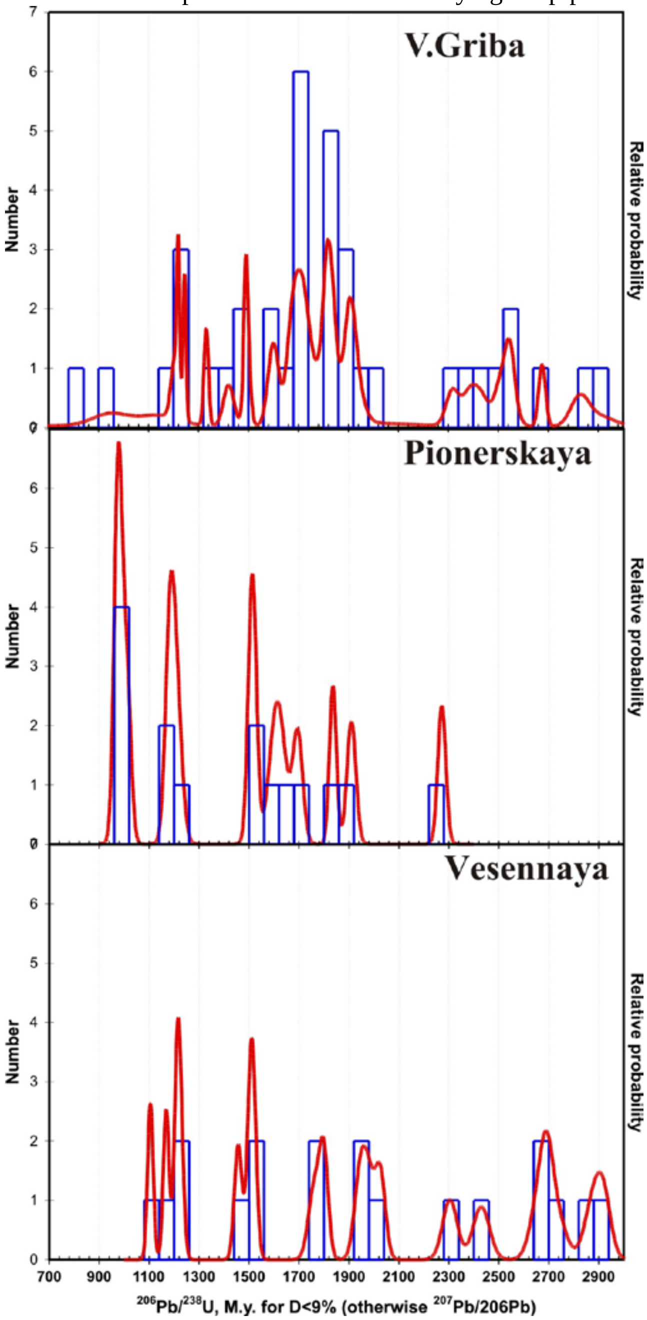

Fig. 4. Histograms of the U-Pb zircon ages for the zircon xenocrysts from kimberlitic pipes of the ADP.

Sm–Nd isotopic characteristics of the kimberlites, which reflect the compositional peculiarities in both the mantle source of these rocks and evidently contaminating crustal material, also point indirectly to the heterogeneous nature of the crystalline basement in the Arkhangelsk diamondiferous province and probable confinement of diamond- bearing kimberlites to areas with the Paleoproterozoic crust. The relatively young (probably, Paleoproterozoic) age of the crust, which hosts diamond-bearing kimberlites of the Zolotitskoe, Verkhota, and Kepa fields of the Zimnii Bereg area, is emphasized by the Sm–Nd isotopic–geochemical characteristics of these kimberlites (εNd (380) from –4 to +3). To the contrary, εNd (380) values obtained for diamond-free kimberlite sills of the Mela River area, alkali picrites of the Izhmozero field, and Nenoksa melilitites located north and south of the Zimnii Bereg zone () vary from –5 to –10, which implies an older, probably Archean age of the basement intruded by these rocks.

DISCUSSION AND CONCLUSION

Thus, all these data indicate that diamond-bearing kimberlites of the Arkhangelsk diamondiferous province are localized in the Paleoproterozoic collisional suture, which is inconsistent with "Clifford's rule." It should be emphasized that the data under consideration were obtained from the distribution area of commercial diamond-bearing kimberlites, which strengthens arguments in favor of inferences and allow the assumption that the confinement of kimberlites to collisional sutures is not incidental, but regular, although there is limited evidence substantiating the last assumption, which is explained by insufficient knowledge. Indeed, data on localization of kimberlites in suture zones have been obtained only for shields, where the Early Precambrian crust is relatively well studied. Substantially less extensive data on the age and tectonic type of old structures are obtained for kimberlite provinces localized in plate areas of old platforms, where the Early Precambrian basement is buried under a thick platform cover. Nevertheless, even in such regions there are grounds to assume an association of some diamondbearing kimberlites with collisional sutures, since it is known that localization of kimberlites is controlled by major tectonic fractures. Despite the fact that these structures originated in the Late Precambrian or Phanerozoic, they inherit in most cases positions of older sutures, along which blocks of the primitive lithosphere were stitched into the first large continental masses. The tectonic model under consideration does not conflict with ideas on preserved roots of the Archean lithosphere representing hypothetical sources for diamonds transported by kimberlites. Indeed, it proposes a probable mechanism of their formation. Hence, tectonic accretion on collisional zones could provide burial of preserved fragments of the cooled Archean lithosphere at significant depths; i.e., the cold lithospheric root, which serves as a diamond source, increased.

ACKNOWLEDGMENTS

This work became possible owing to support by the ALROSA Company Administration. Core material for studies was kindly donated by E.M. Verichev (V. Grib Pipe) and I.L. Makhotkin (Borehole 1200). Xenoliths and

samples for zircon studies from kimberlites of V. Grib Pipe were collected by V.A. Pervov.

This work was supported by ALROSA Company Administration and the Russian Foundation for Basic Research, projects no. 11-05-01130-a and 10-05-00901-a.

REFERENCES

Arzamastsev A., Travin A. and Arzamastseva L. Final episode of Paleozoic magmatism in the NE Fennoscandian Shield: 40Ar/39Ar isotope dating of diamond bearing kimberlites and picrites from the southern Kola. Finland // Abstracts for the 6th workshop of the Svekalapko, an Europrobe project. Institute of Geosciences, Oulu, Finland. 2001. P. 4

Cawthorn R. G. Kaapvaal Craton, South Africa: Repeated Basic Magmatism, Diamonds and Plumes // AGU Chapman Conference. The Great Plume Debate: The Origin and Impact of LIPS and Hot Spots. Fort William, UK. 28 August – 1 September 2005. Abstracts.

Clifford T.N. Tectono-metallogenic units and metallogenic provinces of Africa // Earth and Planetary Sci. Lett. 1966. P. 421-434.

Daly J.S., Balagansky V.V., Timmerman M.J., Whitehouse M.J. The Lapland–Kola orogen: Palaeoproterozoic collision and accretion of the northern Fennoscandian lithosphere // Gee D.G. & Stephenson R.A. (eds). European Lithosphere Dynamics. Geological Society, London, Memoirs. 2006. 32, 579–598.

Deines P., Viljoen F., Harris J. W. Implications of the carbon isotope and mineral inclusion record for the formation of diamonds in the mantle underlying a mobile belt: Venetia, South Africa // Geochimica et Cosmochimica Acta, 2001.Vl. 65, P. 813–838.

Helmstaedt H.H., Gurney J.J. Geotectonic controls of primary diamond deposits: implications for area selection // J. Geochem. Explor. 1995. P. 125–144.

Jaques A., Lewis J., and Smith C., Kimberlites and Lamproites of Western Australia (Geol. Surv. Western Australia, 1986; Mir, Moscow, 1989)

Kononova V. A., Nosova A. A., Pervov V. A., and Kondrashov I. A. Compositional variations of kimberlites of the East-European Platform as a result of sublithosphere geodynamic processes // Doklady Earth Sciences. 2006. 409A. P. 952-956

Kostinen, T., Stephens, M.B., Bogachev, V., Nordgulen, O., Wennerstrom, M. & Korchonen, J. 2001. Geological map of the Fennoscandian Shield, scale 1:2000000. Geological Survey of Finland, Norway and Sweden and North-West Depatment of Natural Resources of Russia.

Lepekhina E., Presnyakov S, Matukov D. et al. Single grain U-Pb zircon dating (SHRIMPII) from Grib kimberlite pipe (Zimny Bereg, Archangelsk region, Russia) // 32 IGC. 2004. G10.05.

Markwick A.J.W., Downes H. Lower crustal granulite xenoliths from the Arkhangelsk kimberlite pipes: petrological, geochemical and geophysical results // Lithos. 2000. V. 51. P. 135–151.

O'Brien H.E., Peltonen P., Vartiainen H. Kimberlites, carbonatites, and alkaline rocks. In: Lehtinen M., Nurmi P.A., Ramo O.T. (Eds.). Precambrian geology of Finland – key to the evolution of the Fennoscandian Shield // Elsevier B.V., Amsterdam. 2005. P. 605-644.

Pogrebitskii Yu. E., Shimaraev V. N., Verba V. V., et al., The Map of the Anomalous Magnetic Field of Russia and Adjacent Land and Sea Areas, 1 : 10 000 000 (NPO Sevmorgeo, Russia; Geol. Surv. Canada; Conoco Incorporated, USA; 1993

Puchtel I.S., Haase K.M., Hofmann A.W., et al. Petrology and geochemistry of crustally contaminated komatiitic basalts from the Vetreny belt, southeastern Baltic Shield: Evidence for an early Proterozoic mantle plume beneath rifted Archean continental lithosphere // Geochim. Cosmochim. Acta. 1997. V. 61. P. 1205-1222.

Stachel T., Brey G.P., Harris J.W. Inclusions in sublithospheric diamonds: Glimpses of deep Earth // Elements. 2005. P. 73-78.

Ushkov VV, Ustinov VN, Smith CB, Bulanova GP, Lukyanova LI, de Vries DW, Pearson DG Kimozero, Karelia; a diamondiferous Palaeoproterozoic metamorphosed volcaniclastic kimberlite // 9th International Kimberlite Conference Extended Abstract No. 9IKC-A-00199. 2008

White S.H., de Boorder H., Smith C.B. Structural controls of kimberlite and lamproite emplacement // J. Geochem. Explor. 1995. P. 245–264.

Contact: Alexander Samsonov
Chief of the Laboratory Petrography,
INSTITUTE OF GEOLOGY OF ORE DEPOSITS, PETROGRAPHY, MINERALOGY AND GEOCHEMISTRY RUSSIAN ACADEMY OF SCIENCES (IGEM RAS)
IGEM, Staromonetny per., 35, Moscow, 119017 Russia
e-mail: samsonov@igem.ru