

# MEGACRYSTS FROM GRIBA KIMBERLITE PIPE (ARKHANGELSK PROVINCE)

By S.I. Kostrovitsky<sup>1</sup>, E.M. Verichev<sup>2</sup>, V.K. Garanin<sup>3</sup>, L.V. Suvorova<sup>1</sup>, I.V. Aschepkov<sup>4</sup>, V. Malkovets<sup>4</sup>, W.L. Griffin<sup>5</sup>  
<sup>1</sup> - Inst. of Geochemistry, Irkutsk, Russia; <sup>2</sup> - Arkhangelskgeolrazvedka, Arkhangelsk, Russia; <sup>3</sup> - Moscow State University, Moscow, Russia; <sup>4</sup> - Inst. of Geol., Geophys. and Mineral., Novosibirsk, Russia; <sup>5</sup> - CSIRO Div. of Explor. and Mining, Australia

The composition of macro/megacryst minerals from Griba kimberlite pipe, Arkhangelsk province, Russia was studied. The mineral association includes garnet, clinopyroxene, picroilmenite (magnesian ilmenite), phlogopite as well as garnet-clinopyroxene intergrowths. The crystalline inclusions, involving mainly clinopyroxene and picroilmenite were studied in garnet megacrysts. Mineral composition was analyzed by microprobe "JEOL" JXA-50A at Moscow State University and JXA-733 at the Institute of Geochemistry, Irkutsk. The mineral geochemistry was investigated by the proton microprobe in CSIRO Div. of Exploration and Mining, Australia.

## MINERAL COMPOSITION

**Picroilmenite** is a predominant mineral of the kimberlite heavy fraction. It occurs as rounded, oval-flattened and fragmental-angular grains up to 1 cm and over and as microcrystalline inclusions in garnet and phlogopite megacrysts. We have studied the composition of both macro/megacryst grains, varying in size from 5 to 15 mm and picroilmenite microinclusions 300x20 to 400x250 microns. In addition to rounded and rounded-oval inclusions some of them are sliced and angular-like with resorption margins. Tables 1 and 2 give the representative picroilmenite composition.

**Table 1. Representative compositions of picroilmenite from pipe Griba.**

	1	2	3	4	5	6	7
SiO <sub>2</sub>	0,19	0,09	0,07	0,37	0,28	0,03	0,3
TiO <sub>2</sub>	55,33	56,06	50,59	54,51	55,18	51,46	54,53
Al <sub>2</sub> O <sub>3</sub>	0,45	0,52	0,47	0,48	0,26	0,28	0,42
Cr <sub>2</sub> O <sub>3</sub>	2,19	1,64	8,31	2,04	2,62	7,78	2,4
Fe <sub>2</sub> O <sub>3</sub>	6,22	3,28	7,4	7,52	4,02	4,22	3,6
FeO	21,55	26,42	20,12	19,77	23,45	24,67	24,94
MnO	0,18	0,22	0,47	0,22	0,32	0,31	0,26
MgO	13,69	12,73	12,84	15,53	13,91	11,37	12,9
MgTiO <sub>3</sub>	48,5	43,7	44,8	52,8	47,8	39,7	44,8
FeTiO <sub>3</sub>	42,9	50,8	39,4	37,8	45,3	48,4	48,73

1-6 – separate macrocrysts, 7 – average of 66 analysis.

**Table 2. Representative compositions of picroilmenite inclusions in the garnet megacrysts, pipe Griba.**

	1	2	3	4	5	6	7
SiO <sub>2</sub>	0,29	0,34	0,09	0,47	0,18	0,39	0,32
TiO <sub>2</sub>	56,13	54,85	54,22	56,25	56,23	53,9	55,21
Al <sub>2</sub> O <sub>3</sub>	1,15	0,93	0,68	0,91	0,57	0,99	0,81
Cr <sub>2</sub> O <sub>3</sub>	3,2	3,46	4,37	2,41	3,01	3,63	3,17
Fe <sub>2</sub> O <sub>3</sub>	0	0	1,13	0	0	2,27	0,75
FeO	27,36	28,65	27,5	27,8	27,69	25,56	27,31
MnO	0,19	0,15	0,28	0,22	0,25	0,28	0,26
MgO	11,78	11,55	11,82	11,83	12	12,87	12,12
MgTiO <sub>3</sub>	41,3	39,8	40,57	41,4	41,8	43,9	41,8
FeTiO <sub>3</sub>	53,8	55,4	52,99	54,6	54,1	48,9	53

1-6 – separate inclusions, 7 – average of 9 analysis.

Picroilmenite macro/megacrysts from Griba pipe are marked by wide variations of major elements, low iron

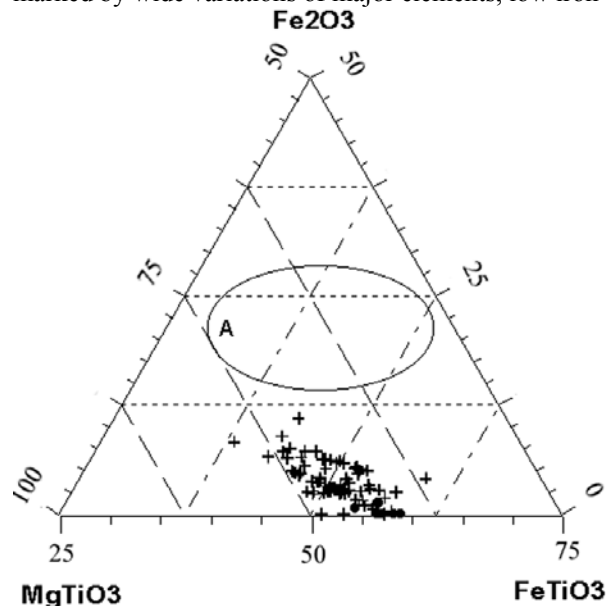


Figure 1. Plot of picroilmenite compositions: plus – macro/megacrysts from pipe Griba, black circle – inclusions in garnets from p. Griba, oval A – field of compositions of picroilmenite from Yakutian province.

oxidation and are rich in chromium (Fig. 1). Average Cr<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> contents amount to 2,4 and 3,6 wt %, respectively.

correspondingly. The macrocryst picroilmenite with such averaged compositional parameters hasn't been found in kimberlites of the Yakutian province. For example, in ilmenites from the Daldyn field the maximum average Cr<sub>2</sub>O<sub>3</sub> concentrations can reach as high as 1.5-1.8% (Osennya pipe), while minimum Fe<sub>2</sub>O<sub>3</sub> content amounts to 10 % (Leningradska pipe). The composition of picroilmenite from inclusions in garnet is similar to that of ilmenite macrocrysts, though the picroilmenite is richer in Cr<sub>2</sub>O<sub>3</sub> and the poorest in Fe<sub>2</sub>O<sub>3</sub> (Table 2).

Very low concentrations of trace elements from HFSE group (Zr, Nb, Hf, Ta) are also common to picroilmenite from Griba pipe.

**Garnet** occurs as separate macro/megacrysts. They are typically rounded, in cases with relics of crystallographic shape. Macrocrysts are as a rule not over 1 cm in size. Intergrowths of garnet and chrome-diopside are frequently found. Therewith the interactions between minerals are different. Clinopyroxene and garnet of intergrowths commonly occur in equal proportions. These minerals can occur both in the center and on peripheries of megacrysts. In cases clinopyroxene is found on margins of the garnet megacrysts, forming separate grains with uneven borders or discontinuous rim. Megacryst intergrowths with a predominant clinopyroxene and garnet as fine inclusions are rare.

Garnets from Gar-Cpx intergrowths (Table 3) are

**Table 3. Representative compositions of garnets from pipe Griba**

	1	2	3	4	5	6	7
SiO <sub>2</sub>	41,77	41,9	41,09	40,97	41,98	41,90	42,02
TiO <sub>2</sub>	0,3	1,02	0,24	0,03	0,1	0,24	0,68
Al <sub>2</sub> O <sub>3</sub>	21,47	19,9	19,94	21,69	19,74	21,24	20,39
Cr <sub>2</sub> O <sub>3</sub>	1,32	3,11	4,23	2,53	5,09	2,65	2,23
FeO	10,57	9,02	7,51	7,33	7,07	8,07	9,77
MnO	0,29	0,34	0,4	0,38	0,33	0,36	0,35
MgO	19,16	19,7	20,58	21,66	20,46	20,58	19,5
CaO	4,62	4,85	4,55	4,33	4,76	4,51	4,59
Na <sub>2</sub> O	0	0,18	0,01	0,02	0,08	0,02	0,07
Total	99,5	100,0	98,55	98,94	99,59	99,57	99,6
Pyr	67,0	69,3	71,8	74,4	70,5	71,87	68,2
Alm	20,8	17,8	14,9	14,1	14,2	15,87	19,27
Spess	0,58	0,68	0,80	0,74	0,67	0,73	0,71
Gross	7,2	0,87	0	3,7	0	3,5	3,8
Ti-Andr	0,79	2,69	0,63	0,08	0,26	0,64	1,8
Uvar	3,7	8,7	10,9	6,9	11,9	7,22	6,0
Knor	0	0	0,96	0	2,5	0,18	0,2
Mg#	76,4	79,6	83,0	84,0	83,8		

1-5 – from separate Gar-Cpx intergrowths, 6 - average of 20 analysis for intergrowths, 7 - average of 51 analysis for macro/megacrysts. Mg# = Mg/(Mg+Fe)\*100.

similar in composition to the macrocryst garnet, though on the whole they are richer in Cr<sub>2</sub>O<sub>3</sub> and MgO. By the classification (Dawson, 1980) garnets belong to groups 1, 2 and 9 and are mainly lherzolite-derived. (Fig. 2). It should be noted that titanium and high-titanium pyroxenes, belonging to groups 1 and 2, correspondingly (the majority of studied grains) are richer in Cr<sub>2</sub>O<sub>3</sub>.

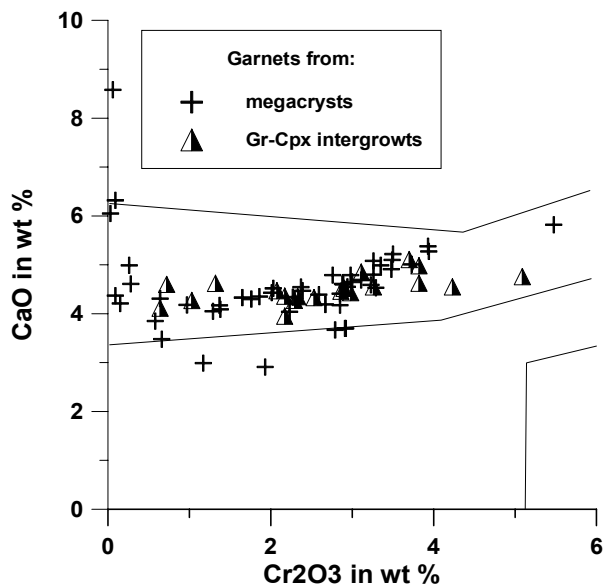


Figure 2. Plot of Cr<sub>2</sub>O<sub>3</sub> vs CaO for the garnets from pipe Griba.

Having wide variations in Cr<sub>2</sub>O<sub>3</sub> (1.3-9.6%) and CaO (3,6-11.0 %), macro/megacryst garnets are characterized by relatively stable MgO (15,4-22,3-wt.%) и FeO (5,2-9,9-wt.%) amounts. Variations in garnet composition are mainly due to the decrease of the uvarovite mineral content with a corresponding increase of the pyrope one. Garnet and chrome-diopside in intergrowths demonstrate wide variations in composition.

The majority of investigated garnet macrocrysts turned out to be homogenous. Only some macrocrysts show a weak zoning with a slight increase of Cr<sub>2</sub>O<sub>3</sub> concentration and decrease in TiO<sub>2</sub> content towards peripheries.

**Clinopyroxenes** occur as separate macro/megacrysts which are rounded, elongated in cases subidiomorphic with crystallographic shape. The macrocrysts are 1 cm or over in size.

By the classification (Dawson, 1980) pyroxenes from macrocrysts and from intergrowths with garnet from Griba pipe belong to chrome-diopside and jurtitic diopside. Pyroxenes (Table 4) are marked by wide variations in content of such oxides as Cr<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub> and Na<sub>2</sub>O (0.56-2.95; 0.86-3.25; 1.3-3.0 wt.%, correspondingly) and in Mg/(Mg+Fe) and Ca (Ca+Mg) ratios, changing within 87.4-94.3; 43,1-50.7 ranges, correspondingly.

Clinopyroxenes from macrocrysts and from intergrowths have very similar compositions (Fig. 3).

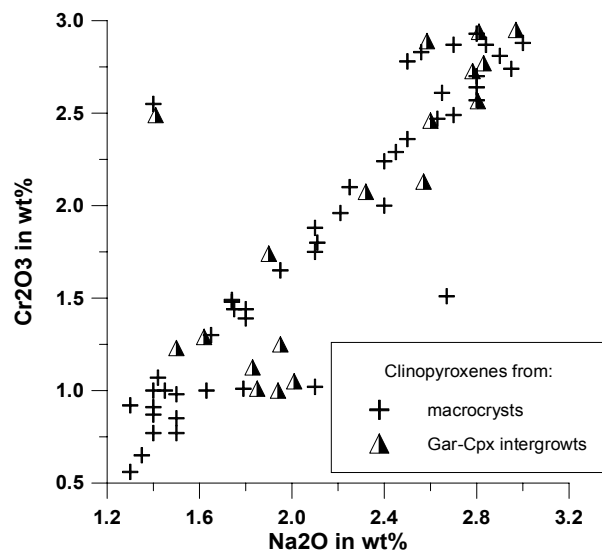


Figure 3. Plot of correlation  $\text{Na}_2\text{O}$  and  $\text{Cr}_2\text{O}_3$  in clinopyroxenes of pipe Griba.

Rare pyroxene macrocrysts are inhomogeneous in composition. Margins of grains are rich in  $\text{Cr}_2\text{O}_3$  and

**Table 4. Representative compositions of clinopyroxene from pipe Griba**

	1	2	3	4	5	6	7
$\text{SiO}_2$	54,45	54,41	55,41	54,57	54,83	54,67	55,21
$\text{TiO}_2$	0,21	0,25	0,5	0,14	0,17	0,25	0,18
$\text{Al}_2\text{O}_3$	3,47	2,87	1,88	2,64	3,04	1,78	2,48
$\text{Cr}_2\text{O}_3$	1,51	0,92	0,8	2,89	2,13	1,84	1,47
$\text{FeO}$	1,97	1,8	3,47	1,445	1,44	2,81	2,04
$\text{MnO}$	0,06	0,16	0,14	0,04	0,09	0,07	0,08
$\text{MgO}$	14,66	15,66	16,2	15,28	15,52	16,01	15,78
$\text{CaO}$	20,75	21,35	18,76	19,46	19,1	20,16	19,91
$\text{Na}_2\text{O}$	2,67	1,3	2,02	2,58	2,57	2,11	2,14
Total	99,75	98,72	99,18	99,04	98,88	100,7	99,29
Mg#	92,99	93,94	89,27	94,96	95,05	91,1	93,28
Ca#	50,46	49,52	45,46	47,83	46,97	47,6	47,6
Cr#	22,59	17,7	22,21	42,34	31,97	40,4	27,04

1-5 – separate macrocrysts, 6 - average of 50 macrocryst analysis, 7 – average of 19 analysis from Gar-Cpx intergrowths.

$\text{Al}_2\text{O}_3$  and poor in  $\text{MgO}$ .

Like picroilmenites, garnets and clinopyroxene from Griba pipe have low concentrations (as compared with megacrysts from the Yakutian pipes) of trace elements from HFSE group (Zr, Nb, Hf, Ta). REE amount is high and widely varies in particular for clinopyroxene. REE distribution in garnets and clinopyroxene (Fig.4) corresponds to the pattern of their

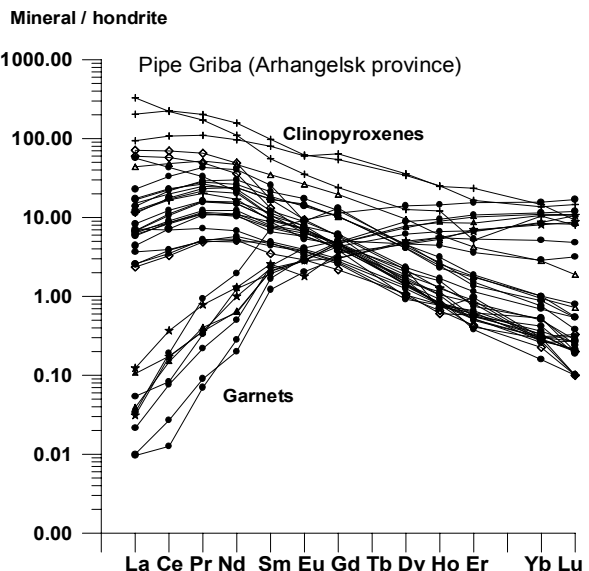


Figure 4. Chondrite normalized rare-earth element patterns for megacrysts of garnet and clinopyroxene from pipe Griba. Filled circles correspond to different homogeneous megacrysts; plus, triangle, square, romb, star correspond to unhomogeneous megacrysts (2-4 analysis for each grain).

joint crystallization and is typical of minerals from the megacryst association.

**Phlogopite** is found as large lamellar macro/megacryst crystals with rounded margins (from 2-3 mm to 15 mm along a long axis). Phlogopite megacrysts show (Tabl. 5) high magnesium (23-30.2, average as 25.4 wt.% of  $\text{MgO}$ ) and moderate  $\text{TiO}_2$  (0.32-1.18, average as 0.67 wt.%)

**Table 5. Some compositions of phlogopite from pipe Griba**

	1	2	3	4	5	6	7
$\text{SiO}_2$	42,46	42,86	41,75	39,33	40,95	40,68	41,14
$\text{TiO}_2$	0,6	0,58	0,53	0,95	1,07	0,43	0,67
$\text{Al}_2\text{O}_3$	11,59	12,15	11,66	10,45	11,07	11,16	11,1
$\text{Cr}_2\text{O}_3$	0,24	0,54	0,74	0,54	0,56	0,68	0,59
$\text{FeO}$	3,8	3,98	3,64	3,53	3,65	3,2	3,94
$\text{MnO}$	0	0	0,08	0,11	0	0	0,06
$\text{MgO}$	25,11	25,9	25,41	23,4	24,13	24,44	25,41
$\text{K}_2\text{O}$	11,51	11,92	11,37	11,07	11,26	11	10,51
Total	95,31	97,95	95,18	89,39	92,69	91,6	93,44
Mg#	92,17	92,06	92,56	92,2	92,18	93,16	91,3

1-6 – separate macrocrysts, 7 - average of 39 analysis.

and  $\text{Cr}_2\text{O}_3$  (0.22-0.85 average as 0.6 wt. %) contents, that is typical of the primary phlogopite from mantle peridotite xenoliths.

## DISCUSSION

Kimberlites from Gribo pipe include abundant macrocrysts and megacrysts of picroilmenite, garnet, clinopyroxene and phlogopite. High MgO and moderate to high Cr<sub>2</sub>O<sub>3</sub> content is common for minerals. The genetic similarity of minerals and a common paragenesis are confirmed by studies of co-existing minerals from intergrowths and crystalline inclusions. Garnet and clinopyroxene from intergrowths show a clear direct correlation (Fig. 5) in terms of chromium coefficient (Cr/(Cr+Al) ratio). Therewith minerals from garnet-clinopyroxene intergrowths and from macrocrysts demonstrate similar variations in composition. It indicates a synchronous crystallization of garnet and chrome-diopside macrocrysts. On the other hand like picroilmenite macrocrysts, crystalline picroilmenite inclusions from garnet megacrysts are characterized by high chromium content. They do not differ from the latter in MgO concentration. It is the strongest argument to include picroilmenite in the same paragenetic mineral association together with garnet and chrome-diopside. The paragenesis under discussion typically contains chrom-spinelid but not picroilmenite as in Gribo pipe. Garnet-clinopyroxene intergrowths were crystallized (Krough, 1988) under a wide low-temperature (732 - 1125 °C) range. Under temperature decrease the crystallization trend is directed towards the increase of MgO and Cr<sub>2</sub>O<sub>3</sub>

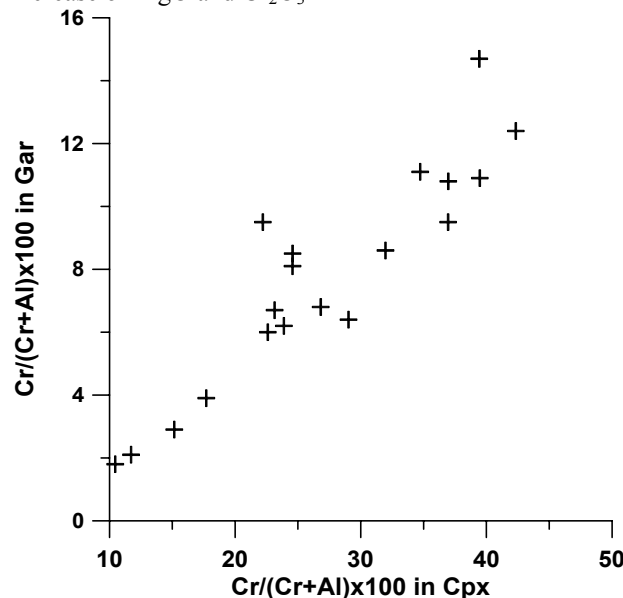


Figure 5. High correlation of compositions of garnet and clinopyroxene from intergrowths from pipe Gribo.

contents in clinopyroxenes and decrease of TiO<sub>2</sub> abundance in garnets. The crystallization trend of picroilmenite tends towards the MgO content increase if the crystallization under minimum oxidizing potential

is taken as the trend start (Fig. 1). Picroilmenite crystallization (that results from low hematite minal and high Cr<sub>2</sub>O<sub>3</sub> abundances) approximates to conditions of the diamond crystallization. In this respect kimberlite from Gribo pipe is most likely the exception, which demonstrates connection of picroilmenite with diamond.

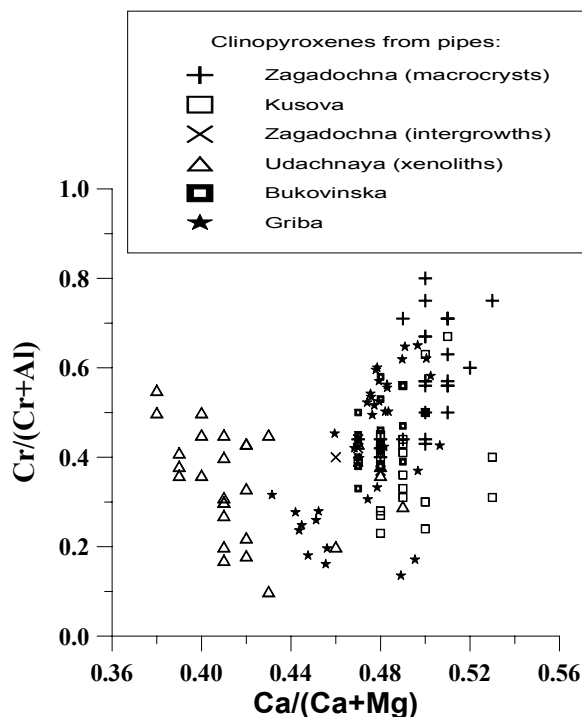


Figure 6. Plot of ratios Ca/(Ca+Mg) vs Cr/(Cr+Al) for the clinopyroxene from different pipes (see legend). Data for xenoliths are taken from (Sobolev, 1977). Data for the rest pipes are unpublished by authors.

In composition the minerals from the described association differ from the corresponding minerals of the mantle lherzolite-derived xenoliths. However, they show the similarity with the macrocryst mineral association from mica-bearing kimberlites of Zagadochnaya, Kusova and Bukovinskaya pipes (Yakutian province). They were supposed (Kostrovitsky, De Bruin, 1998) to have the phenocryst origin. On a Ca/(Ca+Mg)-Cr/(Cr+Al) plot chrome-diopsides from Gribo pipe and those from mica-bearing kimberlites form a common trend (Fig. 6). The macro/megacryst mineral association of Gribo pipe presumably originates due to the crystallization of the kimberlite melt on protomagmatic stage of the mantle chamber evolution. In addition to ilmenites and other macrocrysts the host kimberlites from Gribo pipe are poor in HFSE (Zr group) (Krotkov, et al., 2001). The inhomogeneous composition of some megacrysts, wide variations in REE abundance in particular for clinopyroxene suggest an influence of asthenosphere

metasomatic fluid after the crystallization of most minerals.

We suppose that depending on the primary melt composition different paragenetic associations of macro/megacrysts can be crystallized in kimberlites. They include: 1) Fe-Ti (Mir, Udachnaya pipes); 2) high-Mg, Cr (Zagadochnaya, Kusova pipes); 3) high-Mg, Cr, Ti (Griba pipe). Compositions different in terms of major elements are mainly due to inhomogeneous lithosphere source of the melt. Rare element composition of megacrysts in particular for incoherent elements indicates features in the composition of the asthenosphere source.

Investigations were supported by RFBR (grant № 02-05-64793).

## REFERENCES

- Kostrovitsky S.I., De Bruin D. (1998) Ultramafic association of minerals (garnet-ureyit diopside-chromspinelid) in micaceous kimberlites of Yakutian province. In: Extended abstracts, 7IKC, Cape Town, pp. 463-465.
- Krogh E.J. (1988) The garnet-clinopyroxene Fe-Mg geothermometer - a reinterpretation of existing experimental data // Contrib. Mineral. Petrol., v. 99, pp. 44-48.
- Aschepkov I.V. (2001): Clinopyroxene barometer for a deep rocks. Abstracts of reports of XIV Russian conference on the experimental mineralogy. Chernogolovka, p. 250.
- Dawson J.B. (1980): Kimberlites and their xenoliths. Springer-Verlag Berlin, New York.
- Kostrovitsky, Alymova et al. (2003): Structure of the Daldyn field (Yakutian province) on the base of study of picroilmenite composition. This issue. 8IKC.
- Krotkov V.V., Kudriavtseva G.P., Bogatkov O.A. et al (2001): New technologies of diamond deposits exploration. Moscow: GEOS, 310p.
- Mitchell R.H. (1986): Kimberlites. Mineralogy, geochemistry, and petrology. Plenum Press. New York. 442 p.
- Sobolev N.V. (1977): Deep-seated inclusions in kimberlites and the problem of the composition of the upper mantle. American Geophys. Union, Washington D.C.

---

Contact: S.I. Kostrovitsky, PO Box 4019 Irkutsk, Russia, 664033, E-mail: [serkost@igc.irk.ru](mailto:serkost@igc.irk.ru)