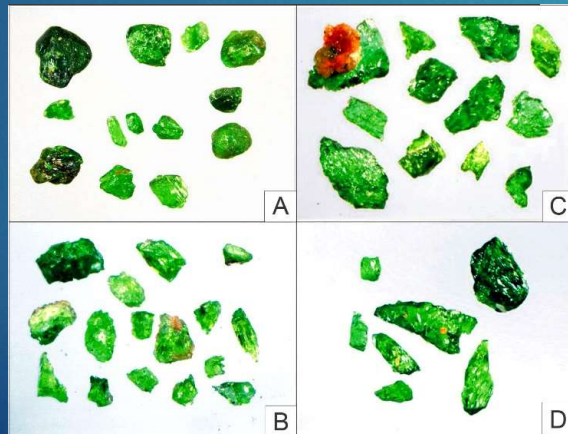
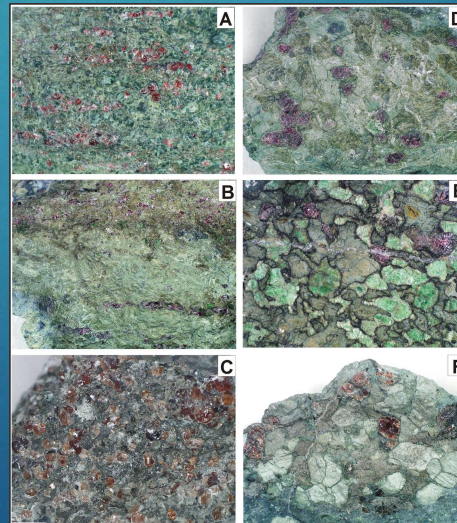


Unusual mineralogical features and origin of the mantle substratum Nakyn kimberlite fields (Yakutia)

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*“The essence of the rocks determines its **mineral composition**
and **composition of its minerals**”*
S.M.S.

Introduction

Kimberlites are original mineralogical reservoir for many endemic, unusual minerals. Mineralogical characteristics of kimberlites reflect material features of the initial (parent) mantle substratum and are the most important for the determination of the basic knowledge about the reasons and conditions of their origin. Sometimes the characteristic features determining individuality of the kimberlites are not only the variations of the rock forming minerals (for example, dominating olivines, pyroxenes and garnets), and some small, rare but very bright, effective and even unexpected features of minor or accessory minerals. In addition, for the person determining these features the most interesting it is not only attractive color of and the petrological significance.

The Nakyn field with their specific mineralogical reservoir was open about 40 years later, than all the others diamondiferous fields in Yakutia (Bobrievich et al, 1964; Cherny et al., 1998). The mineralogical features of Nakyn kimberlites have no analogues not only among kimberlites other fields of the Yakutia province, but also among the other kimberlitic provinces of the World.

Nakyn kimberlites sharply differ from the others diamondiferous Yakutian kimberlites by very low contents of all incompatible elements excluding large ion lithophile elements (LILE) - potassium, rubidium and phosphorus. More ancient age -399 million years, related to early Devonian (Sablukov et al., 2007), instead of 320-370 Ma, late Devonian - early Carboniferous (Sun et al., 2014; Brakhfogel, 1984) and some unusual isotope characteristics (Kononova et al., 2005; Sablukov et al., 2007b). The basic, evident to all difference Nakyn kimberlites from others Yakutian kimberlites is a sharp prevalence of pyrope and chrome spinel above the picroilmenite of the "megacrystic" associations (Kornilova et al., 2001; Tomshin et al., 1998), that is typical for Groups-2 kimberlites of Southern Africa (Smith et al., 1985). However, judging by the Nd-Sr isotope characteristics Nakyn kimberlites correspond to Group-1 kimberlites as the other kimberlites fields of Yakutia (Kostrovitsky et al., 2013). Such uniqueness of Nakyn kimberlites is defined by a unusual set and composition of protokimberlite evolution determining the variations of megacrystic suits and their in reaction with mantle substrate, and so also by the original structure of mantle beneath the Nakyn field as a whole (Ashchepkov et al., 2010; 2014).

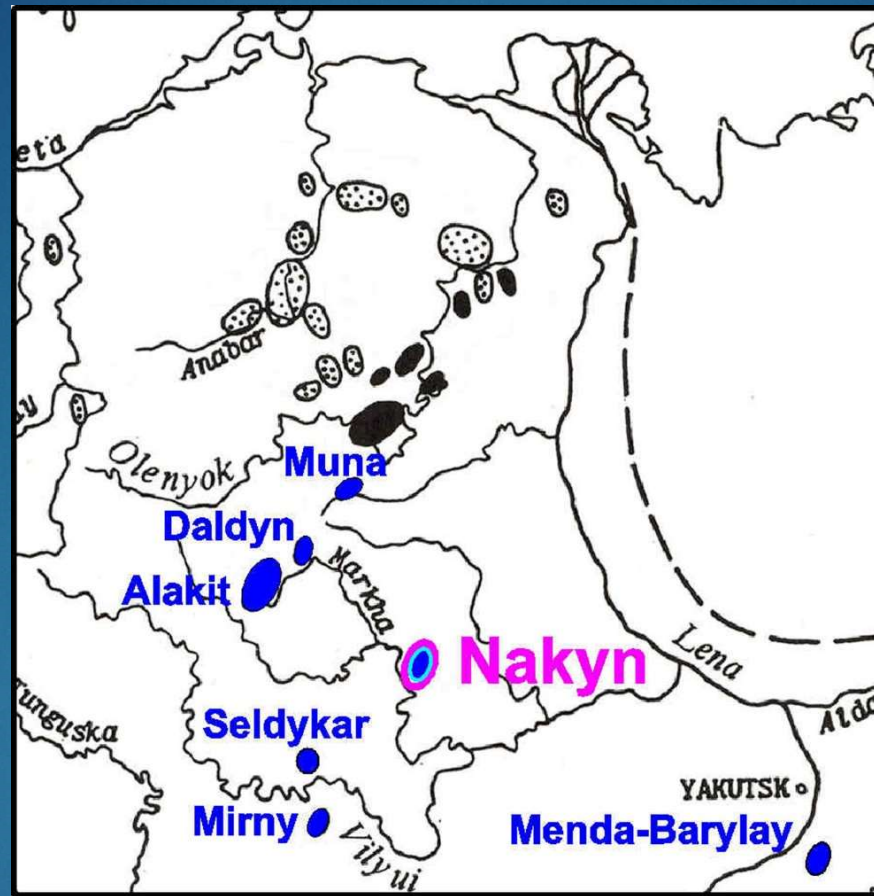


Fig. 1. Distribution of kimberlite fields on the Yakutia Province.

Geological objects

Nakyn fields diamondiferous kimberlites (Cherny et al., 1998) are located separately, on significant distance (~300 km) from other fields Yakutia provinces (fig. 1). In 2006-2016 years we studied in detail the Nakyn field and most detail the Nyurbinskaya kimberlites pipe (together with the “precursor dike”), Botuobinskaya pipe and Mayskaya pipe (checked ~ 85 drill holes, more than 10000 meter of a core material, the walls of mines, a material of ores from the court yard). We also washed the material of the diamond placers near the Nyurbinskaya and Botuobinskaya pipes (more than 120 drill holes).

Samples and methods of research

We collected and investigated in detail more than 1100 mantle xenoliths (about 1000 samples in Nyurbinskaya pipe and approximately ~ 50 samples from both Botuobinskaya and Mayskaya pipes). The mineralogical analysis is made for about 100 probes of kimberlites and about 400 probes of placers. electron microprobe analysis of different minerals (about 4000 analyses) was done at the laboratory of "Gintsvetmet" using "Cameca SX-50" device at accelerating voltage of 20 kV, current 15-20 nA. The relative standard deviation does not exceed 1.5%; the precision was close to 0.02-0.01% for minor elements. The trace element composition of garnets (30 analyses) was studied at the Center of Isotope Researches FGUP CSEGEI (St.-Petersburg) using LA-ICPMS method. For the laser ablation the DUV-193 with excited-state dimer laser COMPex-102 was used connected with the mass spectrometer Element-II (Finnigan firm). The diameter of a beam is ~ 200 micron; impulse frequency of the laser is 10 hertz. The NIST 610-612 were used as a standards. The precision was about 1-0.5 ppm and relative standard deviation does not exceed 5-10%;

The calculations of TP-parameters of formation mineral paragenesis was carried out with the original program "PT-Quick".

Compositional features of the deep seated mantle minerals

The set of the basic, prevailing deep-seated minerals in Nakyn fields kimberlites (and mantle xenoliths) is different from the other Devonian kimberlites in Yakutian province and is more typical of the Groups - 2 Southern Africa kimberlites (Smith et al., 1985): it conferences mainly the olivine, red-violet pyropes and chrome spinel.

Olivine

Olivine macrocrysts and megacrysts (0,5-2 cm, up to 6 cm in the size) make up to 40 % of kimberlite volume of all 3 studied pipes. However all olivine is completely replaced with the aggregate of secondary minerals (serpentine, a carbonate). Fresh (not altered) olivine it is met only in a unique sample kimberlites of the Nyurbinskaya pipe on depth of 896 m. Olivine grains are colorless, with very weak greenish or yellowish shade, sometimes with inclusions violet pyropes. Olivine has usual composition for kimberlite chrome - magnesium mineral association: 6,8-9,4 % FeO, 0,30-0,50 % NiO, 0,01-0,07 % Cr₂O₃, < 0,05 % CaO.

Chrome spinel

Chrome spinels are distributed in all studied kimberlites and especially in Nyurbinskaya pipe it occurs much less in mantle xenoliths than garnet. Compositional features are various enough, from chrome spinel from spinel-pyroxene facies (B) up to diamond-pyrope facies (D) (Sobolev, 1974), and the chromites of the high-pressure facies are prevailing. In kimberlites, the chrome spinels of the diamond association compile up to 20-25 % of their total is increased. The compositional features of the majority of chrome spinel are quite usual for the other diamondiferous kimberlites

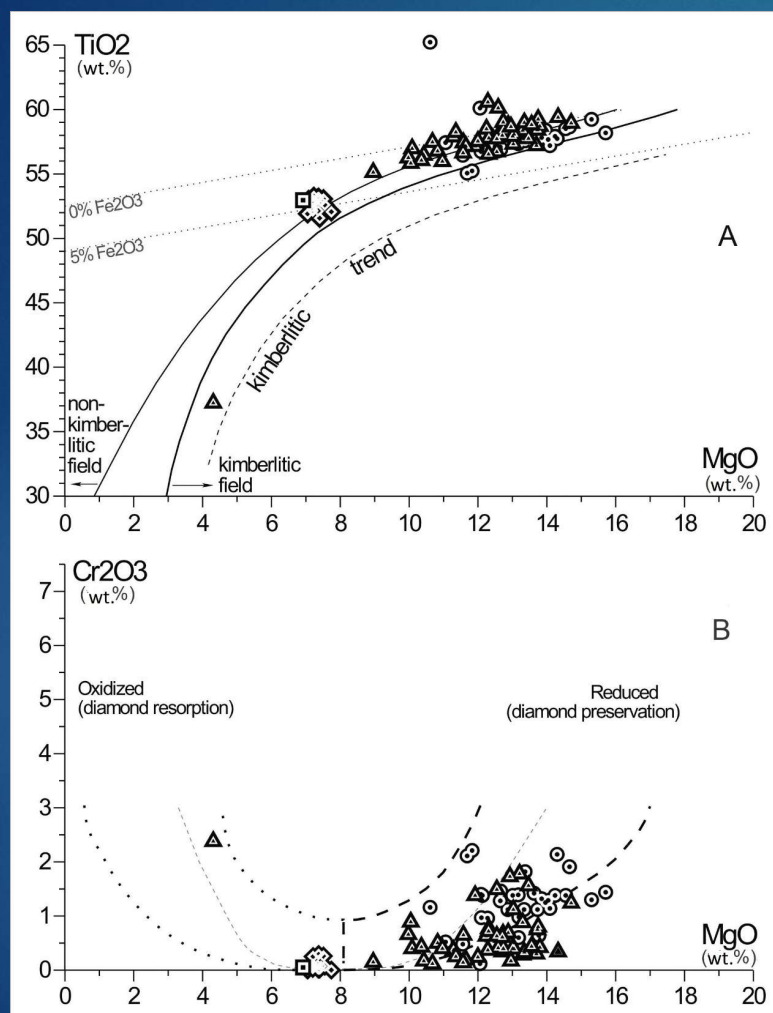


Fig. 4. Chemical composition of the ilmenite from Nyrbinskaya pipe mantle xenoliths: diagram (Wyatt et al., 2004) (top); diagram (Gurney et al., 1991; Haggerty, 1975) (bottom).

Symbols: points of compositions: a circle – garnet peridotites; a triangle – garnet clinopyroxenites and eclogites; a rhombus and a square – marids and lamprophyre type protokimberlites

Picroilmenite

Picroilmenite of the "megacryst" associations is completely absent in Nakyn kimberlites. It contradicts them Nd-Sr isotope parameters, related Bulk Silicate Earth (BSE) source (Kononova et al., 2005; Sablukov et al., 2007b), as well the others Yakutian kimberlites and Groups-1 kimberlites of Southern Africa (Smith et al., 1985), where the picroilmenites are very frequent. The abundance of ilmenites usually characterizes the influence of the asthenospheric protokimberlite sources on the mantle substratum.

Absence of picroilmenites of the "megacryst" associations in Nakyn kimberlites especially is surprising, because a significant amount of orange-red titanium pyropes from the appropriate pyrope "megacryst" associations usually associated with picroilmenites is wide spread in Nakyn kimberlites. These orange-red titanium pyropes occur in Nakyn kimberlites as typical "megacrysts" - large nodules and garnetite aggregations with the size from 1 up to 5,5 cm (fig. 2). The serpentinized olivine megacrysts with the inclusions of titanium orange pyrope (up to 6 cm in size) are also frequent. And megacrystalline garnet peridotite and clinopyroxenite xenoliths (the size up to 10 cm) with orange pyrope of the "megacryst" associations are widespread. However, picroilmenites in all these mantle formations are not present.

However, picroilmenite in all kimberlite pipes Nakyn fields nevertheless are found. They were met in tuffitic kimberlites of Nyurbinskaya pipe and occurs in surrounding diamond placers. Picroilmenites are present only in garnet-bearing mantle xenoliths (peridotites, pyroxenites, eclogites), or in metasomatic rocks (MARIDs, glimmerites) derived from the protokimberlites of the lamprophyric types).



In all mantle xenoliths (peridotites, pyroxenites, eclogites) picroilmenite is the accessory mineral occurring as rare grains in the size up to 1 mm. The picroilmenite contents sometimes reaches 0,1-0,5 % of volume and it's segregations are forming sideronitic microtexture of the rocks. Picroilmenites were meets only in garnet peridotites and garnet clinopyroxenites of the directive (sheared) structures focused: chained, linear, plane-parallel, including in clearly parallel-zone (stratified, layered) rocks (fig. 3). Picroilmenite is not met in peridotites and clinopyroxenites with massive structure (both allotriomorphic, panidiomorphic, and proto granular textures). Picroilmenite also meets as fine grains and in accessory amounts in metasomatic mantle rock nodules (MARIDs, glimmerites). The maximum quantity of picroilmenite (up to 5 %), is detected in protokimberlite -derived lamprophyric type of xenolith, sometimes with elements sideronite textures. This type rocks according to the structure and composition are nearer to metasomatic mantle rocks such as MARIDs and glimmerites probably having coherent relations. They, by analogy to character of formation of term "MARID" (Mica-Amphibole-Rutile-Ilmenite-Diopside), rocks of this type can be named by term "MAOIte" (Mica-Apatite-Olivine-Ilmenite) inclusions.

The picroilmenite compositions from the various types of mantle xenoliths from Nyurbinskaya pipe (garnet peridotites, garnet clinopyroxenites and eclogites) by their characteristic features may determine the genetic types mantle rocks (table 1). They are characterized by the high contents of TiO_2 , MgO and Cr_2O_3 , very low contents of hematite component. On the classification diagram (Wyatt et al., 2004) (fig. 4) their compositions plots outside the area of typical kimberlitic picroilmenites of the "megacryst" association. Small distinctions between garnet peridotite ilmenites on the one hand, and also garnet clinopyroxenite and eclogite ilmenites on the other hand are marked basically by the increased contents of chrome and magnesium in peridotite ilmenites (0,5-2,2 % against 0,25-0,89 % Cr_2O_3 and 11.9-15.3 % against 9,98-13,75 % MgO).

Picroilmenite from prothokimberlite lamprophyric type inclusions ("MAOItes") and MARIDS significantly differs from picroilmenites from garnet peridotites-pyroxenites-eclogites the lowered contents of magnesium (7,0-7,7 % MgO), the lowest contents chrome and alumina (0-0,08 % Cr_2O_3 and 0-0,10 % Al_2O_3) and the increased contents of manganese (0,85-0,95 % MnO), but at the same time they shows similarity in high contents of the titanium and the low contents of the hematite components. Its composition also falls outside the limits composition typical ilmenites from kimberlites and practically forms the uniform trend with the ilmenites formed in garnet peridotites-pyroxenites-eclogites from Nyurbinskaya pipe. It emphasizes genetic unity of these completely different types of deep inclusions of a Nyurbinskaya pipe. An opposite to Nyurbinskaya pipe kimberlites, in Nyurbinskaya placers were found the compositions of picroilmenites of the typical "megacryst" associations.

Individual picroilmenites of the garnet peridotite inclusions from the Botuobinskaya pipe and Mayskaya pipe fully coincides in textural position, and chemical compositions to picroilmenites of the garnet peridotite inclusions from the Nyurbinskaya pipe.

Originality of picroilmenite compositions is one of the most interesting mineralogical features Nakyn field kimberlite pipes.

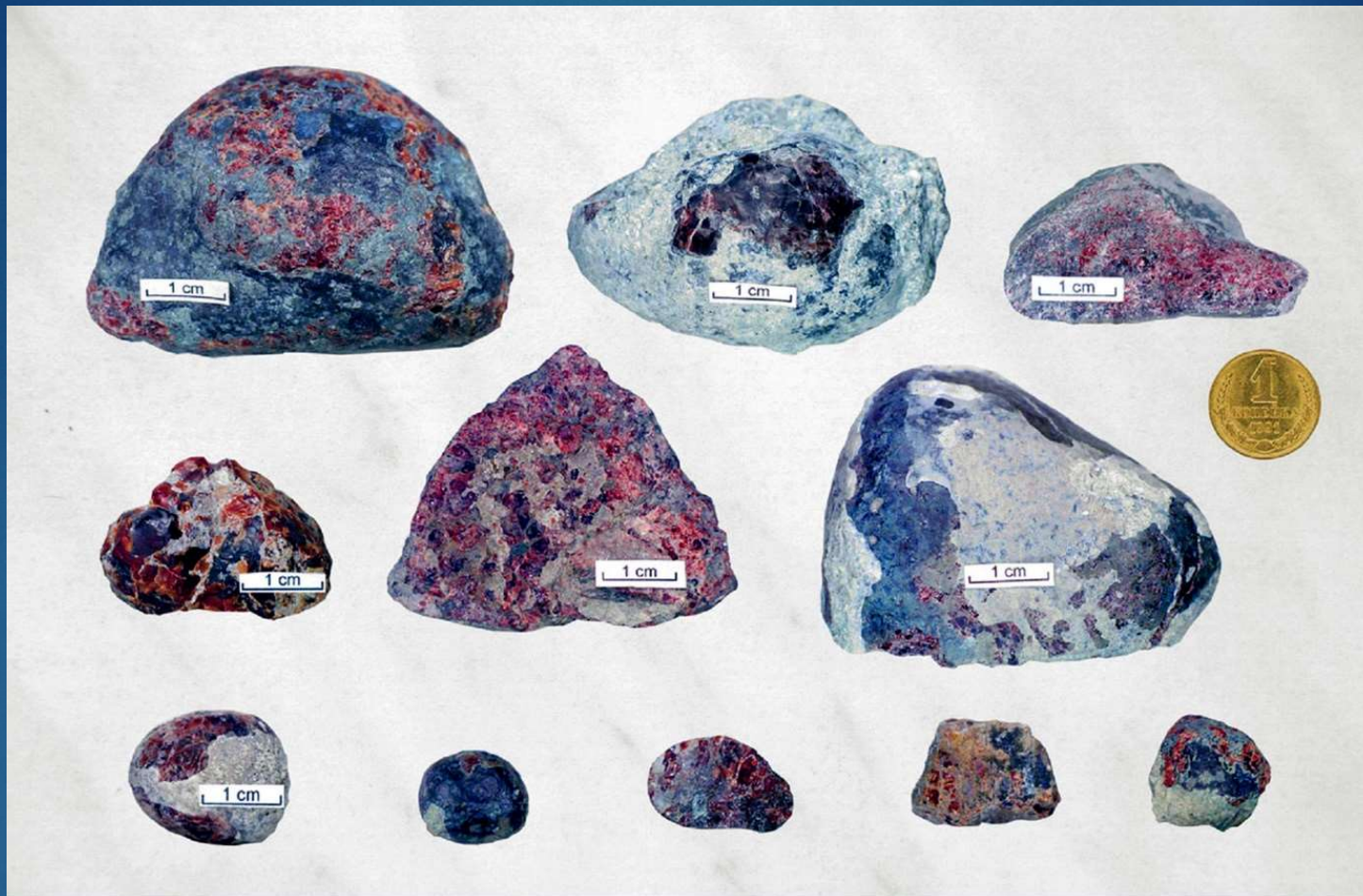


Fig. 2. Orange-red titanous pyrope megacrysts from Nyrbinskaya pipe kimberlites.

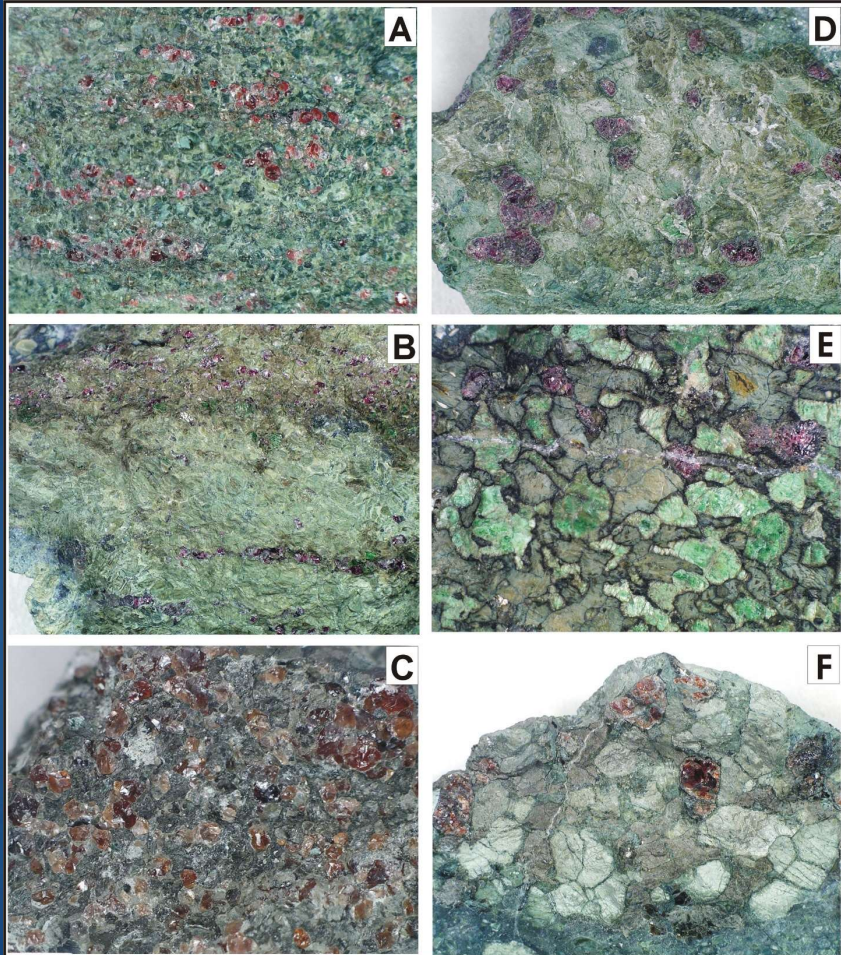


Fig. 3. Structural types mantle xenoliths, containing clinopyroxene as omphacite and chrome- omphacite (A, B, C) and as chrome-diopside (D, E, F). A, B – garnet peridotites with directive structures ; C - eclogite. D, E - garnet peridotites: D – proto granulare (panidiomorphhic) textures, E - allotriomorphhic textures; F - the titan-garnet peridotite "megacryst" associations panidiomorphhic textures. A field of a photo 3*4 see.

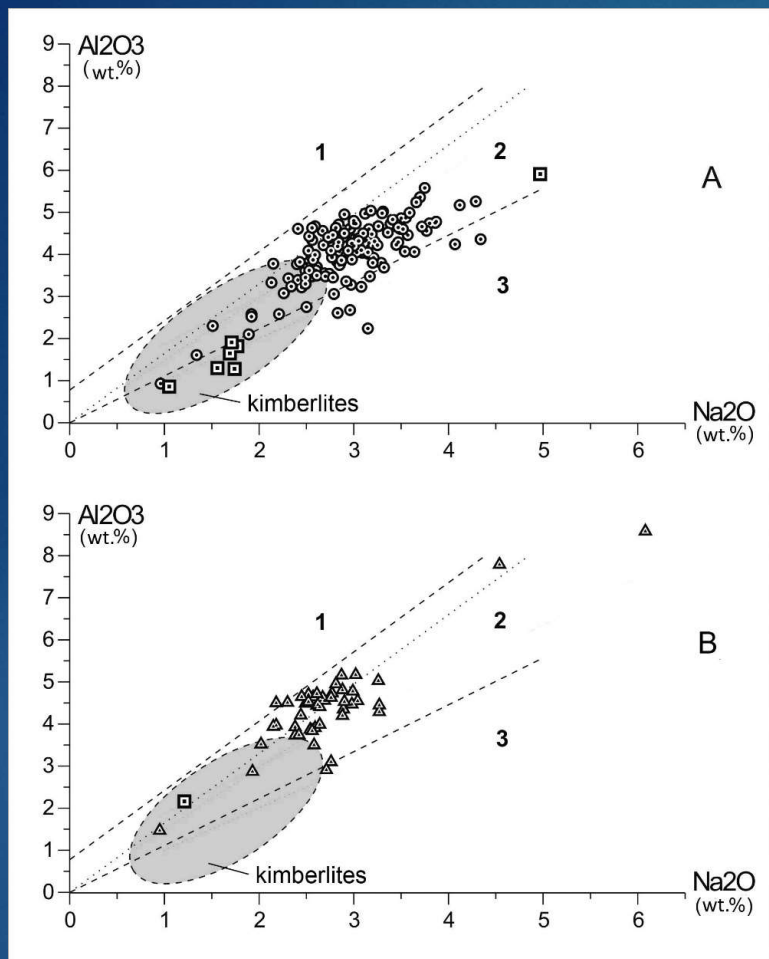


Fig. 6. Chemical composition of the clinopyroxene from Nyrbinskaya pipe mantle xenoliths: diagram (Ilupin, 1984; Sablukov et al., 1988; Sablukov et al., 2000): A – garnet peridotites with directive structures (circle), and garnet peridotites with protogranulare structures (square). Depth subfacies (after Sobolev, 1974): 1 - spinel-pyroxene facies “B” (7-17 kbar) and spinel-pyroxene subfacies “C1” (17-22 kbar); 2 - grospydite subfacies “C2” (22-34 kbar); 3 - coesite subfacies “C3” (34-40 kbar)

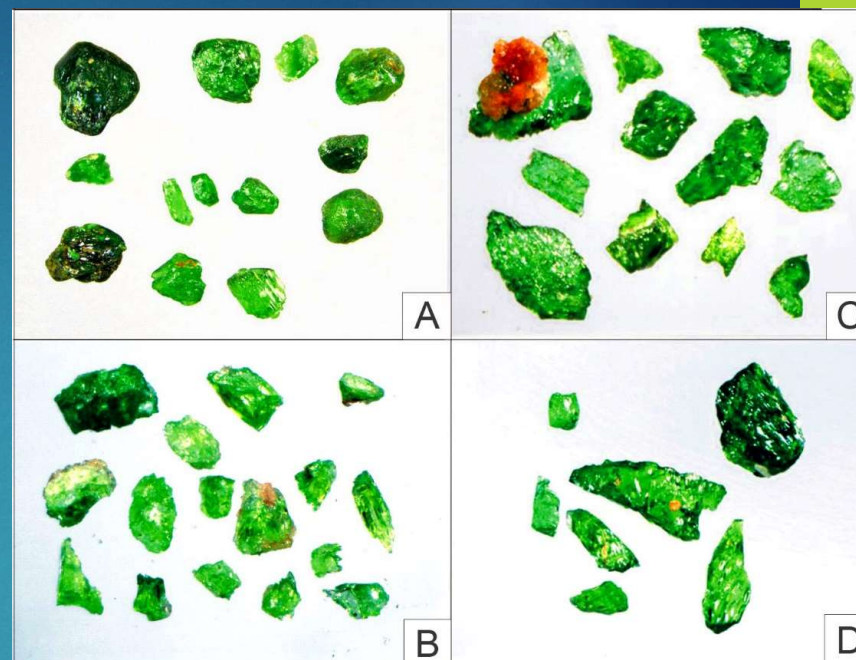


Fig. 5. Chrome-omphacite from kimberlites: A - Nyrbinskaya pipe; B – Botuobinskaya pipe; C,D – Mayskaya pipe

Orthopyroxene

Other typical mineralogical feature of the Nakyn field kimberlites is practically full absence of orthopyroxenes both in kimberlites, and in mantle xenoliths, even as pseudomorphoses. Usually clinopyroxene pseudomorphoses are diagnosed in Nakyn mantle xenoliths, but much more expressive and easily determined orthopyroxene pseudomorphoses in the Nakyn mantle xenoliths are practically absent. From approximately 1000 investigated mantle xenolith samples we detected only four xenoliths with orthopyroxene pseudomorphoses: 3 orthopyroxenite xenoliths and one websterite xenolith. Therefore overwhelming part of peridotite xenoliths from Nakyn kimberlites judging by composition of a garnet are "lherzolithic", (Sobolev, 1974) or refer to "wehrlite" field. Probably, the unusual increased contents of "wehrlite paragenesis" garnets is a typical feature of some kimberlite pipes of the Nakyn fields (see lower).

This unusual mineralogical feature Nakyn kimberlites - practically full absence orthopyroxene which have no explanation.

Clinopyroxene

Clinopyroxenes are widely distributed in Nakyn field kimberlite pipes. Due to very high degree of kimberlites alteration the fresh clinopyroxene occurs in kimberlites rarely, but in the deeper drill cores the amount of fresh grains grows.

Major part of clinopyroxene grains from Nakyn kimberlites and mantle xenoliths has typical bright emerald-green color (fig 5).

For clinopyroxene from kimberlites and different mantle xenolith types of Nyurbinskaya pipe (in great number of inclusions) unexpectedly close features of composition (table 2, fig. 6,7,8) are characteristic are high calcium (47,6-50,6 % Ca#), the elevated content of sodium (2-5 % Na₂O) and aluminium (3,5-5,5 % Al₂O₃), and the lowered contents of iron (1,3-2,4 % FeO) and magnesium (12,6-15,0 % MgO) at variable contents chromium (0,07-4,5 % Cr₂O₃). The clinopyroxene compositions of only individual (rare) samples plot outside these narrow compositional range. The high-sodium and high-aluminium areas, dropping with a plenty of grains settle down (fig. 6), this is untypical for the chrome-diopside from kimberlites and mantle xenoliths other regions Worldwide.

The component analysis of minerals shows, that overwhelming majority chrome-bearing clinopyroxenes of the Nyurbinskaya pipe refer to “chrome-omphacite”, instead of chrome-diopside” (as in others kimberlite regions). For identification of a clinopyroxenes as omphacite the following conditions (in formular units) should be satisfied (after Udovkina, 1985)):

$0,15 < Na \leq 0,75$; $Al^{IV} = 0 - 0,15$; $Fe^{3+} = 0 - 0,12$; $(Na - Fe^{3+}) / Fe^{3+} > 1$; $Al^{IV} / (Al^{IV} + Fe^{3+}) > 0,15$.



According to these criteria, the percentage of omphacite among the selected chrome-bearing clinopyroxenes in Nyurbinskaya pipe and of rocks some other regions was determined (table 3). So, in Zimny Bereg kimberlite area (Arkhangelsk diamondiferous province) the percentage of omphacite among clinopyroxenes is less than in Nyurbinskaya pipe in three-four times. Such high percentage of omphacites in Nyurbinskaya pipe is caused by a plenty of garnet peridotites with directive structures. It is well visible by comparison of figures of clinopyroxene compositions for peridotites and eclogites-clinopyroxenites (fig. 6,7). On the discrimination diagram (Taylor et al., 1989) (fig. 7) it is visible, that clinopyroxenes from garnet peridotites as a whole are less magnesium, than clinopyroxenes from eclogites and garnet clinopyroxenites which is quite unusual fact.

So, clinopyroxenes from prevailing types mantle xenoliths of Nyurbinskaya pipe are omphacite (according to Udovkina, 1985): There are simple “omphacites” (eclogitic), or “chrome-bearing omphacite” (garnet clinopyroxenites), or “chrome-omphacite”. These include practically all garnet and chrome spinel peridotites). Thus distinction the between peridotite clinopyroxenes and clinopyroxenite clinopyroxenes (switching to eclogites) is clearly determined only by the content of chrome (more than 1 % and less than 1 % Cr₂O₃, accordingly).

The typical “chrome-diopside”, with relatively low Na-Al content have only four individual mantle xenoliths types: 1) primary-magmatic garnet peridotites with proto granular and allotriomorphic textures; 2) garnetites of chromious association; 3) garnet clinopyroxenites with titanitic garnets of "megacryst" type; 4) metasomatic rocks of MARID series.



Singularity of composition of clinopyroxenes of Nyurbinskaya pipe mantle xenoliths is well visible and on the Cr_2O_3 - Al_2O_3 diagram (Ramsay, 1992) (fig. 8). The significant part clinopyroxenes from garnet peridotites and garnet clinopyroxenites with directive structures plots in the field of «off-craton Gt-peridotites and Sp-peridotites». In a field of «on-craton Gt-peridotites» all chrome-diopside from the listed above four type mantle xenoliths are plotted, and also chrome-omphacite from a part of garnet peridotites.

Investigated clinopyroxenes of Botuobinskaya pipe were divided to chrome-omphacites and chrome-diopsides approximately half-by-half. Clinopyroxenes from a Mayskaya pipes are characterized by higher content of Al_2O_3 (3,1-6,2 %), Na_2O (4-6,8 %) and Cr_2O_3 (4-7,2 %), lowered contents FeO (1,7-2,3 %) and MgO (less than 12 %). They correspond chrome-omphacites of high-pressure deep-facies with unusually high percentage of ureyite (cosmochlore) component and some points located far outside of the discrimination diagrams (Ramsay, 1992).

As a whole, on unusual clinopyroxene compositions s of Nyurbinskaya pipe (and also Botuobinskaya pipe and Mayskaya pipe) essentially differ from kimberlites from the other fields of the Yakutian province, kimberlites of Arkhangelsk diamond provinces, and other diamond regions of the World. The unusual clinopyroxene compositions from kimberlites and mantle xenoliths, probably, are explained by unusually high percentage of high Al eclogitic (metapellitic material) in Nakyn mantle (Spetsius, 2004).

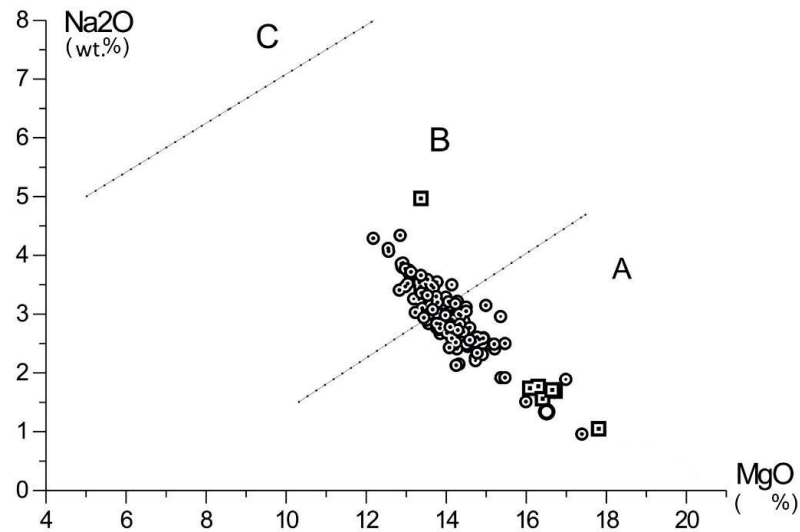
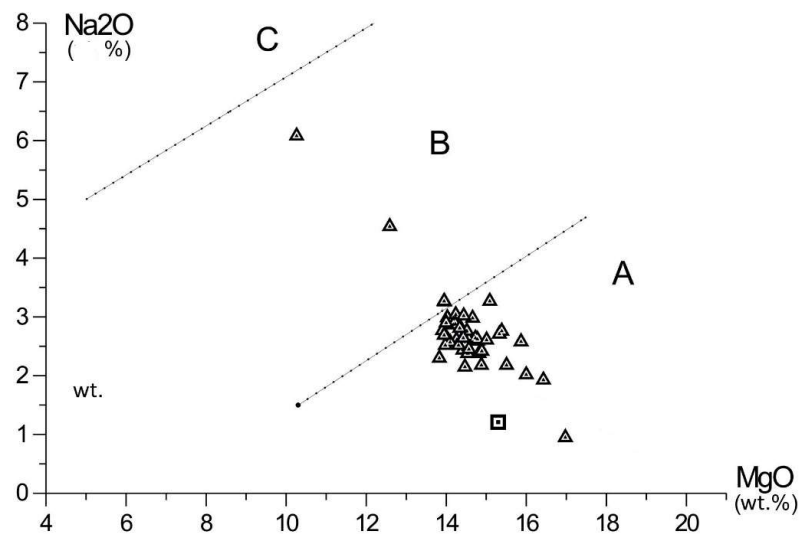


Fig. 6. Chemical composition of the clinopyroxene from Nyrbinskaya pipe mantle xenoliths: diagram (Ilupin, 1984; Sablukov et al., 1988; Sablukov et al., 2000): A – garnet peridotites with directive structures (circle), and garnet peridotites with protogranular structures (square); B – garnet clinopyroxenites, eclogites (triangle) and marides (square). Depth subfacies (after Sobolev, 1974): 1 - spinel-pyroxene facies “B” (7-17 kbar) and spinel-pyroxene subfacies “C1” (17-22 kbar); 2 - grosspyroxite subfacies “C2” (22-34 kbar); 3 - coesite subfacies “C3” (34-40 kbar).

Table 1. Chemical composition of the clinopyroxenes from Nyrbinskaya pipe mantle xenoliths (wt. %).

No	Rock*	Sample No	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	Total
1	GP	H-291	54.71	0.37	5.02	2.21	1.55	0.06	13.69	18.35	3.31	0	99.27
2	GP	H-364	54	0.34	4.48	1.66	1.67	0.05	14.09	19.23	3.19	0	98.71
3	GP	H-394	53.81	0.21	4.02	2.93	1.42	0.04	13.67	19.25	3.15	0	98.5
4	GP	H-460	54.01	0.42	4.66	1.61	2.08	0.08	13.56	18.91	2.84	0.01	98.18
5	GP	H-473	54.18	0.36	4.32	1.71	1.63	0.05	14.5	19.72	3.12	0	99.59
6	GP	H-531	54.27	0.27	4.22	1.86	2.5	0.03	13.32	19.29	3.25	0	99.01
7	GP	H-532	54.84	0.4	4.87	1.92	1.66	0.03	13.77	18.98	3.55	0	100.02
8	GP	H-563	54.68	0.3	3.61	1.48	2.1	0.08	14.47	20.39	2.49	0	99.6
9	GC	H-292	54.75	0.36	4.73	0.91	1.75	0.06	13.91	19.56	2.77	0	98.8
11	GC	H-292	54.49	0.39	4.81	0.94	1.67	0.07	14.17	19.78	2.88	0.01	99.21
13	GC	H-998	54.42	0.36	4.49	0.55	1.67	0.04	14.5	20.78	2.49	0	99.3
12	GC	H-267	54.87	0.34	3.52	0.22	1.69	0.11	16	20.24	2.02	0.02	99.03
10	GC	H-937-1	55.01	0.39	4.29	1.13	2.14	0.03	13.95	20.04	3.27	0	100.25
14	GC	H-692	54.17	0.33	4.51	0.09	2.75	0.09	13.83	20.71	2.3	0.02	98.8
15	E	H-104	54.59	0.3	3.97	0.18	1.95	0.02	15.51	20.39	2.18	0	99.09
16	E	H-1033	53.4	0.4	4.72	0.17	1.96	0.02	15.01	20.51	2.61	0	98.8
17	E	H-534	54.98	0.19	3.94	0.39	5.06	0.06	14.47	17.75	2.15	0.34	99.33
18	GP Pr-Gr	H-528	55.32	0.05	0.86	1.35	2.06	0.05	17.81	21.44	1.05	0.12	100.11
19	GP Pr-Gr	H-885	54.71	0.04	1.28	2.63	1.79	0.1	16.09	21.09	1.74	0.03	99.5
20	GP Pr-Gr	H-902	54.72	0.18	1.82	1.79	2.27	0.05	16.3	20.09	1.77	0.06	99.05
21	GP Pr-Gr	H-996	54.24	0.1	1.3	1.69	2.52	0.11	16.41	20.9	1.56	0.07	98.9

Note: * GP – garnet peridotite; GC – garnet clinopyroxenite; E – eclogite; GP Pr-Gr – garnet peridotite of protho-granular texture, massive structure.

Table 2. Chemical composition of the garnet from Nakyn field kimberlites and mantle xenoliths (wt%)

No	Pipe*	Rock	Sample No	Colour	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	Total
1	N	alkremite xenolith	H-678	pale pink	41.63	0.07	23.72	0.16	7.83	0.22	18.77	7.51	0	99.91
2	ND	kimberlite	HΔ137	pale pink	41.99	0.07	23.78	0.11	7.48	0.29	20.76	4.8	0.02	99.3
3	ND	kimberlite	HΔ137	pale pink	42.01	0.12	23.82	0.12	7.38	0.35	20.79	4.92	0.03	99.54
4	ND	kimberlite	HΔ137	pale pink	41.82	0.31	22.75	0.61	7.15	0.41	21.92	3.83	0.08	98.88
5	B	kimberlite	Б-4/3,0	green	38.25	0.34	11.79	13.85	7.72	0.45	10.61	15.8	0.03	98.84
6	B	kimberlite	Б-2/14,2	green	38.22	0.3	13.96	10.56	7.43	0.42	11.15	16.14	0.04	98.22
7	B	kimberlite	Б-4/7,0	green	37.55	1.33	10.24	14.5	5.94	0.45	10.74	17.3	0.04	98.09
8	B	kimberlite	56/540-117	green	37.08	1.77	9.41	14.86	5.47	0.38	7.96	22.26	0.3	99.49
9	B	kimberlite	56/540-117	green	37.99	1.57	10.42	13.74	5.68	0.48	8.13	21.49	0.03	99.53
10	B	kimberlite	56/540-117	green	37.75	1.5	10.05	14.12	5.8	0.39	7.92	21.61	0.06	99.20
11	B	kimberlite	56/540-117	green	37.25	1.64	9.24	14.93	5.68	0.52	7.89	22.26	0.24	99.65
12	B	kimberlite	56/540-117	green	37.52	1.59	9.35	14.88	5.5	0.34	8.05	22.06	0	99.29
13	B	kimberlite	122/120-83-2	green	37.71	1.66	10.82	12.3	6.92	0.43	7.37	22.07	0	99.28
15	M	kimberlite	P-7/3-67,0	green	38.46	1.52	10.84	12.85	5.77	0.44	7.99	21.27	0.03	99.17
17	M	kimberlite	P-7/6-74,3	green	38.96	0.44	13.91	9.46	5.94	0.36	5.32	25.34	0.03	99.75
16	M	kimberlite	P-8/3-72,2	green	38.82	0.58	15.87	7.56	6.13	0.38	7.14	22.18	0.06	98.72
14	M	kimberlite	P-8/3-72,2	green	39.15	0.63	15.98	7.64	6.08	0.44	7.26	22.37	0.05	99.59
18	M	kimberlite	P-7/3-67,0	green	40.06	0.59	17.67	6.78	7.38	0.51	11.44	15.43	0.1	99.95
19	M	kimberlite	P-7/3-68,7	green	40.28	0.51	17.02	7.61	6.87	0.45	11.75	16.06	0.04	100.59
20	M	kimberlite	P-7/3-73,5	green	40.13	0.38	17.96	6.67	7.33	0.53	12.16	14.88	0.07	100.09
21	M	kimberlite	P-7/6-68,0	green	39.38	0.1	17.59	6.66	6.23	0.48	11.33	17.01	0.04	98.8
22	M	kimberlite	P-7/6-68,0	green	39.3	0.11	17.73	6.35	6.26	0.45	11.6	16.89	0.02	98.7
23	M	kimberlite	P-7/6-68,0	green	40.15	0.07	17.97	6.86	6.33	0.4	10.98	17.02	0.03	99.79
24	M	kimberlite	P-7/6-68,0	green	40.28	0.14	17.92	6.84	6.23	0.45	11.05	17.03	0.04	100

Garnets

Pyrope of the red-purple colors

Pyrope is the most widespread "fresh" (not altered) deep mineral of the Nakyn kimberlites. Both in kimberlites, and in mantle xenoliths the pyrope of usual red - violet color of different shades and tones is sharply prevailing. The composition of the majority pyropes also is quite usual for chromic mineral association of the different type kimberlites: 0,5 - 14 % Cr₂O₃, 7,5-9,0 % FeO, 1-9 % CaO, 0,05 - 0,6 % TiO₂.

Pink garnets

Among the prevailing quantity of red-violet pyropes in Nakyn field kimberlites there are the pale pink low-chromium low-titanium pyropes which on composition correspond to garnets from rare type mantle xenoliths - alkremites (Ponomarenko, 1975). Among the investigated ~1000 mantle xenolith samples from Nyurbinskaya pipes the only one sample of alkremite xenoliths (fig. 9) (Sablukov et al., 2012) was found. However in Nyurbinskaya precursor dike kimberlites the high contents of garnets of such type and composition (table 4) was found, that can specify the wider distribution of these rare rocks - alkremites in a mantle of region.

Green garnets

One of the most interesting mineralogical features Nakyn field kimberlites is presence of green color garnets.

Green garnets (grossular-uvarovite-pyrope) are very rare in concentrates diamondiferous kimberlites of Yakutia, Southern Africa, Venezuela, Canada. For the first time green garnets in Yakutian kimberlite concentrates, in grosspydite xenoliths, and inclusions in diamonds are described by N.V.Sobolev (Sobolev, 1971; Sobolev et al., 1968; Sobolev et al., 1973). Detailed research xenoliths with a green garnets from Newlands dike kimberlites (Republic of South Africa) has shown, that they are metasomatic rocks similar of olivine – uvarovite – chrome spinel veins occurred in moderate depths of the upper mantle (80-90 km) (Sablukova et al., 2012; Sablukov et al., 2014). The new type "modal" mantle metasomatic process - "calcium" metasomatism (with versionsof : “chrome-calcium” and the “titanium–chrome-calcium” metasomatism).

Detailed research of Nakyn field kimberlites and placers allows us at first time to find out the green garnets in such significant amount, which was earlier marked only in Newlands dike kimberlites (Republic of South Africa).

In Nakyn field green garnets are of various colors and shades (fig. 10,11): there are grains green, emerald-green, grey-green, marsh-green and bluish-green up to dark blue color garnets. The green garnets from a Mayskaya pipe (fig. 11) are most various in color. These garnets are characterized by wide spectrum of compositional variations (table 4, fig. 12) of CaO (10-26 %), Cr₂O₃ (4-15 %), TiO₂ (0,1-1,86 %), FeO (5,5-9 %) and refer to uvarovite-grossulars and uvarovite-pyropes.

The trace element compositions shows the elevated LREE, Y contents, but is especially high Zr - up to 652-1042 ppm (Sablukov et al., 2014). The various shades refer to some features of the chemical compositions. So, for example, Mayskaya pipe garnets of *emerald-green* color are characterized by high contents of CaO (23-25,5 %), Cr₂O₃ (9-11,0 %) and lowered contents of TiO₂ (0,3-0,6 %) and FeO (5,5-6,5 %). The garnets of *bottle-green* color are characterized by lowered contents of CaO (15-16 %), Cr₂O₃ (6-8 %) and TiO₂ (0,3-0,6 %) and elevated contents of FeO (6,0-8,0 %).

Distinction types of green garnet characteristics are determined for the separate Nakyn field pipes. In Mayskaya pipe, green garnets as a whole differ from Botuobinskaya pipe green garnets by the lowered contents of chromium and the titanium. In addition, if to take into account that in the Nyurbinskaya pipe the green garnets were not found absolutely, it is possible to count green garnet the basic, mineral-indicator for Nakyn field kimberlites. The separate pipes differ as at a quantitative level (by a principle «more - less»), and at a qualitative level (by a principle «present - not present »).

Such high contents of green garnets as in a Botuobinskaya and Mayskaya pipes, it is typical only for Newlands dike kimberlites (Republic of South Africa). But such quantity and a variety on color and a chemical composition of green garnets (and wherlite paragenesis garnets as a whole) as in Botuobinskaya and Mayskaya pipes, is not present in one other kimberlites of the World.

Green garnets are the brightest, typomorphic mineralogical markers for Nakyn field kimberlites.

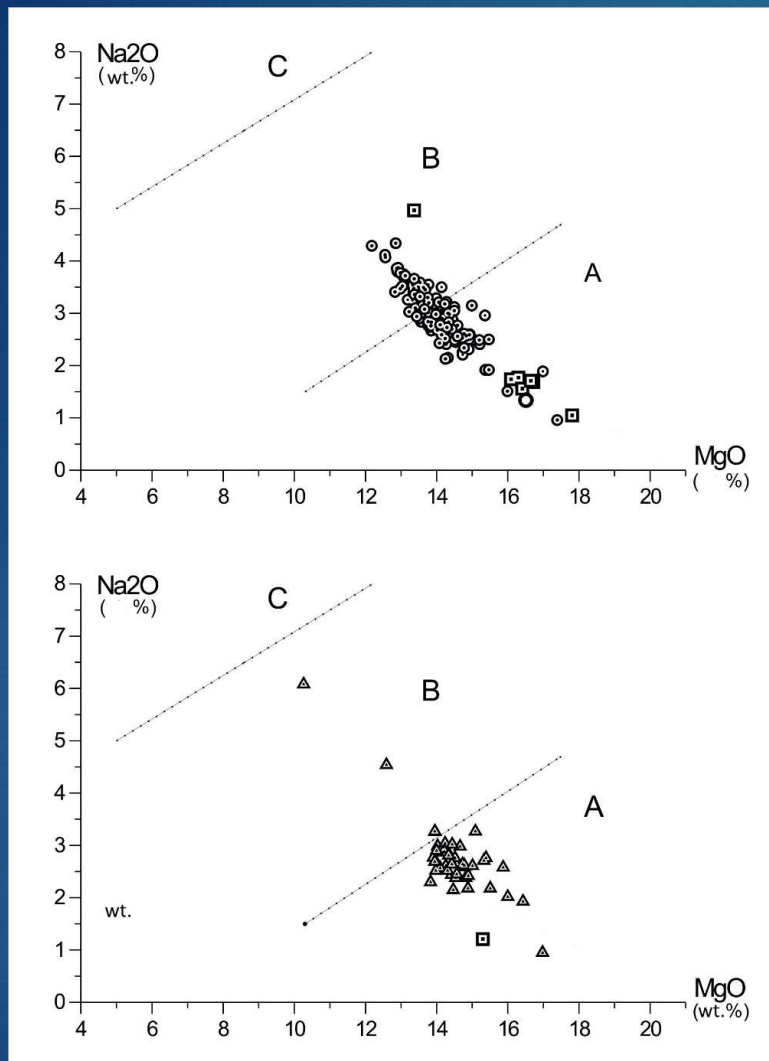


Fig. 7. Chemical composition of the clinopyroxene from Nyrbinskaya pipe mantle xenoliths, diagram (Taylor et al., 1989): top - garnet peridotites with directive structures (circle), and garnet peridotites with protogranular structures (square); bottom - garnet clinopyroxenites, eclogites (triangle) and marides (square). A, B, C - eclogite types after (Coleman et al., 1965).

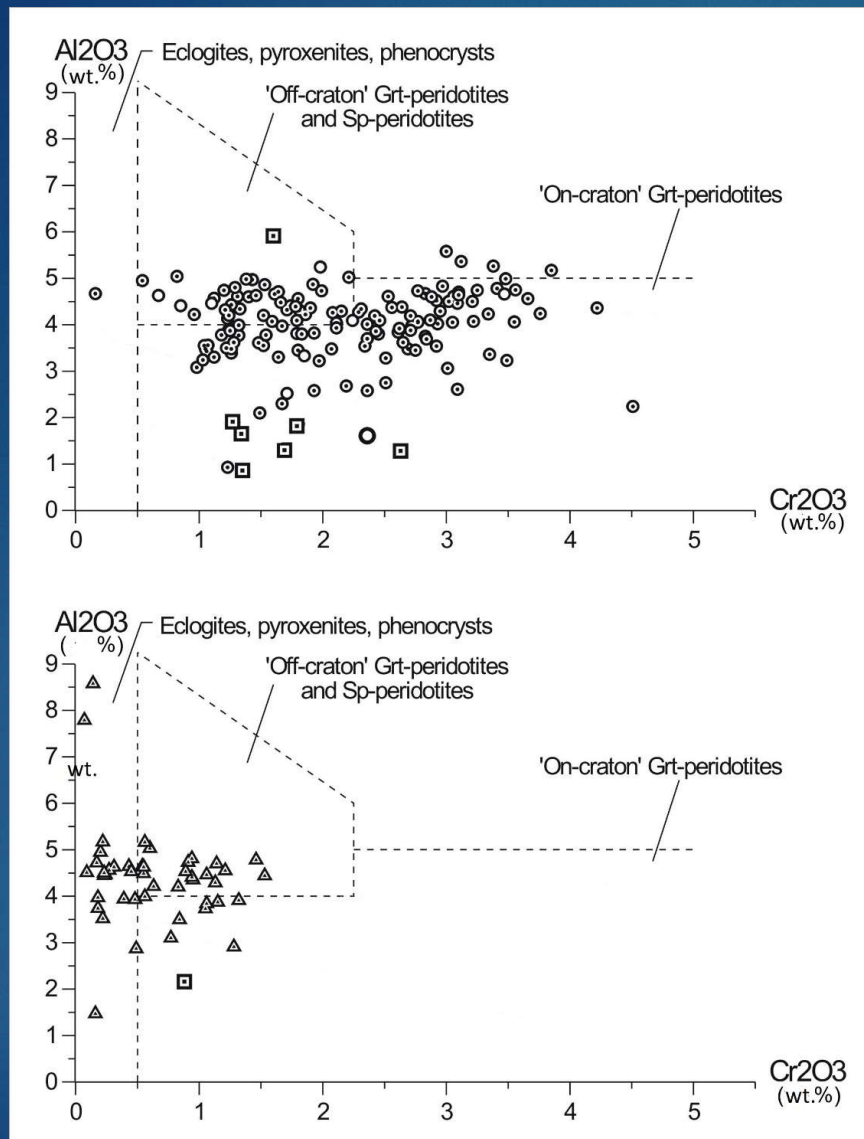


Fig. 8. Chemical composition of the clinopyroxene from Nyrbinskaya pipe mantle xenoliths, diagram (Ramsay, 1992): top - garnet peridotites with directive structures (circle), and garnet peridotites with protogranular structures (square); bottom - garnet clinopyroxenites, eclogites (triangle) and marides (square).

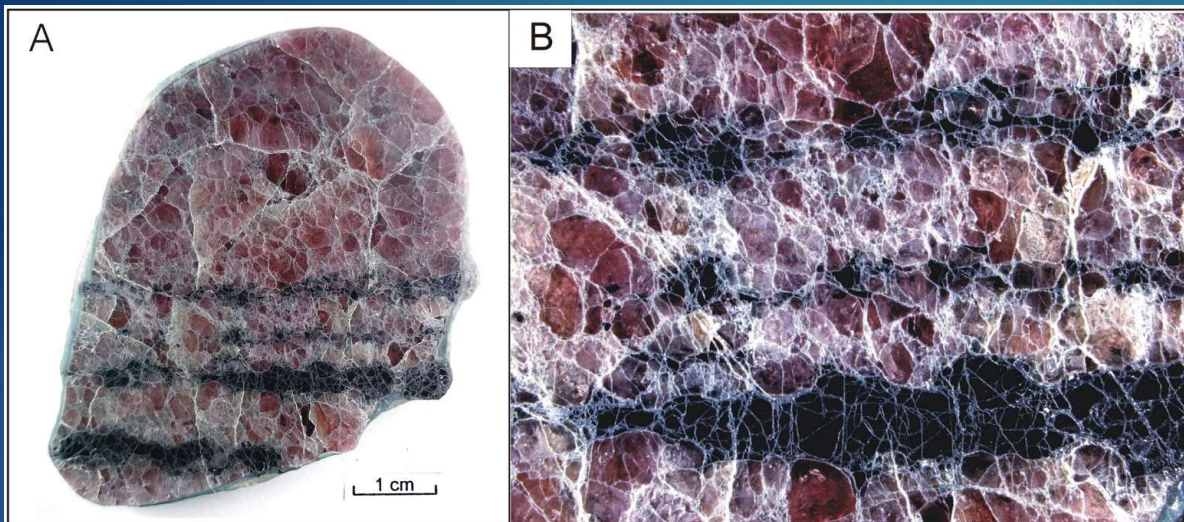


Fig. 9. Alkremite xenoliths in the Nyurbinskaya pipe, sample H-678: A – general appearance; B - banded structure of the alkremite, slice section, field 2.5 cm.

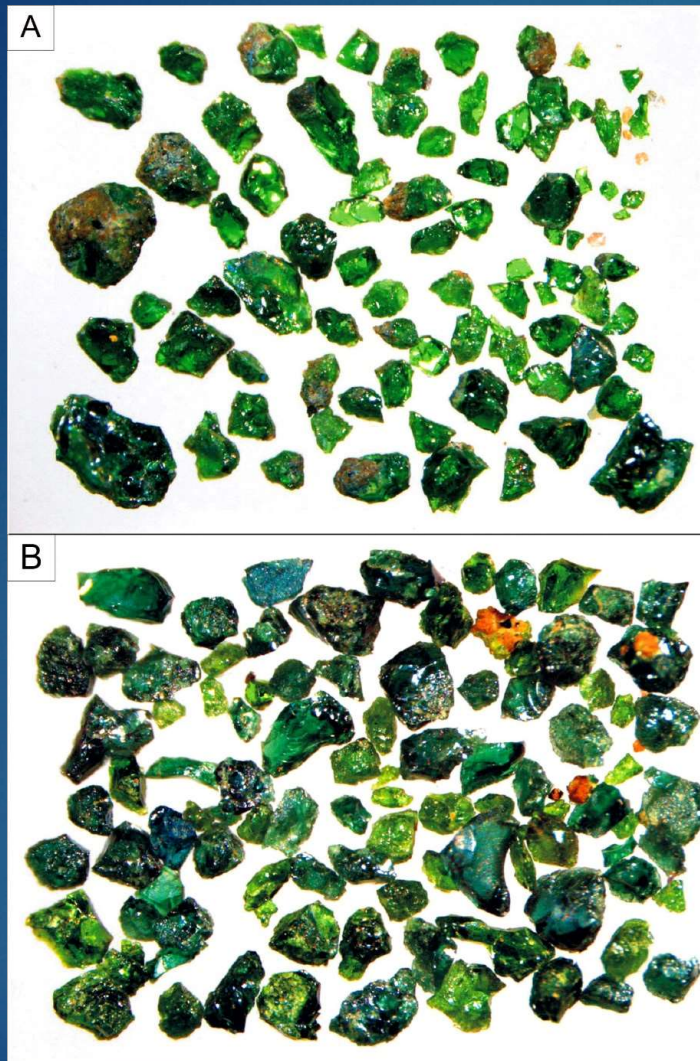


Fig. 10. General appearance of green garnets monofractions from pipe kimberlites; A - probe with one-colour garnets; B - probe with multi-coloured garnets. A size class $-1+0.25$ mm.



Fig. 11. General appearance of green garnets monofractions from Mayskaya pipe kimberlites; A - size class $-4+1$ mm; B - monofractions of “green” garnet color versions. A size class $-1+0.25$ mm.

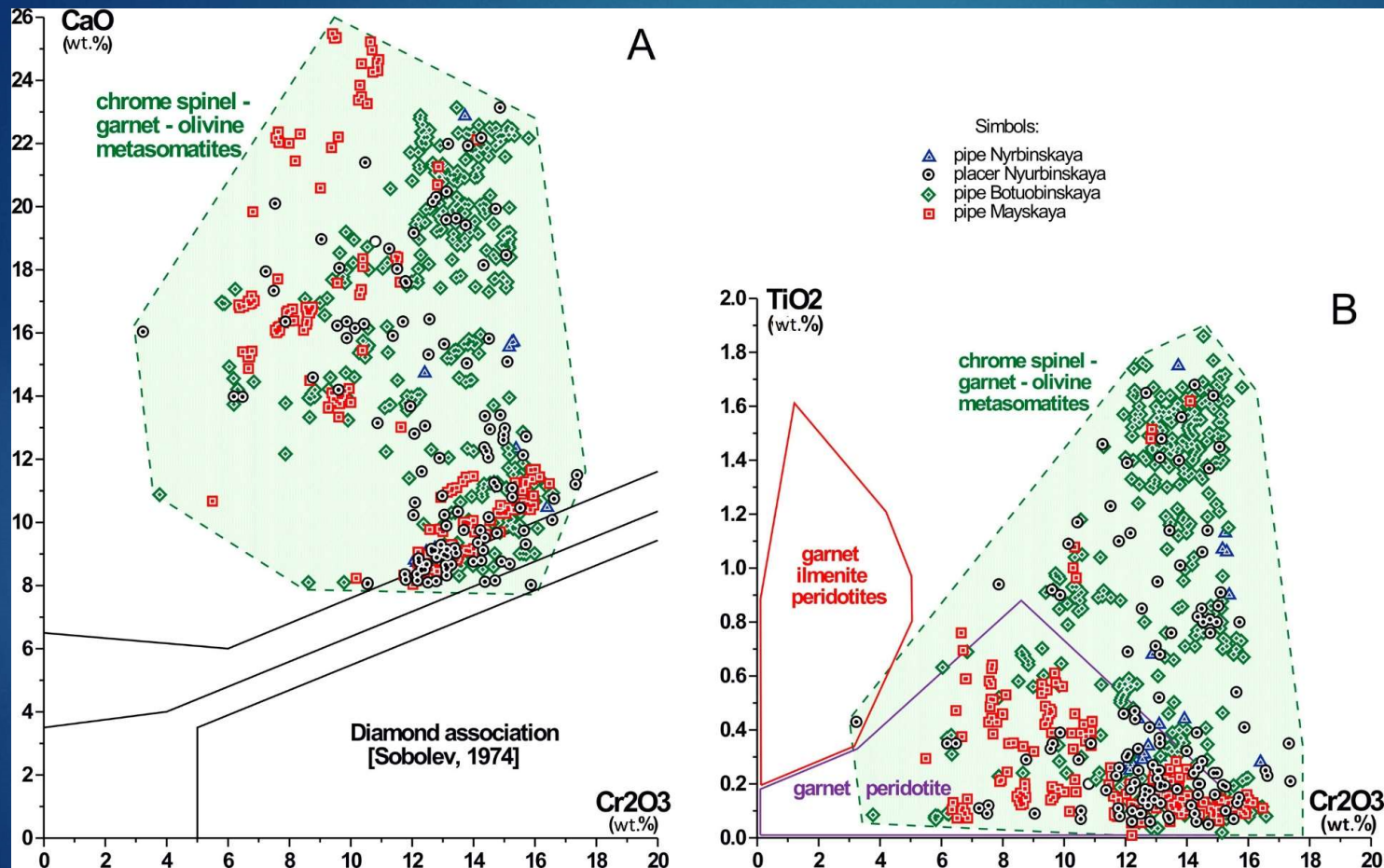


Fig. 12. Chemical composition of the “green” garnet from Nakyn field kimberlites. A - diagram (Sobolev, 1974); B - diagram (Sablukova et al., 2014).

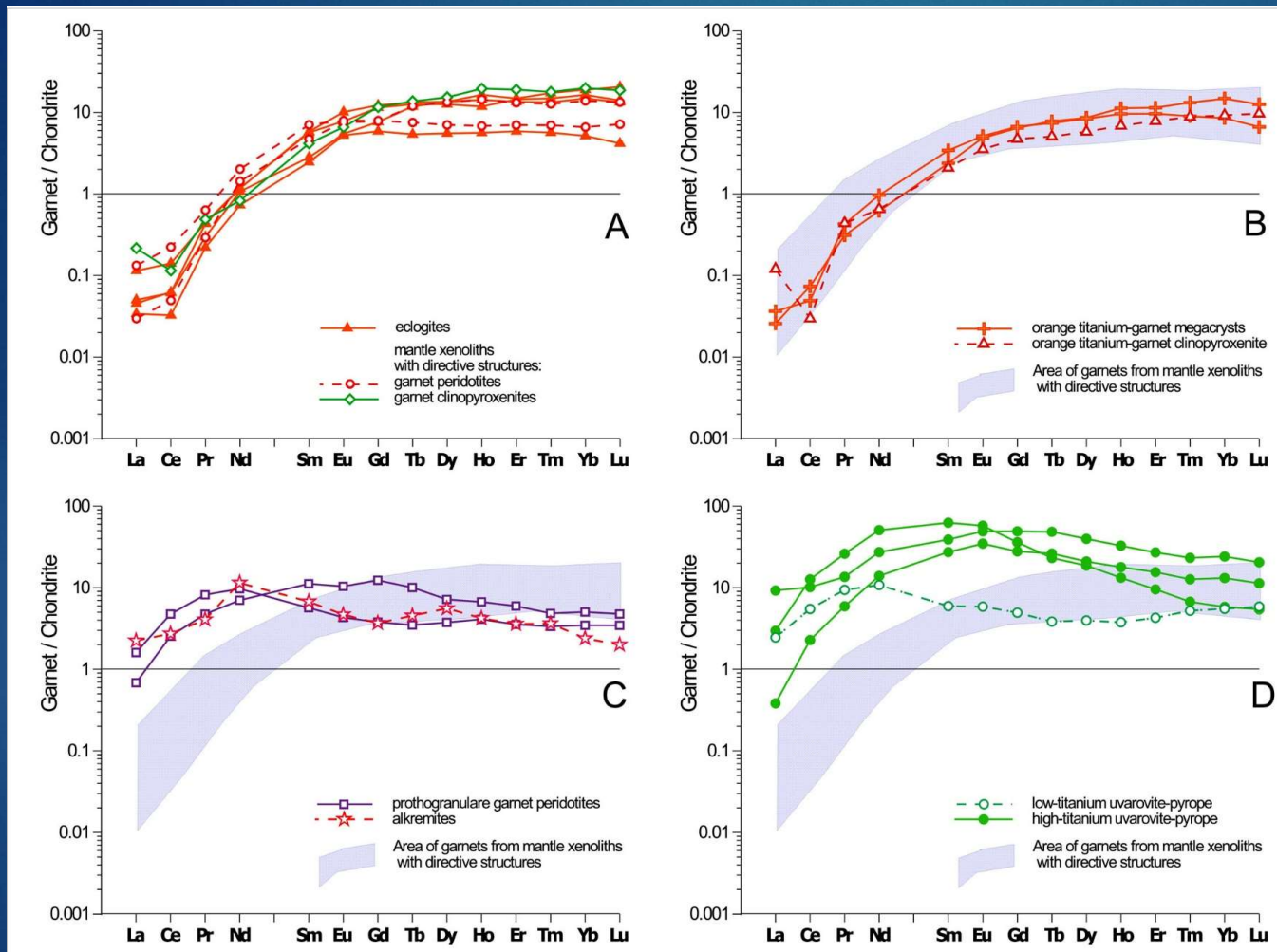


Fig. 13. Chondrite (McDonough and Sun, 1995) normalized REE patterns in garnets from Nyrbinskaya pipe different mantle xenoliths. A - garnet peridotites and garnet clinopyroxenites with directive structures, eclogites; B - orange titanium-garnet megacrysts and titanium-garnet clinopyroxenite; C - garnet peridotites with prothogranular texture and alkremites ; D - uvarovite-pyroxene (Sablukova et al., 2012; Sablukov et al., 2014).

The trace elements distribution in garnets.

For garnets from the basic mantle xenoliths types contents of microelements was determined by LA ICP-MS method. It has allowed to specify some features of their origin.

1. In Nyurbinskaya pipe various types of mantle xenoliths, containing clinopyroxenes as chrome-omphacite (instead of chrome-diopsides) – garnet peridotites and garnet clinopyroxenites with directive structures, and also eclogites sharply prevail.

Garnets in these rocks also have various chemical composition, but are characterized by very similar, "normal" type of distribution REE (fig. 13A). It emphasizes similar and simple enough conditions of formation of these types mantle rocks in structure of subducted oceanic crust with the mantle basenit and initial stratified basic-ultrabasic complexes in upper part. There are now obvious metamorphic transformation in a subduction zones (obvious metasomatism).

2. The same simple, "normal" type of distribution REE characterizes also orange orange titanous garnets of megacrystic type (the titanium-garnet clinopyroxenites) (fig. 13B). These mantle rocks, were probably formed at crystallization from asthenocpheric protokimberlite melts.

3. Mantle rocks with initial structures characteristics containing clinopyroxene as "usual" chrome-diopside, such as garnet peridotites proto granular textures, have "flattened" distribution of REE with distinct metasomatic enrichment in the field of LREE (fig. 13C). Garnets from alkremites have also about the same "flattened" character of REE distribution (fig. 13C).

4. The most abnormal character of distribution REE is fixed in green garnets of the uvarovite metasomatites (fig. 13D). And if low-titanium uvarovite distribution REE ("flattened", with distinct enrichment in LREE) it is similar on proto granular garnet peridotites. This suggests that high-titanium uvarovites sharply differ from all other investigated garnets by the "elevated" type of MREE and LREE distributions. These features fix intensive influence metasomatic processes on these garnet bearing rocks.

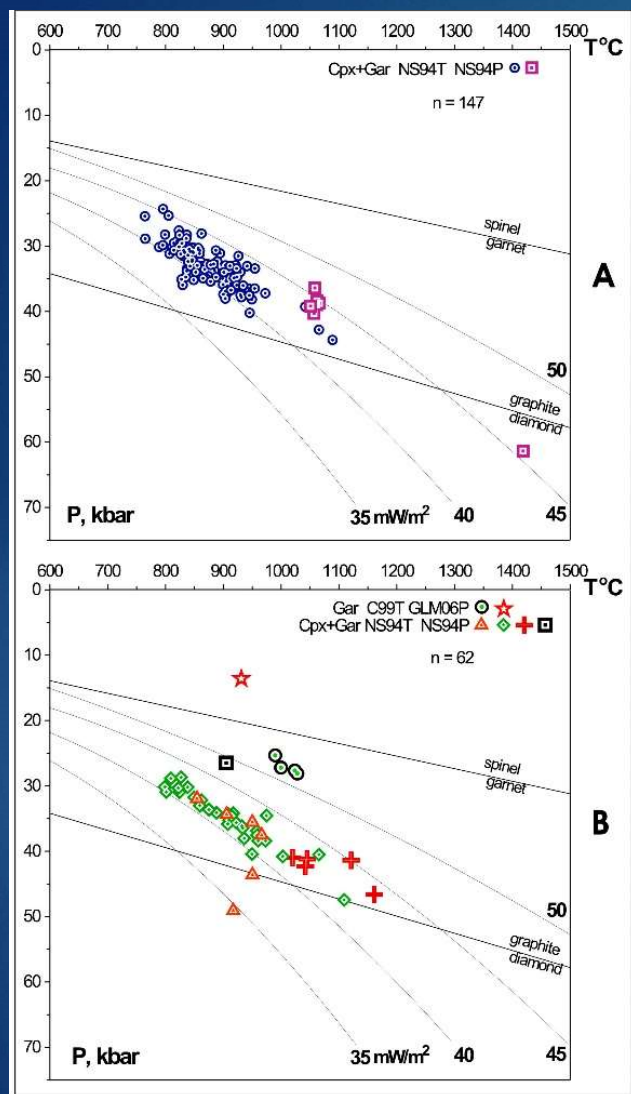


Fig. 14. Pressure – temperature conditions of formation mantle xenoliths of Nyurbinskaya pipes. A - garnet peridotites proto granulare (panidiomorphhic) and allotriomorphhic textures of a massive structure (square), garnet peridotites with directive types of structures (circle). B - eclogites (triangle), garnet clinopyroxenites with directive types of structures (rhombus), titanium-garnet clinopyroxenite "megacryst" associations (cross), alkremites (star), marids (square), chrome spinel – uvarovite metasomatites (circle).

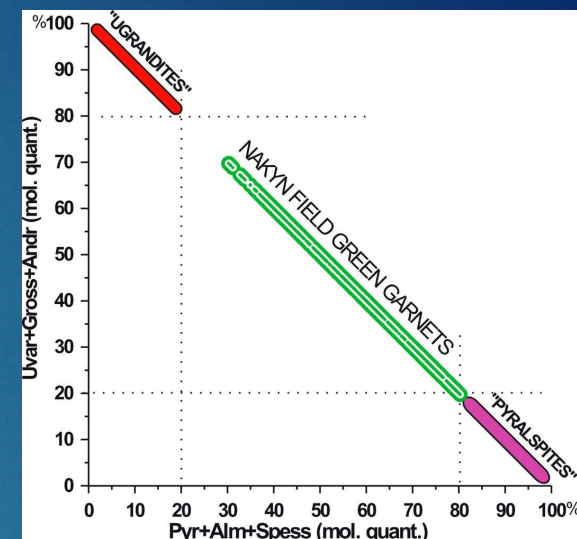


Fig. 15. Composition of green garnets from Nakyn field kimberlites in relation to two main groups of garnets: "pyralspite" and "ugrandite".

PT-parameters of mantle rocks formation.

The available set of deep minerals and mineral paragenesis for the PT calculations is extremely limited due to high degree altered of kimberlites. It is possible to use only separate garnets and clinopyroxenes and rarely the paragenesis of garnet+clinopyroxene. And there practically impossible to find the complete associations with two pyroxenes, garnets and olivines.

It was used more than 20 different geothermometers, geobarometers and their combinations. First of all calculation of TP-parameters of formation mantle xenoliths was carried out using monomineral clinopyroxene geothermobarometer NT00 (T°) - NT00 (P, kbars) (Nimis and Taylor, 2000). The significant part of samples (approximately half) is characterized by obviously underestimated, unreal values of temperatures (100-600 °C), that it is not realistic and means that the altered grains were analyzed.

PT-parameters of formation of alkremite xenoliths and separate green garnet grains were determined using the garnet composition: the temperature was defined via thermometer (Canil, 1999) (C99T), and pressure via barometer of Grutter, Latti and Menzies (2006) (GLM06P).

Using for calculation the most widespread mineral paragenesis: garnet+clinopyroxene gives the closest to real a picture of an arrangement of points of PT-parameters of formation mantle xenoliths. The temperature was determined on geothermometer NS94T, pressure - on barometer NS94P (Nikitina and Simakov, 1994). The small dispersion of the received results and the close correspondence between PT parameters and petrographic features mantle xenoliths confirms the correctness of application of this method (fig. 14). Overwhelming majority of various garnet peridotites and garnet clinopyroxenites with directive structures, and eclogites form an uniform, compact field with parameters 800-950 °C and 25-37 kbar, tracing the ~ 40 mW/m² (Pollack et al., 1977) conductive geotherm.

The sharp deviations to more high-temperature and high-pressure conditions demonstrate only primary-magmatic garnet peridotites with proto granular (panidiomorphic) and allotriomorphic textures (1000-1070 °C and 35-40 kbar) and Ti-garnet clinopyroxenites of "megacryst" series (900-1150 °C and 33-47 kbar). At the same time such types of inclusions as MARIDS, spinel-uvarovite metasomatites, deviate to smaller pressure conditions (24-27 kbar and 900-1030 °C), and alkremites are the most low-pressure from the investigated samples (13.6 kbar and 930 °C).

Conclusions

Detailed study of kimberlites and their mantle xenoliths Nakyn field kimberlites (Nyurbinskaya, Botuobinskaya and Mayskaya pipes) has revealed their unusual and important mineralogical features.

The set of the basic, prevailing deep minerals in kimberlites and mantle xenoliths of Nakyn fields is typical for Groups-2 of Southern Africa kimberlites: it is olivine, red-violet pyrope and chrome spinel. Orthopyroxene is practically absent, that suggest the activity of the carbonate rich melts and the processes of the wehrlitization,

Absence of picroilmenite megacrysts in Nakyn kimberlites is filled with presence of large orange-red titanious-pyropes of "megacryst" associations, underlining the reduced character astenospheric influences on the mantle substratum of area

Picroilmenites in Nakyn kimberlites are present only in xenoliths of eclogites, and garnet peridotites and clinopyroxenites with directive structures related to the zones of the metasomatism or melt interaction. The picroilmenite compositions from these rock inclusions sharply differs from composition of picroilmenite typical "megacryst" associations the raised contents of the titanium and the lowest share hematite component. In the same types mantle rocks is unusual also the composition of clinopyroxene: omphacite-chrome-omphacite (but not chrome-diopside) suggesting the high activity of the Na-Al metasomatism probably related to the oceanic spilitic metasomatism. The important participation in their formation of subduction processes allows to assume the specific features of a structure, mineral composition and composition of minerals of these rock inclusions.

Deep-seated rocks which were formed as a result of crystallization of mantle melts – garnet peridotites of proto granular and allotriomorphic textures, chromic association garnetites and titan-garnet clinopyroxenites of titanium ("megacrystic") series contain "usual" for kimberlites clinopyroxene – chrome-diopside. Pink pyrope from alkremites, widely distributed in Nyurbinskaya precursor dike kimberlites, specify possible wider distribution of these rare rocks in mantle of Nakyn fields.

Unusually wide distribution in Nakyn kimberlites various on color and composition of green garnets specifies on intensive influence of processes "calcium" ("chrome-calcium" and the "titanium–chrome-calcium") metasomatism on mantle substratum. Green garnets is an ideal, easily diagnosed prospecting mineralogical marker.

As a whole, the made works have allowed to reveal uniqueness Nakyn field pipes on mineralogical features kimberlites and mantle xenoliths, as among others pipes Yakutia Diamond Provinces, and among kimberlite pipes of the World.

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