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ON THE ORIGIN OF KIMBERLITES AND DIAMONDS PRESENT THEREIN

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Hypotheses of diamond and kimberlite formation are tested with regard to correlations of rock compositions and accessory minerals. The mean chemical compositions of kimberlites from Yakutian diamond fields and their diamond contents are compared with the mean compositions of pyropes and picroilmenites included there. The comparison shows that major parameters of kimberlite composition variability and diamond contents correlate with pyrope and picroilmenite compositions. It is concluded that pyropes, diamonds, and major minerals of kimberlites, determining the bulk rock composition, are comagmatic. The study comprises data on diamond fields in Yakutia, including kimberlite pipes Botuobinskaya, Nyurbinskaya, Internatsionalnaya, Mir, Aikhal, Yubileinaya, Sytykanskaya, Udachnaya-West, Udachnaya-East, and Zapolyarnaya. The database on rock chemical compositions includes over 7 000 analyses, of which 1 976 are supplemented with data on diamond contents and 1 529 neutron activation chromium assays. The bulked pyrope composition database includes 1 491 microprobe analyses. Picroilmenite compositions are characterized by 986 microprobe analyses. Data from the literature on the disagreement between the ages of kimberlites and inclusions in diamonds are considered. It is demonstrated for the first time that Nd isotope ratios are altered by hydrothermal metasomatism of kimberlites; thus, the current age estimates are dubious. To confirm the conclusions, we present new data on the comparison of variation coefficients for major oxides in 25 igneous rock associations with those of rocks of the kimberlite association differently altered by secondary processes.

Key words: diamond, inclusion, kimberlite, chemical composition, diamond content, pyrope, correlation, comagmaticity.

There is an oddity in kimberlite petrology. Many scientists consider diamond formation separately from the formation of kimberlites, thereby emphasizing the greatest probability of the exotic origin of diamond.

This contradiction is based on the Precambrian Sm-Nd age of peridotitic garnets and Re–Os ages of sulphide inclusions in diamonds from younger kimberlites, which indicate that the diamonds are xenogenic matter. The Sm-Nd age of kimberlites from the Premier pipe is 1,180±0,03 Ga; the age of eclogitic inclusions in diamonds, 1,150±0,04 Ga, and the age of harzburgite garnets included in diamonds, 3,2±0,04 Ga [18]. The Sm-Nd isochronous age of inclusions in diamonds from Udachnaya pipe kimberlites is about 2,0 Ga, and the Re-Os age of sulphide bodies from the same pipe varies from 3,1±0,3 to 3,5±0,3 Ga [16]. The age of crystallization of these “peridotitic” diamonds is the same as in corresponding diamonds from Premier kimberlites [17], and the K-Ar age of kimberlites from the Udachnaya pipes varies within

322–425 Ma [17]. Garnets of peridotitic paragenesis from Cretaceous kimberlites (95–94 Ma) of the Finsch pipe, South Africa, have the Sm-Nd age 3,3 Ga [9].

The hypothesis regarding diamonds as exotic inclusions can be referred to as xenogenic. It presumes that kimberlites are but diamond transporters. Diamonds formed in mantle peridotites and eclogites, which were subsequently degraded by the turbulent motion of fluid, releasing the diamonds. Mantle rock xenoliths store petrological and geochemical information of the conditions of diamond growth [6]. This hypothesis provides no clear indications on the nature and formation of kimberlites.

Another hypothesis is magmagenic. According to it, diamonds formed synchronously with the major minerals of kimberlites during selective melting of the mantle substrate saturated with water, carbon dioxide, methane, and other volatile components.

The choice between the hypotheses can be done on the base of the presence or absence of correlation between the compositions of kimberlite pyropes and contents of major oxides in rocks (hypotheses on rock origin) or between diamond contents in kimberlite and major oxide contents, or compositions of kimberlite pyropes (hypotheses on diamond origin).

Employment of statistical correlations between the compositions of pyrope and rocks in pyrope-hosting kimberlites for checking genetic hypotheses is substantiated by the regularity of pyrope composition variation with peridotite composition established by N. Sobolev [21]. As the igneous nature of peridotites is generally accepted, other rocks showing statistical correlations between rock compositions and accessory minerals they host can also be considered igneous. With no correlations, the magmagenic hypothesis is considered little probable and rejected.

Materials and methods. The aforementioned hypotheses were tested with the mean contents of major oxides in kimberlites and oxides in indicator minerals: magnesium garnet and picroilmenite in rocks from pipes of the Nakyn (Botuobinskaya and Nyurbinskaya), Mirny (Internatsionalnaya and Mir), Alakit–Markha (Aikhal, Yubileinaya, and Sytykanskaya), Daldyn (Udachnaya-West and Udachnaya-East), and Upper Muna (Zapolyarnaya) kimberlite fields.

Most of the 7 307 samples were taken at 2 m intervals from core samples of 422 prospecting boreholes. The samples were tested by X-ray spectrometry by L. Kholodova at the Institute of Geology and Mineralogy (IGM). The kimberlite samples characterized the pipes in the range from the day surface to the 1 250 m depth. In our study, all analyses present in the database were bulked without differentiating with regard to any traits, e. g. altered, unaltered, or other composition types. We did so to avoid criticism concerning biased use of the database for obtaining desirable results.

The mean compositions and variation coefficients of rocks and minerals are shown in tables 1 and 2. Diamond contents (ct/t) are presented for 1 976 analyses of the whole set. The mean contents of elements and diamonds in this subset are also shown in table 1.

Chromium was assayed in 1 529 rock samples by the neutron activation method at IGM. Iron(II) and iron(III) were assayed in 1 006 samples at the chemical laboratory of IGM.

The set of chemical compositions of magnesium garnets (1 491 microprobe analyses) and picroilmenites (986 microprobe analyses) in rocks from the pipes considered was taken from Minin and Ashchepkov's database. The relation of coordinates of core samples from which the analyzed minerals were sampled to coordinates of samples for bulk silicate analysis is unknown. Therefore, the correlation between the compositions of rocks and minerals will be estimated from their mean parameters in kimberlite pipes.

Table 1

Mean compositions of kimberlites from diamond fields of East Siberia
and pyrope and picroilmenite present there, wt. %

Components	Diamond fields and kimberlite pipes			
	Nakyn		Mirnyi	
	Botuobinskaya	Nyurbinskaya	Internatsional-naya	Mir
1	2	3	4	5
Kimberlites				
SiO_2	29,98	31,98	32,82	32,60
TiO_2	0,42	0,56	0,47	1,41
Al_2O_3	3,83	5,15	3,00	2,50
Cr_2O_3	0,08	0,07	0,12	0,15
Fe_2O_3	5,37*	6,57*	2,83	4,74
FeO	N. d.**	N. d.	2,82	3,72
MnO	0,12	0,14	0,10	0,12
MgO	23,55	20,64	27,17	27,73
CaO	14,06	12,14	8,39	5,51
Na_2O	0,01	0,10	0,81	0,29
K_2O	1,22	1,45	0,89	0,70
P_2O_5	0,44	0,55	0,41	0,35
LOI	21,13	20,65	20,22	17,93
Kimberlites with known diamond contents				
SiO_2	29,41	30,96	32,45	31,02
TiO_2	0,41	0,44	0,47	1,44
Al_2O_3	3,65	3,87	2,73	2,27
Cr_2O_3	0,09	0,06	0,128	0,161
Fe_2O_3	5,40*	5,74*	2,98	5,43
FeO	N. d.	N. d.	2,74	3,13
MnO	0,12	0,13	0,10	0,12
MgO	23,87	23,49	27,57	27,87
CaO	14,40	13,09	8,40	8,21
Na_2O	0,01	0,01	0,92	0,35
K_2O	1,14	1,09	0,83	0,72
P_2O_5	0,45	0,47	0,42	0,35
LOI	21,25	20,97	20,43	18,78
$A_{ct/t}$	8,28	6,70	3,82	1,99
Pyrope***				
SiO_2	41,19	41,47	41,39	41,46
TiO_2	0,23	0,24	0,19	0,14
Al_2O_3	18,24	18,77	19,13	19,89
Cr_2O_3	6,38	5,68	5,34	3,35
FeO	7,72	4,87	8,25	8,05
MnO	0,42	0,43	0,49	0,42
MgO	19,63	19,87	19,11	20,62
CaO	5,42	5,29	4,90	4,47
Na_2O	0,05	0,06	0,07	0,04
K_2O	N. d.	N. d.	0,01	–

Continuation of table 1

1	2	3	4	5
Picroilmenite***				
TiO_2 Al_2O_3 Cr_2O_3 FeO MnO MgO	N. d.	N. d.	48,65 0,63 0,48 40,01 0,27 9,05	44,10 0,63 0,68 46,36 0,20 7,34
Number of analyses				
Kimberlites	1 001	1 023	400	725
Kimberlites with diamond contents	492	373	124	180
Cr_2O_3 assays	90	N. d.	127	376
FeO assays	N. d.	N. d.	128	129
Pyrope	376	187	221	29
Picroilmenite	N. d.	N. d.	45	108

Components	Diamond fields and kimberlite pipes					
	Alakit–Markha			Daldyn		Upper-Muna
	Aikhal	Yubilei-naya	Sytykan-skaya	Udachnaya-West	Udachnaya-East	Zapolyar-naya
1	2	3	4	5	6	7
Kimberlites						
SiO_2	22,86	30,16	28,79	25,89	26,23	30,71
TiO_2	0,43	0,99	1,78	0,86	1,18	1,30
Al_2O_3	2,44	2,05	1,88	2,33	2,16	2,15
Cr_2O_3	0,19	0,14	0,17	0,12	0,13	0,08
Fe_2O_3	2,48	4,32	6,06	3,92	3,05	6,28
FeO	1,52	2,49	2,04	2,34	2,42	1,31
MnO	0,10	0,15	0,11	0,10	0,12	0,14
MgO	23,29	27,82	27,70	25,12	27,51	32,87
CaO	17,47	10,62	10,89	15,51	13,33	8,75
Na_2O	0,17	0,14	0,11	0,17	0,15	0,03
K_2O	0,87	0,35	0,22	0,64	0,59	0,31
P_2O_5	0,64	0,37	0,25	0,30	0,34	0,39
LOI	26,34	20,55	19,39	23,10	21,08	17,99
Kimberlites with known diamond contents						
SiO_2	23,96	28,52	29,21	26,87	26,35	N. d.
TiO_2	0,45	0,99	1,82	0,89	1,25	
Al_2O_3	2,56	1,92	2,14	2,38	2,10	
Cr_2O_3	0,210	0,142	0,197	0,132	0,134	
Fe_2O_3	2,17	4,44	5,65	3,30	3,79	
FeO	2,03	2,50	2,38	3,02	3,18	
MnO	0,12	0,14	0,13	0,10	0,12	
MgO	25,65	27,72	28,68	27,32	28,30	

End of table 1

1	2	3	4	5	6	7
CaO Na_2O K_2O P_2O_5 LOI	15,14 0,06 0,99 0,68 26,34	11,95 0,14 0,28 0,39 21,41	9,67 0,11 0,26 0,29 18,95	13,07 0,23 0,76 0,35 21,71	13,31 0,30 0,65 0,35 20,16	N. d.
$A_{ct/t}$	4,02	0,53	0,45	1,16	0,63	0,59
Pyrope***						
SiO_2 TiO_2 Al_2O_3 Cr_2O_3 FeO MnO MgO CaO Na_2O K_2O	41,37 0,43 18,40 5,40 7,88 0,40 20,06 5,22 0,06 0,03	41,51 0,50 18,31 5,51 8,23 0,39 20,18 4,82 0,07 0,01	41,42 0,49 18,84 4,96 7,81 0,37 20,61 4,50 0,07 0,02	41,94 0,28 19,19 5,30 7,68 0,39 21,02 4,14 0,06 N. d.	41,45 0,32 17,91 6,47 7,88 – 19,80 5,05 0,09 N. d.	42,33 0,46 19,70 4,28 7,38 0,12 20,64 4,49 0,06 0,01
Picroilmenite***						
TiO_2 Al_2O_3 Cr_2O_3 FeO MnO MgO	49,13 0,56 0,84 38,68 0,26 10,03	49,09 0,33 2,61 37,06 0,32 9,86	49,57 0,43 1,77 37,80 0,29 9,92	48,77 N. d. 1,18 N. d. N. d. N. d.	47,30 N. d. 0,93 N. d. N. d. N. d.	49,28 0,48 2,32 35,64 0,30 11,09
Number of analyses						
Kimberlites	329	1 101	542	1 013	820	353
Kimberlites with diamond contents	127	206	268	71	135	N. d.
Cr_2O_3 assays	17	283	375	129	83	49
FeO assays	118	191	242	71	78	49
Pyrope	256	230	104	1	38	49
Picroilmenite	274	90	175	106	126	62

*ΣFe_2O_3; **N. d. – not determined; ***Analyses from V. Minin and I. Ashchepkov's collection.

Peridotitic garnets. The distribution of CaO and Cr_2O_3 contents in magnesium garnets of various peridotite types from xenoliths in kimberlites was formerly studied by V. Sobolev et al. [20, 21]. Two features of magnesium garnets are illustrated in fig. 1:

1) calcium content in garnets depends on that in host rocks. This regularity was found in peridotite xenoliths present in kimberlites. It agrees well with the regularities observed in all igneous rocks where the distributions between solid phases and melts have reached a steady state. Therefore, mineral composition variations follow variations in rock composition;

Table 2
Variation coefficients of the contents of oxides and diamond in diamond fields of East Siberia

Components	Diamond fields and kimberlite pipes			
	Nakyn		Mirnyi	
	Botuobinskaya	Nyurbinskaya	Internatsional-naya	Mir
1	2	3	4	5
Kimberlites				
SiO_2	22	35	17	13
TiO_2	39	56	39	36
Al_2O_3	46	72	46	38
Cr_2O_3	39	35	48	98
Fe_2O_3	34	48	47	35
FeO	N. d.	N. d.	34	27
MnO	16	28	37	25
MgO	28	34	15	14
CaO	43	56	52	42
Na_2O	122	414	102	210
K_2O	50	81	51	77
P_2O_5	32	75	38	48
LOI	24	37	18	17
Kimberlites with known diamond contents				
SiO_2	20	35	82	11
TiO_2	40	87	108	34
Al_2O_3	29	72	20	28
Cr_2O_3	29	52	43	70
Fe_2O_3	14	48	41	30
FeO	–	–	35	37
MnO	18	29	24	13
MgO	28	34	54	32
CaO	46	56	15	33
Na_2O	125	413	120	201
K_2O	57	81	46	68
P_2O_5	32	76	40	49
LOI	24	32	19	16
$A_{ct/t}$	81	74	74	37
Pyrope				
SiO_2	2	2	2	2
TiO_2	87	90	87	113
Al_2O_3	10	12	11	20
Cr_2O_3	47	62	53	51
FeO	15	13	14	16
MnO	17	17	15	25
MgO	7	6	10	19
CaO	27	21	41	35
Na_2O	83	100	115	79
K_2O	388	344	97	–

Continuation of table 2

1	2	3	4	5
Picroilmenite				
TiO_2	N. d.	N. d.	4	12
Al_2O_3			16	18
Cr_2O_3			178	161
FeO			9	14
MnO			23	28
MgO			15	28

Components	Diamond fields and kimberlite pipes					
	Alakit–Markha			Daldyn		Upper-Muna
	Aikhal	Yubilei-naya	Sytykan-skaya	Udachnaya-West	Udachnaya-East	Zapolyar-naya
1	2	3	4	5	6	7
Kimberlites						
SiO_2	27	24	13	18	14	8
TiO_2	37	36	28	32	34	24
Al_2O_3	45	52	45	37	47	46
Cr_2O_3	44	64	36	54	23	68
Fe_2O_3	48	38	54	44	34	30
FeO	55	36	42	44	45	73
MnO	36	25	47	24	14	16
MgO	26	26	21	24	17	13
CaO	44	68	59	38	35	65
Na_2O	141	286	66	58	92	121
K_2O	68	94	98	68	61	170
P_2O_5	51	44	69	53	49	53
LOI	19	21	32	21	20	13
Kimberlites with known diamond contents						
SiO_2	22	15	12	10	13	N. d.
TiO_2	33	33	30	36	29	
Al_2O_3	44	42	32	25	27	
Cr_2O_3	40	45	25	41	35	
Fe_2O_3	46	34	37	48	35	
FeO	20	33	35	39	37	
MnO	27	48	38	42	14	
MgO	14	25	20	13	20	
CaO	29	64	66	26	45	
Na_2O	183	161	41	37	130	
K_2O	56	44	86	61	55	
P_2O_5	39	36	70	28	27	
LOI	17	18	37	18	20	
$A_{ct/t}$	75	115	264	105	100	176
Pyrope						
SiO_2	2	2	1	N. d.	2	2
TiO_2	84	86	77		90	79

End of table 2

1	2	3	4	5	6	7
Al_2O_3	13	12	8	N. d.	9	7
Cr_2O_3	52	59	52		60	52
FeO	15	13	13		14	15
MnO	18	20	15		20	11
MgO	13	7	6		10	5
CaO	41	31	28		33	22
Na_2O	54	55	55		54	53
K_2O	132	196	31		154	236
Picroilmenite						
TiO_2	08	6	6	5	9	8
Al_2O_3	21	64	42	N. d.	N. d.	50
Cr_2O_3	68	62	71	98	99	58
FeO	10	9	10	N. d.	N. d.	23
MnO	34	30	30	N. d.	N. d.	34
MgO	18	20	22	N. d.	N. d.	31

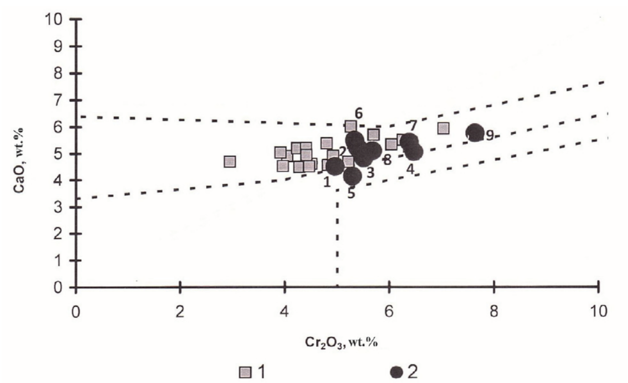

Fig. 1. Distribution of mean Cr_2O_3 and CaO (plot after [20, 21]) contents in magnesium garnets from the Yakutian kimberlite province:

1 – kimberlite pipes; *2* – kimberlite pipes with diamond deposits; pipes: 1 – Sytykanskaya, 2 – Aikhal, 3 – Yubileinaya, 4 – Udachnaya-East, 5 – Udachnaya-West, 6 – Internatsionalnaya, 7 – Botuobinskaya, 8 – Nyurbinskaya, 9 – Maiskaya.

2) variations in chromium content in magnesium garnets are a function of pressure. Garnets enriched in Cr crystallize at higher pressures (see also [15]).

The figurative points of mean compositions of garnets from kimberlite pipes form a linear regression series. More details of the structure of this series at CaO contents within 4,5–5,5 wt. % and Cr_2O_3 within 5,0–8,5 wt. % will be given below.

The correlation of CaO contents in garnets and garnet-hosting peridotites found by N. Sobolev is an important petrological observation. This regularity can be employed in the analysis of hypotheses concerning the formation of kimberlites and diamond.

Prior to the test, the main petrochemical trends in kimberlites within particular deposits, kimberlite fields, and the entire southern Yakutian kimberlite province should be outlined. These trends will then be used in comparing the compositions of garnets and kimberlites.

Typical kimberlite features. It is appropriate to use the petrochemical population model to describe variations in kimberlite composition [5, 7, 26]. Although this model has been described in our previous papers, it is pertinent to consider some of its features once more, because its parameters presented here rest on a much larger dataset.

In the population model, the multitude of kimberlite chemical compositions are divided into seven discrete groups, or populations, formed under similar conditions. A population is characterized by a uniform TiO_2 content. Populations with low titanium contents have high K_2O contents and vice versa. Diamond contents in kimberlite populations are inversely proportional to TiO_2 contents and directly proportional to K_2O (fig. 2).

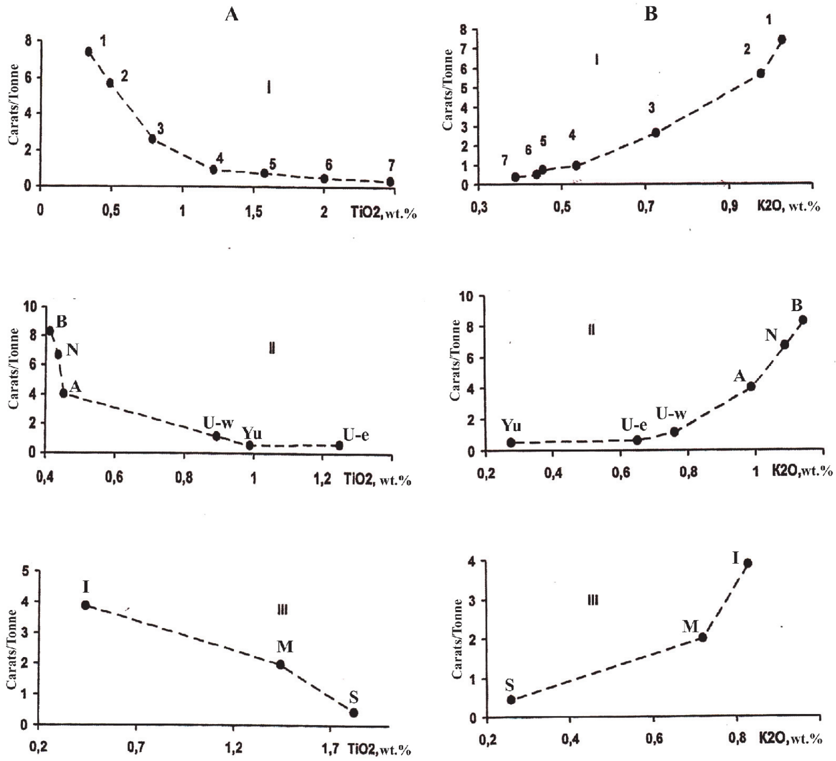

Fig. 2. Distribution of figurative points of mean contents of diamond and TiO_2 (*A*) and diamond and K_2O (*B*) in kimberlite:

I – in kimberlite populations (1, 2, 3 ... 7 – population number); II – in high-Ca kimberlite (pipes: B – Botuobinskaya, N – Nyurbinskaya, A – Aikhal, U-w – Udachnaya-West, U-e – Udachnaya-East, Yu – Yubileinaya); III – in low-Ca kimberlite (pipes: I – Internatsionalnaya, M – Mir, S – Sytykanskaya). Dashed are empirical regression lines.

Populations can be subdivided into second-order subunits (varieties) with regard to CaO/MgO ratios. Calcium oxide contents in the varieties are inversely proportional to MgO. With increasing CaO/MgO, diamond contents in the varieties increase at first and then decrease [5].

Petrochemical population models of particular geologic objects can be constructed according to table 3. We applied it to the set of chemical compositions of kimberlites from Yakutian diamond fields to construct the corresponding model (table 4). Not all chemical analyses of the set are characterized by diamond contents. Therefore, the model described by table 4 should be supplemented with a model of kimberlite with known diamond content (table 5).

Table 3

Populational classification of the compositions of kimberlites from Yakutian diamond fields

<table>
<tr><td colspan="8">Step 1. Identification of populations. Typochemical indicator – TiO_2</td></tr>
<tr><td>Population number</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Boundaries of TiO_2, wt. %</td><td>< 0,4</td><td>0,41–0,60</td><td>0,61–1,00</td><td>1,01–1,40</td><td>1,41–1,80</td><td>1,81–2,20</td><td>2,21–2,90</td></tr>
<tr><td colspan="8">Step 2. Identification of varieties. Typochemical indicator – CaO/MgO</td></tr>
<tr><td>Name of population variety</td><td colspan="2">Kimberlitic carbonatites (Kcb)</td><td colspan="2">Carbonatitic kimberlites (Ca-kmb)</td><td colspan="2">Kimberlites proper (Kmb)</td><td>Magnesium kimberlites (Mg-Kmb)</td></tr>
<tr><td>Boundaries of CaO/MgO</td><td colspan="2">> 8,20 to 1,76</td><td colspan="2">1,75 to 0,83</td><td colspan="2">0,82 to 0,34</td><td>< 0,33</td></tr>
</table>

Table 4

Mean compositions of kimberlite populations from Yakutian diamond fields (*n* = 7 221)

Components	Populations						
	1	2	3	4	5	6	7
SiO_2	29,88	29,59	29,41	27,37	27,41	29,44	29,44
TiO_2	0,38	0,48	0,87	1,18	1,32	2,01	2,58
Al_2O_3	3,56	3,51	2,72	2,04	2,12	1,96	1,98
ΣFe_2O_3	5,40	6,10	6,81	7,39	7,82	8,81	9,41
MnO	0,06	0,12	0,12	0,13	0,12	0,13	0,13
MgO	23,96	24,54	25,61	28,28	27,58	30,47	31,52
CaO	13,29	12,52	12,62	11,96	11,98	7,60	6,19
Na_2O	0,24	0,25	0,22	0,17	0,14	0,15	0,12
K_2O	1,08	0,92	0,66	0,48	0,46	0,43	0,40
P_2O_5	0,42	0,43	0,33	0,37	0,32	0,37	0,38
LOI	21,81	21,67	20,85	20,88	20,42	17,85	17,51
n	1 550	1 185	1 863	1 377	808	315	123

The population model is also applicable in the construction of petrochemical models of particular kimberlite bodies, fields, and a whole kimberlite province.

The petrochemical population model of the Yubileinaya pipe is shown in table 6 as an example.

It is apparent that the relative numbers of analyses vary from population to population. They increase by population 3 and decrease towards population 6. The populations represented by the greatest numbers of chemical analyses are designated as modal. In this case, these are populations 3 and 4. In other pipes, other pairs of neighbouring populations may be modal.

The relative age of a kimberlite population is deduced from the notion that the populations of diamondiferous kimberlites depleted in Ti and enriched in Ca (the least viscous) are the deepest and that they formed at initial steps of selective peridotite melting.

Table 5

Mean compositions and diamond contents of kimberlite populations from Yakutian fields

Components	Populations						
	1	2	3	4	5	6	7
SiO_2	29,39	29,48	29,75	28,44	29,09	29,50	28,87
TiO_2	0,38	0,49	0,79	1,22	1,58	2,00	2,47
Al_2O_3	3,30	3,46	2,91	2,05	2,00	2,16	2,34
ΣFe_2O_3	5,01	5,82	6,73	7,49	8,48	8,71	9,08
MnO	0,12	0,13	0,10	0,13	0,12	0,14	0,12
MgO	25,79	25,43	25,46	27,77	29,49	29,52	29,68
CaO	14,22	13,06	12,39	11,56	9,40	8,53	7,76
Na_2O	0,14	0,10	0,17	0,24	0,23	0,17	0,12
K_2O	1,03	0,98	0,73	0,54	0,45	0,44	0,39
P_2O_5	0,39	0,53	0,45	0,38	0,34	0,35	0,46
LOI	22,50	22,50	21,22	22,31	22,05	22,47	23,61
A, ct/t	7,4	5,66	2,61	0,92	0,75	0,50	0,35
n	576	458	287	218	227	120	54

Table 6

Petrochemical population model of kimberlites of the Yubileinaya pipe (n = 888)

Components	Populations and their varieties								
	1	2				3			
	Mg-kmb	Kcb	Ca-kmb	Kmb	Mg-kmb	Kcb	Ca-kmb	Kmb	Mg-kmb
SiO_2	31,80	18,08	22,50	28,23	33,24	17,62	24,19	27,82	30,90
TiO_2	0,24	0,52	0,50	0,55	0,54	0,81	0,84	0,85	0,82
Al_2O_3	2,71	2,38	3,04	2,14	2,32	2,05	2,21	1,82	1,73
ΣFe_2O_3	7,60	5,19	5,00	6,76	7,28	5,49	5,76	6,70	7,44
MnO	0,13	0,15	0,13	0,14	0,14	0,15	0,14	0,14	0,14
MgO	33,11	11,55	18,79	26,61	32,33	11,06	19,06	26,84	32,76
CaO	6,34	31,17	22,50	13,42	6,33	31,45	21,52	13,69	6,77
Na_2O	0,14	0,15	0,12	0,15	0,13	0,12	0,11	0,09	0,09
K_2O	0,41	0,28	0,52	0,36	0,31	0,33	0,44	0,30	0,28
P_2O_5	0,40	0,31	0,26	0,36	0,31	0,42	0,34	0,33	0,31
CO_2	4,74	24,31	17,75	9,74	4,78	23,83	17,23	9,88	5,12
LOI	12,47	5,60	8,10	11,45	12,38	6,79	8,11	11,45	13,15
P*	3,3	0,8	1,2	1,6	4,6	1,5	7,5	9,9	20,1

Low-titanium melts give way to high-Ti ones, most viscous, as magma formation zones rise in the lithosphere. Pipe formation ends with the intrusion of the kimberlites richest in Ti [26]. Examples are the population models of Udachnaya-West and Udachnaya-East. Population 3 is modal in the former, and 4, in the latter [5]. This implies that Udachnaya-East intruded later than Udachnaya-West.

According to our data [10], kimberlite fields are concentration regions of igneous bodies of a particular igneous kimberlite assemblage. Petrochemical population models of such an assemblage show the same petrochemical trends and succession of intrusion of kimberlite bodies varying in composition as in individual pipes. It is apparent from the example of the petrochemical model of the Mirny kimberlite field (table 7) that all kimberlite bodies of the field form a series where the titanium contents of modal populations increase.

End of table 6

Compo-nents	Populations and their varieties								
	4			5			6		Mean (n = = 888)
	Ca-kmb	Kmb	Mg-kmb	Ca-kmb	Kmb	Mg-kmb	Kmb	Mg-kmb	
SiO_2	23,70	28,03	29,44	23,87	28,33	30,09	27,88	30,71	28,55
TiO_2	1,18	1,18	1,21	1,47	1,50	1,54	1,97	1,94	1,01
Al_2O_3	2,16	1,78	1,61	2,29	1,99	1,76	2,12	1,65	1,89
ΣFe_2O_3	5,74	6,73	7,81	6,60	6,56	7,83	6,91	7,51	7,08
MnO	0,14	0,15	0,14	0,17	0,13	0,14	0,16	0,18	0,14
MgO	19,47	27,33	33,18	18,77	26,85	32,74	24,18	31,67	28,85
CaO	21,70	13,20	6,56	20,92	13,16	6,41	15,46	6,90	11,12
Na_2O	0,11	0,09	0,11	0,09	0,12	0,12	0,09	0,12	0,11
K_2O	0,41	0,33	0,28	0,37	0,38	030	0,56	0,38	0,32
P_2O_5	0,40	0,43	0,43	0,46	0,47	0,49	0,53	0,55	0,39
CO_2	16,95	9,39	4,85	15,66	8,84	4,50	10,53	5,42	8,32
LOI	9,01	11,17	14,49	9,48	11,95	14,02	9,58	12,30	12,94
P*	2,9	9,9	21,0	0,9	2,5	8,9	0,5	0,7	

*P – percentage of the total number of samples from the pipe.

Table 7

Prevalence of modal populations in kimberlite bodies of the Mirny field, percent of the total number of analyses in the pipe

Pipe	n*	Population						
		1	2	3	4	5	6	7
A-21	8	–	–	–	–	–	–	75
Mir	725	–	–	–	–	44	23	–
Amakinskaya	10	–	–	–	–	90	–	–
Taezhnaya	12	–	–	–	36	24	–	–
23th Congress of CPSU	23	–	40	60	–	–	–	–
Dachnaya	15	–	61	53	–	–	–	–
Sputnik	12	–	46	46	–	–	–	–
Internatsionalnaya	400	61	31	–	–	–	–	–

*n – number of analyses in the pipe.

The series present in the table indicates that rocks of the Internatsionalnaya pipe intruded first, and rocks of vein A-21, last. The position of the Mir pipe deserves special attention: Its high titanium content disagrees with the high diamond content (see table 1). This phenomenon can be explained by the fact that Mir rocks are extremely alkalic [26]. In our opinion, this fact reflects additional supply of alkalies to magma formation zones owing to mantle metasomatism or oceanic crust fragments.

Now consider the population models of kimberlite fields. The main populations of kimberlite fields can be recognized there: populations noted as modal in the greatest number of pipes within a field in question (table 8). It has been shown in [26] that particular pipes, kimberlite fields, and the entire southern Yakutian province show the same general petrologic trends. Magmatism starts with intrusions richest in diamond and calcium and poorest in titanium and evolves to low-diamond, high-Ti, and high-Mg melts.

Table 8

Prevalence (%) of modal kimberlite populations in kimberlite bodies of the Vilyui subprovince, Yakutian kimberlite province, n = 6 954 (percentage of the total number of analyses of kimberlites in the field)

Fields	Populations						
	1	2	3	4	5	6	7
Daldyn	–	–	–	–	47	48	–
Alakit–Markha	–	–	–	55	41	–	–
Mirny	–	44	33	–	–	–	–
Nakyn	50	50	–	–	–	–	–

Thus, the variations in the contents of TiO_2, K_2O, CaO, and diamond are the main factors of kimberlite composition variation. Just these components should be taken into account in the consideration of magnesium garnet and picroilmenite present in kimberlites.

Features of magnesium garnet and picroilmenite from kimberlite. The chart presented in [20] was refined on the base of mean composition of pyrope (1 491 analyses) and picroilmenite (986 analyses) from kimberlites with regard to the distribution of figurative points of diamond fields (see fig. 1). Figure 3 shows that three variation curves of mean pipe compositions from low-calcium to high-calcium ones can be drawn in the field of pyrope compositions within chromium content ranging from 4,5 to 8,0 % and calcium, from 4,0 to 6,0 %. Within these curves, the diamond contents in pipes increase with the contents of Cr_2O_3 and CaO in pyrope. Mean contents of K_2O increase in these directions. The highest-Ca curve covers pipes with highest diamond contents. The lowest-Ca curve covers figurative points of fields with lowest diamond contents. Thus, we see a correlation between diamond contents and compositions of pyropes in the host rocks.

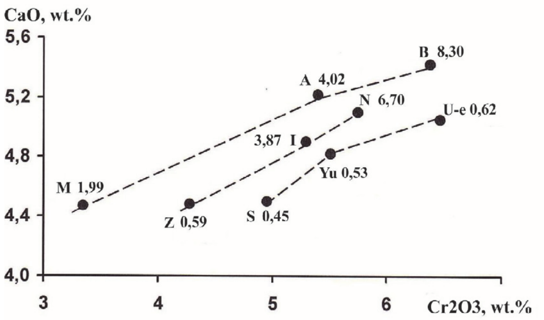

Fig. 3. Distribution of figurative points of mean Cr_2O_3 and CaO contents in pyrope presented in kimberlites of diamonds fields. Hereafter letters indicate pipes, as in fig. 2 (Z – Zapolyatnaya), and numerals, their mean diamond contents.

The content of CaO in kimberlite correlates with that in pyrope (fig. 4). Two positive regression curves can be drawn: for Ca-richer pyrope in diamond-richest kimberlites and for Ca-poorer pyrope in diamond-poorer high-titanium kimberlites.

With regard to the Cr_2O_3/CaO ratio and diamond content (fig. 5), low-Ti and diamondiferous pipes (Botuobinskaya, Nyurbinskaya, Aikhal, and Internatsionalnaya) differ markedly from low-diamond high-Ti ones (Udachnaya-West, Udachnaya-East, Yubileinaya, Sytykanskaya, and Zapolyarnaya).

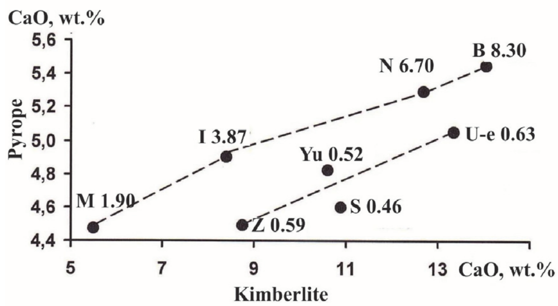

Fig. 4. Distribution of figurative points of mean CaO contents in kimberlite and pyrope present therein.

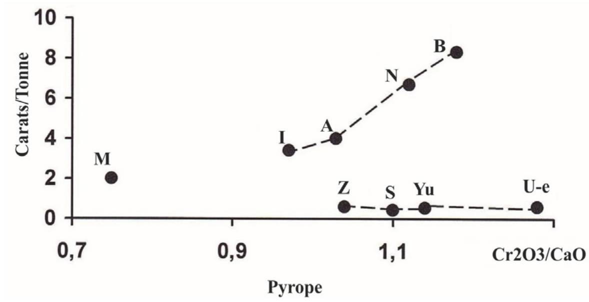

Fig. 5. Distribution of figurative points of Cr_2O_3/CaO ratios in pyrope and mean diamond contents in kimberlites from diamond pipes.

A correlation between titanium contents in rocks and in pyrope is also noted (fig. 6). Pyropes from low-Ti and high-diamond kimberlites have lower titanium contents than kimberlites with higher contents of Ti and lower contents of diamond. The more titanium is present in kimberlites of diamond fields, the more is present in the pyrope of the rock.

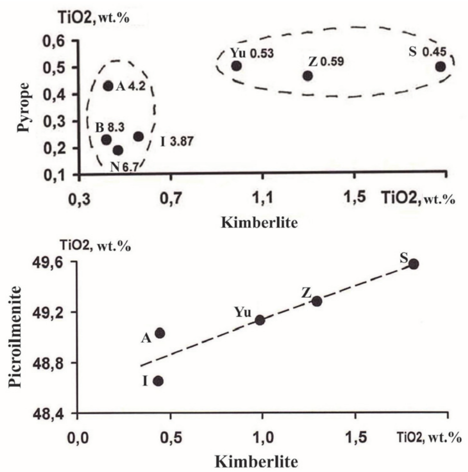

Fig. 5. Ratios of mean TiO_2 contents in kimberlites and accessory kimberlite minerals (pyrope and picroilmenite).

The relationship of titanium contents in kimberlite and picroilmenite follows the same trend (see fig. 6). Kimberlites richer in Ti contain picroilmenite also richer in Ti.

The comparison of mean kimberlite compositions in the pipes under study with the compositions of pyrope and picroilmenite hosted there shows that:

– contents of CaO and Cr_2O_3 in pyrope from kimberlite correlate with diamond content in the kimberlite;
– contents of CaO and Cr_2O_3 in pyrope correlate with K_2O content in the kimberlite;
– contents of CaO in pyrope correlate with CaO in kimberlite and its diamond content;
– the set of pipes with low-diamond kimberlite is clearly separated from diamond-rich pipes in Cr_2O_3/CaO ratio;
– low-titanium garnet ($TiO_2 < 0{,}45$) is common in pipes with low-titanium kimberlite ($TiO_2 < 0{,}47$);
– high-titanium garnet ($TiO_2 \cong 0{,}50$) is characteristic of pipes with high-titanium kimberlite ($TiO_2 > 1{,}0$);
– pipes Udachnaya-West, Udachnaya-East, Yubileinaya, Sytykanskaya, and Zapolyarnaya show a direct proportionality between TiO_2 contents in kimberlite and picroilmenite.

These results prove that the compositions of pyrope and picroilmenite in kimberlites correlate with the main petrochemical trends in kimberlites.

Thus, the magmagenic hypothesis of the formation of diamond and kimberlite is quite probable.

We now move on to a discussion of the material.

1. Regularities deduced from investigation of general collections are often tested by conclusions from several analyses of kimberlite body fragments. The inconsistency between conclusions from general collections and those from local ones is sometimes interpreted as a proof of incorrectness of the general conclusions. Consider an example of inconsistency between conclusions on the base of the general collection of Yakutian kimberlite analyses and a local collection from a single pipe. The example is the correlation between the composition of magnesium red garnets and the compositions of host kimberlites obtained from small sets of rocks and minerals from the Botuobinskaya pipe. The kimberlites belong to the first three populations, of which 1 and 2 are modal [11]. A total of 130 red garnet grains were obtained from 14 kimberlite samples taken from the studied part of the pipe and characterized by chemical analyses. The compositions of kimberlites and garnets are distributed over population varieties of Botuobinskaya (table 9). The results demonstrate linear regression correlations between the contents of Cr_2O_3 in garnets and diamond contents in the rocks and between CaO contents in garnets and in kimberlites (figs. 7, 8).

The particular case of the Botuobinskaya pipe confirms the correctness of conclusions as to the correlation between kimberlite and pyrope compositions based on general collections of kimberlite and pyrope analyses.

Inconsistencies between general and particular conclusions may result from postmagmatic kimberlite alteration [1, 3, 5, 11, 13]. It includes the replacement of olivine and phlogopite by an association of hydrous minerals synchronous with the accumulation of silica minerals. With regard to the degree of postmagmatic alteration, rocks can be divided into unaltered, dolomitized, quartz-containing, and quartzose. The general trends in the alteration of kimberlite composition during serpentinization and subsequent alteration involve decrease in MgO content and increase in SiO_2 content (table 10).

Table 9

Mean compositions of kimberlites from the Botuobinskaya pipe and red garnets present therein

Components	Populations and varieties						
	1-Kcb		1-Ca-kmb		1-Kmb		1-Mg-kmb
	Kmb	Garnet	Kmb	Garnet	Kmb	Garnet	Kmb
SiO_2	16,61	40,68	25,42	41,11	30,99	41,38	32,61
Cr_2O_3	–	6,48	0,047	6,09	0,065	3,81	0,066
CaO	26,84	6,04	18,39	5,33	13,46	4,84	9,39
MgO	12,02	18,38	20,22	19,60	23,02	19,91	29,00
ΣFe_2O_3	2,61	8,36	3,52	7,41	4,77	8,00	5,80
Al_2O_3	3,61	17,59	3,73	18,46	3,85	20,16	3,32
TiO_2	0,28	0,28	0,34	0,20	0,38	0,22	0,33
K_2O	1,81	0,01	1,51	0,01	1,49	0,00	1,07
MnO	0,12	0,41	0,12	0,37	0,12	0,34	0,13
A, ct/t	N. d.	N. d.	21,1	N. d.	8,3	N. d.	10,2
n	1	16	3	14	4	46	3

Components	Populations and varieties						
	1-Mg-kmb	2-Kmb		2-Mg-kmb		3-Kmb	
	Garnet	Kmb	Garnet	Kmb	Garnet	Kmb	Garnet
SiO_2	41,33	32,55	41,24	31,94	41,15	29,21	40,75
Cr_2O_3	4,14	0,080	5,77	0,095	6,57	0,147	8,30
CaO	4,85	10,40	5,32	9,60	4,91	12,69	5,16
MgO	19,48	26,71	19,32	29,41	19,75	25,91	19,74
ΣFe_2O_3	8,38	6,00	8,04	6,64	7,60	7,42	7,33
Al_2O_3	19,69	3,55	18,55	3,64	18,08	2,83	16,52
TiO_2	0,22	0,44	0,27	0,51	0,17	0,76	0,24
K_2O	0,00	1,97	0,00	1,11	0,00	1,29	0,00
MnO	0,41	0,13	0,42	0,1,	0,39	0,12	0,39
A, ct/t	N. d.	15,8	N. d.	22,4	N. d.	N. d.	
n	25	1	3	2	21	1	4

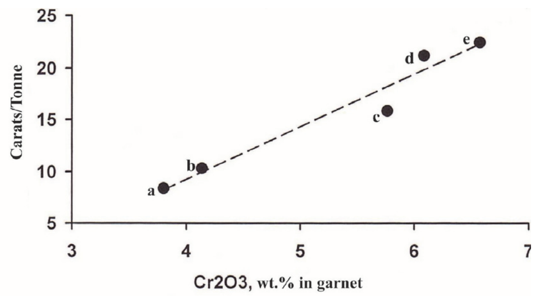

Fig. 7. Figurative points of mean Cr_2O_3 contents in garnet and diamond contents (ct/t) in varieties of kimberlite populations (see table 9) in the Botuobinskaya pipe. Letters indicate population number and varieties: *a* – 1-kmb; *b* – 1-Mg-kmb; *c* – 2-kmb; *d* – 1-Ca-kmb; *e* – 2-Mg-kmb.

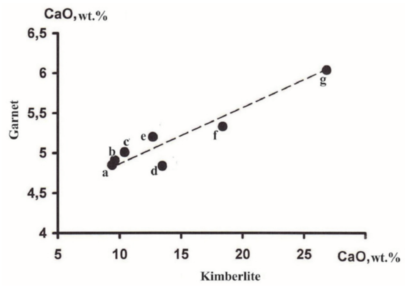

Fig. 8. Figurative points of mean CaO contents in kimberlites of the Botuobinskaya pipe and garnets present therein. Letters indicate population number and varieties: *a* – 1-Mg-kmb; *b* – 2-Mg-kmb; *c* – 2-kmb; *d* – 3-kmb; *e* – 1-kmb; *f* – 1-Ca-kmb; *g* – 1-kcb.

Table 10

Mean compositions of variously altered kimberlite in diamond deposits of the Nakyn, Mirny, Alakit–Markha, and Daldyn fields, Vilyui subprovince

Components	Kimberlite type: Unaltered (n = 2 205)		Dolomitized (n = 422)		Quartz-containing (n = 3 611)		Quartzose (n = 716)	
	x*	v	x	v	x	v	x	v
SiO_2	26,24	15,7	20,92	30,5	29,39	14,3	41,33	26,3
TiO_2	0,92	51,2	0,79	64,9	0,85	64,7	0,84	61,7
Al_2O_3	2,25	36,2	2,41	46,6	2,82	38,4	5,84	82,4
Cr_2O_3	0,146	42,6	0,137	51,2	0,151	29,7	0,095	58,3
ΣFe_2O_3	6,48	32,7	5,78	42,8	6,43	29,9	7,65	56,9
MnO	0,12	38,2	0,14	175,2	0,12	37,1	0,13	32,3
MgO	27,34	19,3	26,18	28,3	25,67	21,0	17,51	45,7
CaO	12,54	52,6	15,74	53,1	12,60	48,3	8,75	83,5
Na_2O	0,32	205,8	0,35	251,2	0,38	151,0	0,39	194,8
K_2O	0,67	73,1	0,97	66,4	0,49	93,4	1,02	99,8
P_2O_5	0,39	50,6	0,48	52,7	0,35	57,4	0,33	59,4
LOI	22,71	22,2	26,13	30,0	22,69	28,9	16,54	42,8

*Statistical parameters: x – mean contents of elements; v – variation coefficients.

Quartzose kimberlites have experienced the deepest alteration. Altered rocks constitute two thirds of the investigated collection, and the most altered quartzose kimberlites, 10 %. In addition, note that the contents of heavy and light rare earth elements decrease dramatically in altered rocks of the Aikhal and Internatsionalnaya pipes.

Thus, we admit that part of quartz-containing and all quartzose kimberlites may be unsuitable for the test of the magmagenic hypothesis.

2. Xenoliths in kimberlites. It is often stated that xenoliths in kimberlites so profoundly change their initial composition that it cannot be reconstructed. Our opinion is different. Our arguments are as follows: Xenoliths in kimberlites are mantle xenoliths, xenoliths of host rocks, and kimberlites of previous intrusion phases. Features of the distribution of mantle xenoliths and their compositions are comprehensively described in [8, 24]. Comparison of the data on particular pipes reported in these papers with petrochemical population models of kimberlites from the same pipes [26] demonstrates [28] that the relative contents of high-potassium (K_2O > 1,2 %) kimberlites from various pipes correlate with the relative contents of pyroxenite xenoliths in the same pipes, and the $Na_2O/(Na_2O + K_2O)$ ratio correlates with the relative contents of eclogite xenoliths. The distribution of kimberlites relatively richer in Ca correlates with the distribution of cataclastic lherzolite xenoliths richer in Mg, and, inversely, kimberlites richer in Mg are associated with the distribution of equigranular lherzolite xenoliths richer in Ca. The association between the compositions of kimberlites and xenoliths therein is obvious; thus, xenoliths cannot be regarded as exotic for kimberlites. Mantle xenoliths are restites of the matter from which the kimberlites have melted out. Xenolith compositions correlate with the compositions of the host kimberlites. Kimberlites rich in calcite more often contain xenoliths with the highest content of olivine, and kimberlites with medium or low calcite, xenoliths with less olivine [28].

Xenoliths of host rocks are confined mainly to tops of kimberlite bodies, where they participate in the formation of breccia-like rocks. It has been shown by the example of the Aikhal, Udachnaya-West, and Udachnaya-East pipes [27] that the amount of kimberlite breccias decreases significantly in subsequent intrusion phases.

Host rock xenoliths getting to the melt simultaneously reduce its alkalinity and temperature; therefore, melt crystallization in the melt + xenolith system starts earlier than the crystallization of the melt without xenoliths.

The effective viscosity in the melt + crystal + xenolith system increases dramatically. When the concentration of the crystalline phase exceeds 30 % v/v, the fluidity point is reached. Fast rise, characteristic of kimberlite magmas, causes melt discontinuity and formation of kimberlite breccias.

The formation of kimberlite breccias favors metastable preservation of diamond. This fact explains the frequently noted diamond content decrease with depth [2].

Inclusions of host rocks and fragments of kimberlite belonging to previous intrusion phases do not influence the content of host kimberlite if they are withdrawn in the preparation of sample weights [11].

3. No influence of host rocks on kimberlite melt compositions has been noted. However, significant influx of components from host rocks to kimberlite melts, which makes kimberlite composition unstable, is sometimes stated, e. g., in [26]. The stability of kimberlite compositions in the Yakutian province can be checked by comparison with rocks of other igneous associations [14]. We compared the variation coefficients of mean compositions (obtained in our study as $v = (s \times 100)/x$, where s is the standard deviation from the mean and x is the mean content of a component in the group of analyses) in the aforementioned igneous rock associations with the variation coefficients of mean compositions in kimberlites not altered by secondary processes (fig. 9). The comparison showed that they were within the distributions of variation coefficients for all oxides in igneous associations. Thus, kimberlites show the same variation in the contents of major oxides as rocks of other igneous associations. The elevated SiO_2 contents in some samples undergoing secondary alteration are considered above.

4. Absolute age of inclusions in diamonds. D. Pearson described Re-Os radiometric ages of four single inclusions in diamonds from kimberlites of the Udachnaya pipe and found that in one of the samples the diamond bordering inclusions had been degraded and replaced by younger diamonds [16]. Dating of such a diamond was impossible. D. Pearson noted that Sm-Nd radiometric assays were complicated by the fact that they demanded significant amounts of diamond grains.

According to our data, Sm-Nd isotope dating should take into account the effect of secondary processes (fig. 10).

It is likely that other isotope systems are affected by secondary processes as well, because in our study about two thirds of over 7 000 samples characterized by chemical analyses have experienced secondary alteration. It is pertinent to remind the fact of diamond dissolution and recrystallization during postmagmatic kimberlite alteration [11]. It casts doubt upon absolute radiometric ages of diamonds. In addition, recent studies point to coordinated ages of diamonds and host kimberlites [12, 19, 22, 23, 25].

There are other sides of the problem of absolute diamond ages:

1) according to data reported in [17], nitrogen aggregates in diamonds of the Udachnaya pipe show properties that indicate that the temperature in the lithospheric mantle remained within 1 100–1 200 °C for a time span comparable with diamond age. Thus, mantle xenoliths in kimberlites seem to be unaltered remains of the magma-generating matter;

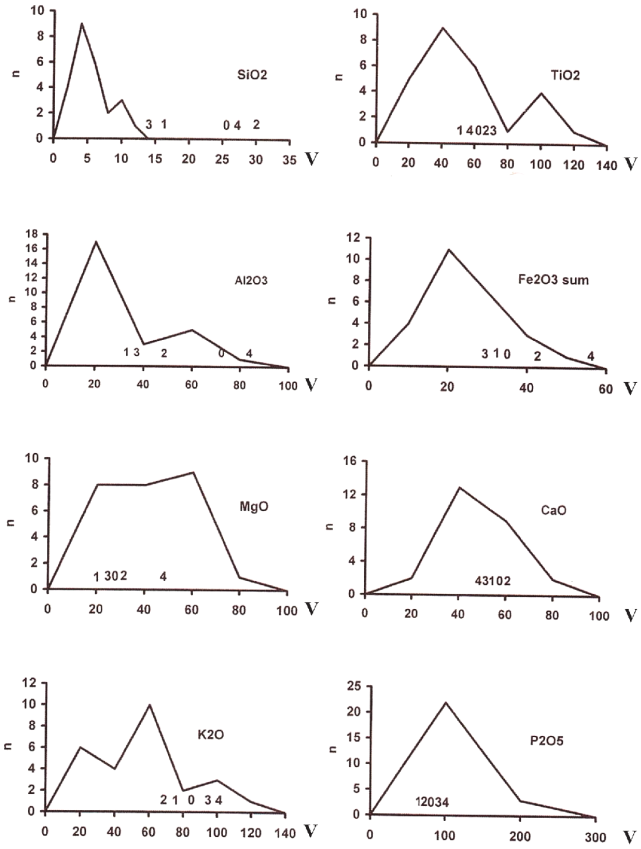

Fig. 9. Distribution of variation coefficients of major oxides in rocks of various igneous associations. Numerals indicate locations of variation coefficients of major oxides in kimberlites altered to different extents:

0 – the entire set of kimberlite analyses; *1* – unaltered; *2* – dolomitized; *3* – quartz-containing; *4* – quartzose.

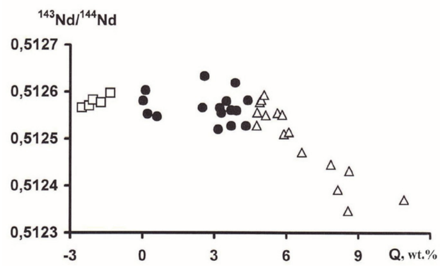

Fig. 10. Figurative points of $^{143}Nd/^{144}Nd$ ratios in kimberlites from pipes Botuobinskaya, Nyurbinskaya, Internatsionalnaya, Aikhal, Poiskovaya, Udachnaya-West, Udachnaya-East, and Komsomolskaya differing in secondary quartz content. The diagram is constructed on the base of isotope analyses both reported in [12, 22] and out own. Rocks: □ – dolomitized; ● – unaltered; Δ – quartz-containing.

2) other data indicate that the formation of De Beers diamonds was stepwise rather than continuous [4]. The first of the steps recognized there was marked by profound depletion of mantle peridotites. In this case, kimberlite formation agrees with our model, in which xenoliths are restites of variously depleted mantle matter.

Thus, there are no uncontestable objections to our results.

Our study demonstrates that the mean compositions of garnet and picroilmenites in kimberlites closely correlate with the chemical compositions of the kimberlites and diamond contents. It is concluded that major and accessory minerals in kimberlites are comagmatic with the diamonds present in the kimberlites.

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ПРО ПОХОДЖЕННЯ КІМБЕРЛІТІВ І НАЯВНИХ У НИХ АЛМАЗІВ

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Зроблено висновок про комагматичність у кімберлітах піропів, алмазів і породоутворювальних мінералів, які визначають валовий хімічний склад порід. Для дослідження використано дані з алмазних родовищ Якутії (кімберлітові трубки Ботуобінська, Нюрбинська, Інтернаціональна, Мир, Айхал, Ювілейна, Удачна-західна, Удачна-східна, Заполярна). Сукупна база даних хімічного складу порід містить понад 7 000 аналізів, з яких 1 976 супроводжуються даними з алмазоносності порід і 1 529 – нейтронно-активаційними визначеннями хрому. Сукупна база даних хімічного складу піропу містить 1 491 мікрозондовий аналіз. Склад пікроільменіту схарактеризовано 986 мікрозондовими аналізами. Проаналізовано літературні дані щодо розбіжності віку кімберлітів і включень в алмазах. Уперше доведено, що під час гідротермально-метасоматичних змін кімберлітів змінюються співвідношення ізотопів неодиму, що ставить під сумнів відповідні визначення віку. Для обґрунтування зроблених висновків наведено оригінальні дані стосовно порівняння коефіцієнтів варіації породоутворювальних оксидів у 25 вулкано-плутонічних формаціях з коефіцієнтами варіації порід кімберлітової формації, які по-різному змінені вторинними процесами.

Ключові слова: алмаз, включення, кімберліт, хімічний склад, алмазоносність, піроп, кореляція, комагматичність.

О ПРОИСХОЖДЕНИИ КИМБЕРЛИТОВ И СОДЕРЖАЩИХСЯ В НИХ АЛМАЗОВ

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Сделано вывод о комагматичности в кимберлитах пиропов, алмазов и породообразующих минералов, которые определяют валовой химический состав пород. Для исследования использовано данные по алмазным месторождениям Якутии (кимберлитовые трубки Ботуобинская, Нюрбинская, Интернациональная, Мир, Айхал, Юбилейная, Сытыканская, Удачная-западная, Удачная-восточная, Заполярная). Совокупная база данных химического состава пород содержит более 7 000 анализов, из которых 1 976 сопровождены данными по алмазоносности пород и 1 529 – нейтронно-активационными определениями хрома. Совокупная база данных химического состава пиропа содержит 1 491 микрозондовый анализ. Состав пикроильменита охарактеризован 986 микрозондовыми анализами. Рассмотрены литературные данные о несовпадении возраста кимберлитов и включений в алмазах. Впервые показано, что при гидротермально-метасоматических изменениях кимберлитов изменяются соотношения изотопов неодима, а это ставит под сомнение соответствующие возрастные оценки. Для обоснования достоверности сделанных выводов приведены оригинальные данные по сравнению коэффициентов вариации породообразующих оксидов в 25 вулкано-плутонических формациях с коэффициентами вариации пород кимберлитовой формации, в разной степени измененных вторичными процессами.

Ключевые слова: алмаз, включение, кимберлит, химический состав, алмазоносность, пироп, корреляция, комагматичность.