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CARBONATITES OF THE TURIY PENINSULA, KOLA: ROLE OF MAGMATISM AND OF METASOMATISM

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ABSTRACT

Two types of carbonatite occur on the Turiy Peninsula (Kola District, Russia); it forms dykes and a stock-like body within an alkaline–ultramafic massif. Chemical data indicate that samples of olivine melanephelinite are generally close to the composition of the initial melts. The main processes are fractional crystallization accompanied by accumulation and liquid immiscibility. Early (magmatic) carbonates are easily modified by metasomatic hydrothermal alteration.

Keywords: melanephelinite, carbonatite, initial melts, Turiy Peninsula, Kola District, Russia.

SOMMAIRE

Deux types de carbonatite affleurent dans la péninsule de Turiy, district de Kola, en Russie; on en trouve mis en place en filons, ainsi que sous forme de pluton circonscrit à l'intérieur d'un massif ultramafique alcalin. Les données chimiques indiquent que les échantillons de mélanéphélinite à olivine se rapprochent de la composition du liquide initial. Les processus principaux mis en évidence sont la cristallisation fractionnée accompagnée d'accumulation de cristaux et l'immiscibilité liquide. Les carbonates primaires précoces sont facilement modifiés par altération métasomatique hydrothermale.

(Traduit par la Rédaction)

Mots-clés: mélanéphélinite, carbonatite, magma initial, péninsule de Turiy, district de Kola, Russie.

INTRODUCTION AND GEOLOGICAL CONTEXT

In the 1920s, Brøgger (1921), Ramsay (1921) and Kranck (1928) published the first information on carbonatites in Russia; they described the carbonatite dykes exposed on the Turiy Peninsula, Kola. A series of carbonatite localities is now known to occur along the Turiy – Kovdor – Sökli zone, which we interpret to be an ancient rift system (Bell *et al.* 1996). Turiy, with its dykes of carbonatite, turjaite and other alkaline rocks, is at the center of the northern coast of Kandalaksha Bay (graben), and Turiy itself is a local horst. Some Paleozoic alkaline–ultrabasic massifs associated with carbonatites have been mapped on the Turiy Peninsula. We consider them to be satellites of a single huge pluton.

THE OCCURRENCE OF CARBONATITE IN DYKES

About 300 dykes cut Proterozoic sandstone and charnockite in shoreline exposures along the coast of the Turiy Peninsula. Beliankin *et al.* (1924) distinguished three age groups. The youngest is the most interesting. Many dyke intersections (Fig. 1) help to establish the order of emplacement, including that of the carbonatites. The earliest dyke-rocks consist of larnite-normative olivine melanephelinite; its composition most nearly corresponds to an initial magma.

The complete series of dykes seems to involve the rock types olivine melanephelinite (with rare melilite microlites), olivine–melilite melanephelinite (with melilite phenocrysts), nepheline melilitite, melilite nephelinite, and nephelinite; there are melilitic rocks among them in addition to the predominant types of nephelinitic rocks, classified according to the scheme of Le Bas (1989). Carbonatite dykes contain pure calcite and have a microlitic texture. They were emplaced partly after the olivine melanephelinite, mostly after the melilite nephelinite, and before the nephelinite. Their origin is considered to be related to liquid immiscibility that was provoked by periodic enrichment of liquids in CO_2 to a level sufficient to

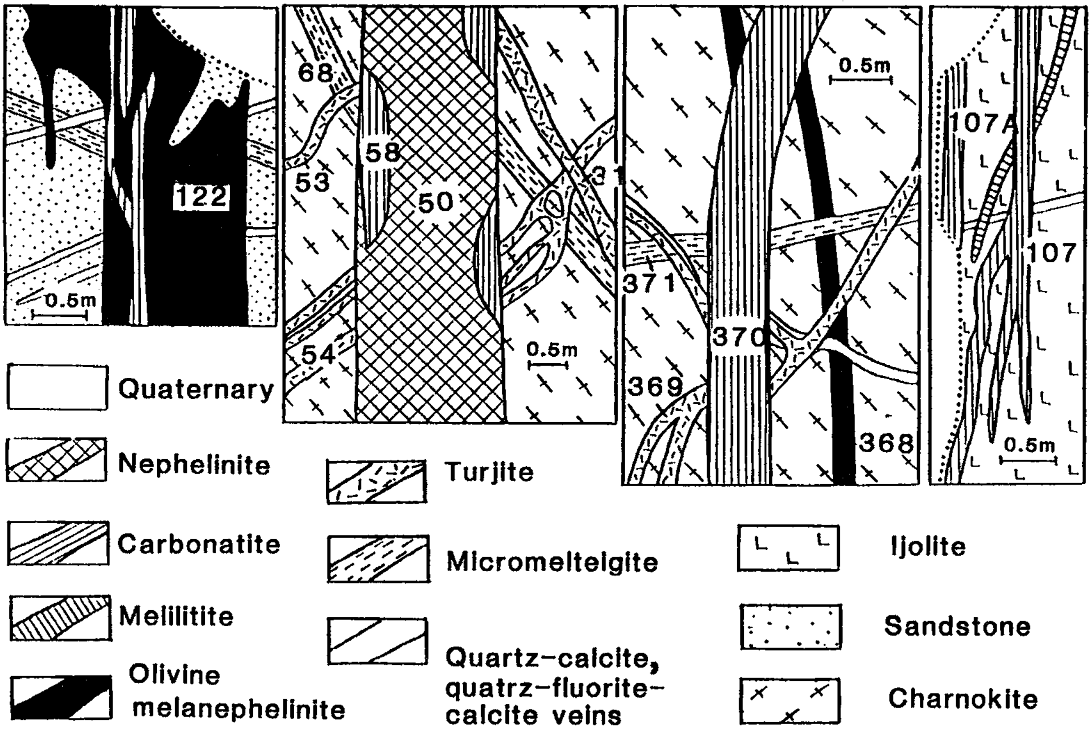

FIG. 1. Sketches of field relationships involving dykes (numbered according to the list compiled by V. Ivanikov).

achieve saturation of a carbonate liquid (Ivanikov *et al.* 1975).

THE OCCURRENCE OF CARBONATITE INSIDE MASSIFS

Carbonatite also forms a stock-like body and many veins inside the Central Turja massif of alkaline ultrabasic rocks (Fig. 2). This massif is unusual (Bulakh 1974) in that it contains evidence of a) several different kinds of melilite-bearing rocks (melilitolite, uncompahgrite, okaite, turjaite), b) two phases of nepheline-bearing rocks, c) a relative age of emplacement of melilite-bearing rocks between melteigite and ijolite, and d) the presence of pipes inside the massif. One small pipe is composed of porphyritic olivine melteigite and fragments of pyroxenite; two others are filled with magmatic breccia, with fragments of melilitolite and other rocks in an ijolitic matrix.

Carbonatite is only one of the rock types in a long series of carbonatite-bearing rocks (Table 1). There are rocks of typical metasomatic and hydrothermal origin at the very beginning of the series. These are hastingsite – diopside – calcite, garnet – diopside – vesuvianite – calcite, and hastingsite – cancrinite – calcite rocks, for example. They generally replace former melilite- and nepheline-bearing rocks. The second step of metasomatic processes is the formation of “tetraferriphlogopite” – calcite, and then richterite – calcite rocks at the expense of pyroxenitic, melteigitic and melilitic rocks. Also, hydrothermal quartz – calcite and fluorite – calcite veins appear at the very end of the series. They occur in fenites outside the massif (Evdokimov 1982).

The carbonatite bodies can be distinguished mineralogically and by the type of wallrocks (Table 2). Among pyroxene – calcite carbonatites, the main types are diopside – calcite and aegirine – diopside – calcite rocks. The former usually occur in pyroxenite and melteigite, and more rarely in fenite; the latter are as a rule found emplaced in ijolite and urtite. Mica – calcite carbonatites are divided into biotite – calcite rocks and phlogopite – calcite rocks; the rocks with biotite usually were formed after the ultrabasic rocks, melteigite and melilite-bearing rocks. Such a division of carbonatites is not exhaustive; thus in pyroxene – calcite carbonatites, it is possible to separate subvarieties of rocks with K-feldspar and others with nepheline. Finally, in addition to the ordinary forsterite – calcite carbonatites, one may find rocks with a monticellite content of up to 10–15%.

In addition to the relations between type of

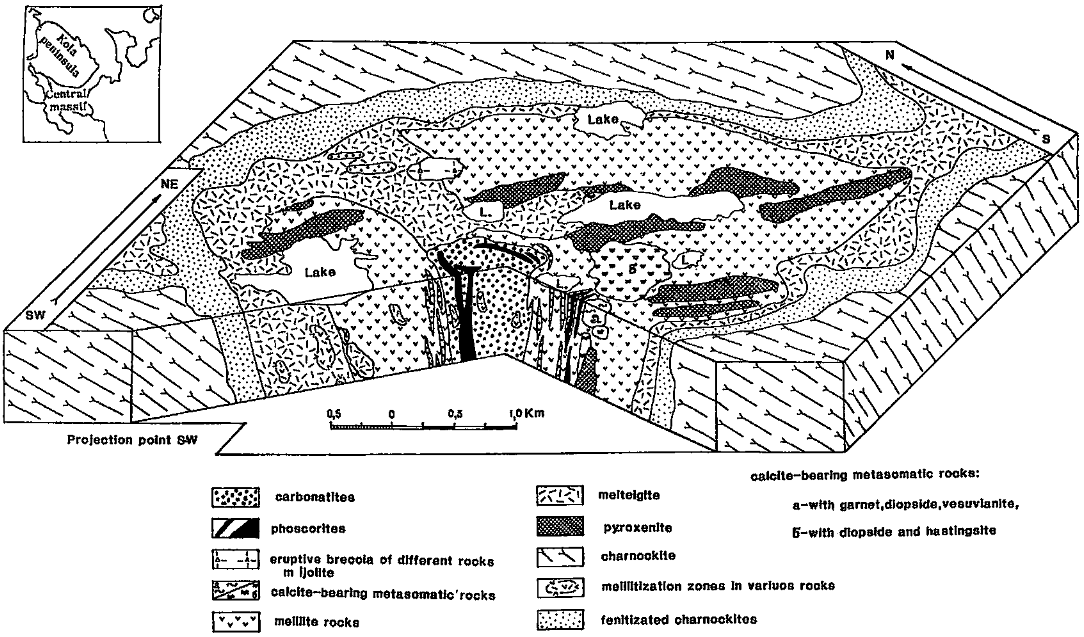

FIG. 2. Geology of the Central Turiy massif, as interpreted by A.K. Bulakh, I. Iskoz-Dolinina and T. Kochurova.

carbonatite and the nature of the wallrocks, there are other phenomena that could signal metasomatic processes during the formation of carbonatites: a) carbonatization of wallrocks and alteration of minerals in these rocks, b) the presence of relics of wallrocks in carbonatites and alteration of minerals in them (for example, pyroxene is replaced with amphibole, mica, and chlorite, olivine is altered to phlogopite and serpentine, perovskite is replaced by ilmenite, *etc.*), and c) episodic recrystallization of calcite and all the other minerals in carbonatites. Moreover, the carbonatite neck is really a stockwork of veins with altered relics of silicate wallrocks located in the network of these carbonatite veins.

TABLE 1. SEQUENCE OF EMPLACEMENT OF ROCKS, TURIY PENINSULA

	Plutonic rocks	Phoscorite–carbonatite series	Dykes within the Central massif	Exocontact metasomatic rocks
I	olivinite pyroxenite nepheline pyroxenite			f
	melteigite melilite rocks (incl. turjaite, okaite, uncompahgrite, melilitolite)		micromelteigite porphyritic olivine melteigite, turjite	e n
II		calcite–bearing metasomatic rocks (+ garnet, diopside, vesuvianite, hastingsite, natrolite)		i
	ijolite		porphyritic ijolite	
		calcite–bearing metasomatic rocks (+ richterite, "tetraferriphlogopite")		t
III		phoscorite		e
		carbonatite		
		quartz–calcite veins (+ fluorite)		s

TABLE 2. TYPES OF CARBONATITE, TURIY PENINSULA

Main type	Wall rocks	Minerals main	Minerals minor
forsterite–calcite	ultrabasic, melteigite, etc.	forsterite–calcite	monticellite
pyroxene–calcite	pyroxenite melteigite ijolite urtite alkali–silicate metasomatic rocks	diopside–calcite aegirine–diopside–calcite	
mica–calcite	ultrabasic melteigite melilite rocks	phlogopite–calcite	melilite
	ijolite urtite alkali–silicate metasomatic rocks	biotite–calcite	nepheline

Fluid inclusions in apatite from phoscorite and carbonatite contain grains of nahcolite and pyrrotite. They become homogeneous in the range 400–320°C (Bulakh *et al.* 1979). Thermodynamic calculations and phase assemblages show that the alteration reactions in the wallrocks and mineral equilibria in phoscorite and carbonatite correspond to a temperature and pressure not more than 500–600°C and 10 kbar (Bulakh & Iskoz-Dolinina 1978, Bulakh 1979). Thus we infer that metasomatic processes associated with carbonatite formation correspond to hydrothermal chemical reactions.

PRIMARY MELTS AND THE ORIGIN OF CARBONATITES

A comparison of the chemical compositions of primary melts in dykes, the average composition of all alkaline carbonatite massifs of Kola, and the composition of porphyritic olivine melteigite in the small pipe (it obviously crystallized from an undifferentiated primary melt) (Tables 3, 4) shows that they are similar. We believe that these compositions are very close to that of the initial magma. This comparison and argument were proposed by Kukharenko *et al.* (1965). Furthermore, the volume proportion of carbonatite in the bulk of dykes and in the Turiy massifs is practically identical (3.5 and 5.0 vol.%, respectively). Incidentally, almost the same volume percentage of carbonatite was established for rock types in the Homa Bay carbonatite–nephelinite province of western Kenya by Le Bas (1977). Moreover, trends of chemical evolution are similar in dykes and in the massifs (Fig. 3). On the whole, rock-forming processes are proposed to be similar in the two settings. Note that fields 13 and 14 (pyroxenite) and 15 (melilitolite and uncompahgrite) lie to the left of the main trend; we contend that these rocks are cumulates (Ivanikov *et al.* 1975). In summary, in these massifs, ultrabasic rocks, melilitolite, uncompahgrite on the one hand, and melteigite, turjaite, okaite, ijolite on the other, are comagmatic; however, they are different products of cristallization by fractionation, cumulates in the first case and fractionated melts in the second. They were formed at different stages of magmatism and are now found together on erosion surfaces of some multiphase alkaline–ultrabasic massifs (Bulakh & Ivanikov 1984, p. 226). Carbonatite is considered to form as a result of the immiscibility of a carbonate liquid from an ijolitic liquid. The same petrogenetic scheme was proposed by Nielsen (1994) in his report on the nature of primary melts and the origin of the ultrabasic-alkaline Gardiner complex in Greenland.

TABLE 3. AVERAGE COMPOSITION OF DYKE ROCKS, TURIY PENINSULA

	1 n = 4	2 n = 3	3 n = 5	4 n = 12	5 n = 5	6 n = 6	7 n = 2	8 n = 3	9
SiO_2	39.76	36.97	40.12	37.31	37.53	40.78	46.36	4.50	36.38
TiO_2	2.68	3.07	2.20	2.55	2.48	1.52	0.75	0.06	3.22
Al_2O_3	9.31	7.98	12.10	12.03	12.02	18.41	18.55	0.13	7.94
Fe_2O_3	6.87	9.86	5.69	6.01	6.01	4.21	6.10	1.02	8.37
FeO	6.02	4.48	5.99	5.50	5.14	3.49	1.91	2.20	6.88
MnO	0.21	0.21	0.20	0.24	0.27	0.22	0.22	0.47	0.12
MgO	10.25	8.73	6.53	5.94	4.97	1.61	1.26	2.63	14.25
CaO	15.35	18.18	13.87	14.77	14.31	9.65	7.74	45.31	14.46
Na_2O	2.89	3.35	4.39	4.70	6.51	10.41	12.00	0.50	3.17
K_2O	1.47	1.88	1.79	2.29	2.28	2.41	3.14	0.24	1.52
P_2O_5	0.31	0.24	0.43	0.59	0.91	0.42	0.20	1.45	0.37
H_2O	0.31	0.35	0.21	0.37	0.21	0.30	0.16	0.03	0.66
LOI	4.55	5.73	6.16	7.36	6.89	6.77	1.92	39.21	1.96
Total	99.99	101.03	99.68	99.66	99.54	100.20	100.31	97.75	100.00
CO_2	1.57	3.45	3.60	3.79	4.24	3.14	0.92		1.80
Sc	20	25	21	14	7.6	3.5		2.9	24
Cr	292	176	139	48	17	14		11	30
Co	51	60	45	45	34	24		11	15
Ni	106	81	49	<40	<40	<40		<40	36
Rb	34	40	46	54	72	58		<3	80
Sr	2026	1710	3081	2608	3474	2492		9420	1300
Ba	732	450	1266	2433	1698	1476		1318	850
La	85	120	117	148	157	123		645	360
Ce	143	193	202	269	281	218		1199	750
Nd	46	63	61	72	69	57		220	290
Sm	8.2	12	10	16	14	9.2		19	30
Eu	2.3	2.9	3.0	4.6	3.6	2.9		7.3	8.8
Tb	0.69	0.96	0.92	1.5	1.6	1.1		2.0	0.94
Yb	1.7	1.5	1.8	1.8	2.7	2.0		2.3	1.2
Lu	0.11	0.10	0.17	0.18	0.26	0.25		0.19	0.30
Y	20	26	25	34	38	25		40	20
Zr	239	304	319	478	515	270		46	340
Hf	4.9	6.2	5.3	8.5	8.6	4.6		0.8	5.1
Nb	105	154	160	194	236	193		396	300
Ta	5.4	8.1	8.5	12	12	14		2.9	34
Th	11	14	12	15	19	17		31	
U	1.9	1.5	2.6	2.8	4.0	4.1		6.0	

Rock types: 1 olivine melanephelinite, 2 olivine–melilite melanephelinite, 3 melanephelinite, 4 nepheline melilitite, 5 melilite nephelinite, 6 nephelinite, 7 phonolite–nephelinite, 8 carbonatite, 9 average composition of all carbonatite massifs on Kola, after Kukharenko *et al.* (1965). LOI: loss on ignition. The compositions were determined by wet–chemical analysis (major elements) and X–ray–fluorescence and neutron–activation methods (trace elements), reported in wt.% and ppm, respectively.

TABLE 4. REPRESENTATIVE COMPOSITIONS OF PLUTONIC ROCKS, TURIY PENINSULA

	1	2	3	4	5	6	7	8	9
SiO_2	43.39	37.37	38.91	39.86	40.24	38.03	40.21	36.27	35.90
TiO_2	2.92	3.82	3.39	2.20	2.75	3.25	2.32	3.33	3.75
Al_2O_3	5.80	7.35	9.28	9.45	12.52	12.30	16.35	12.46	7.46
Fe_2O_3	9.48	11.60	9.18	7.17	7.47	8.79	5.23	5.18	6.12
FeO	4.88	7.36	6.99	5.09	5.69	3.38	4.92	3.94	5.77
MnO	0.17	0.17	0.18	0.18	0.15	0.15	0.16	0.37	0.11
MgO	11.32	9.76	10.09	11.10	8.85	6.66	5.67	5.38	9.90
CaO	20.85	17.99	16.43	16.26	15.13	16.15	12.59	20.15	26.53
Na_2O	0.60	1.81	2.95	3.96	4.39	5.20	7.22	5.85	2.91
K_2O	0.12	0.58	0.92	1.33	1.49	3.16	2.50	2.32	trace
P_2O_5	0.02	0.12	0.20	0.19	0.12	1.91	1.28	1.18	0.07
H_2O	0.28	0.11	0.13	0.21	0.09	0.10	0.17	–	–
LOI	0.64	1.57	1.34	2.49	0.97	1.25	1.32	2.27	0.90
Total	100.46	99.61	99.99	99.59	99.86	100.33	99.94	98.70	99.42
CO_2	0.31	0.57	0.38	1.40	0.36	0.75	0.30	0.78	–

Rock types: 1 pyroxenite, 2 magnetite pyroxenite, 3 nepheline pyroxenite, 4 porphyritic olivine melteigite, 5 melteigite, 6 garnet melteigite–ijolite, 7 ijolite, 8 turjaite, 9 uncompahgrite. LOI: loss on ignition. The compositions were determined by wet–chemical analysis (results in wt.%).

A quantitative model of the formation of Turiy carbonatite complex, based upon mass-balance calculations for the compositional change from parent to derivative liquid by fractional crystallization, was recently proposed by V. Ivanikov and A. Rukhlov (pers. comm.) (Fig. 4). The observed concentrations of

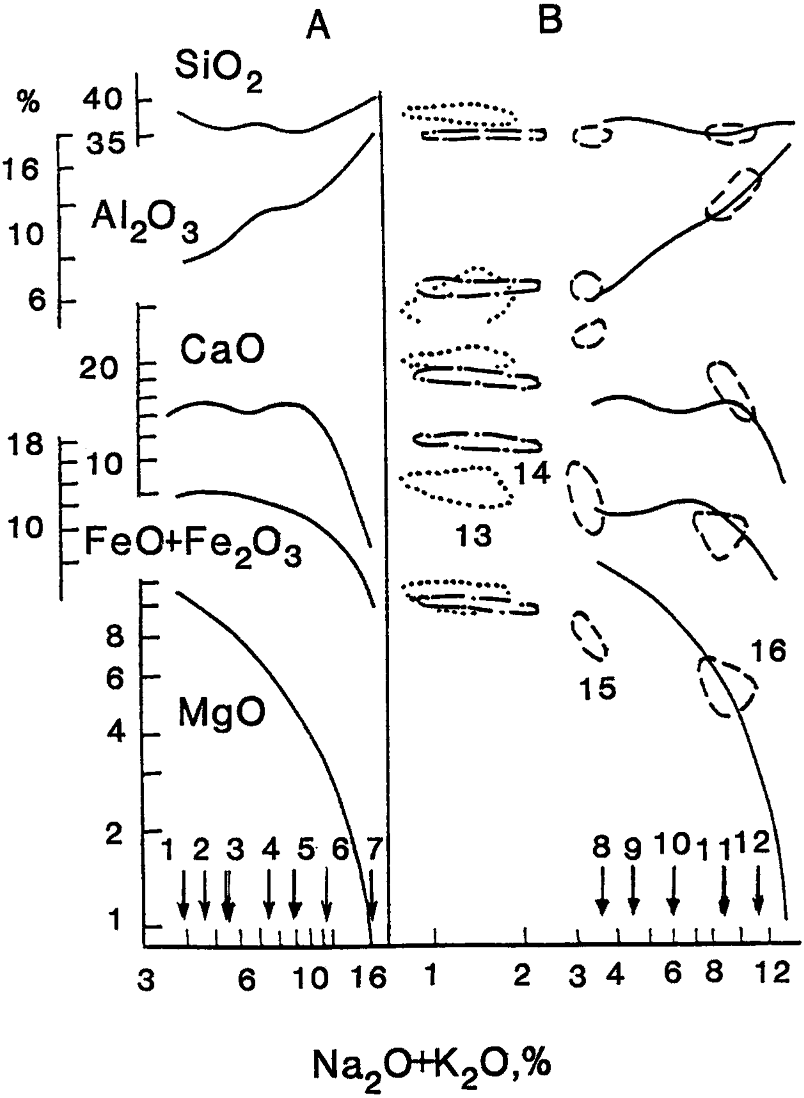

FIG. 3. Trends of chemical evolution of dykes (A) and rocks in the massifs (B). Legend: 1 olivine melanephelinite, 2 olivine–melilite melanephelinite, 3 melanephelinite, 4 melilitite, 5 melilite nephelinite, 6 nephelinite, 7 phonolite–nephelinite, 8 nepheline pyroxenite, 9 porphyritic olivine melteigite, 10 melteigite, 11 garnet melteigite – ijolite, 12 ijolite, 13 pyroxenite, 14 magnetite pyroxenite, 15 melilitolite and uncompahgrite, 16 turjaite and okaite.

trace elements in the dyke rocks (Table 3) correspond reasonably well to concentrations of Ni, Cr, Co, Rb, Sr, Nb, and Y in the derivative liquids calculated using a Rayleigh fractionation model.

Carbonatitic rocks are thus magmatic on the whole, but they may be completely changed by metasomatic processes. Such processes did take place in carbonatite inside the alkaline–ultrabasic massifs of Turiy. We believe that in young and currently active continental rift zones, and in near-surface conditions, gases usually easily escape during the process of carbonatite formation. The features of primary magmatic crystallization of carbonatite in such conditions are partly preserved, and not erased by the metasomatic processes. During the formation of deeper alkaline–ultrabasic massifs (such as those of the Baltic Shield

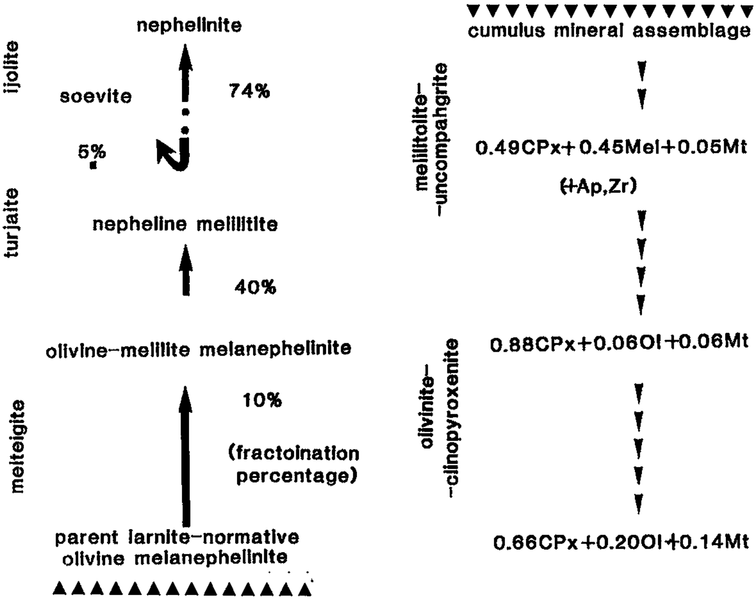

FIG. 4. A quantitative model of the formation of Turiy carbonatite complex.

and the East Sayan region), such systems of carbonatite genesis were more effectively closed. In such conditions, fluid components (H_2O, CO_2, *etc.*) actively affected the primary products of crystallization of carbonate melts, resulting in the long and intense metasomatic alteration of the earlier cumulates and other products of igneous crystallization. Thus the carbonatitic rocks in the deeper massifs of alkaline–ultrabasic affinity are heterogeneous: they contain primary minerals and are intrusive, magmatic; later, secondary processes caused a hydrothermal metasomatic overprint. In this way, secondary processes are responsible for the final appearance, structural features and mineral composition of such carbonatites.

CONCLUSIONS

1. Carbonatite on the Turiy Peninsula occurs in dykes and in a stock-like body and veins inside the alkaline–ultrabasic massifs.
2. Primary magmas were the same in the both cases. Compositions of olivine melanephelinite and porphyritic olivine melteigite are in most cases close to the inferred composition of the initial melt.
3. The main magmatic processes were fractional crystallization of the primary melts, accompanied by accumulation of crystalline phases, and immiscibility. Early magmatic carbonatite is easily overprinted by metasomatic hydrothermal processes.

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