MEGACRYST POPULATION IN NEPHELINITES OF THE CHUKCHI PENINSULA

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ABSTRACT

Neogene volcanoes of nephelinites (SiO_2=38.6-42.4 wt%) in the Chukchi Peninsula make up part of the Bering Sea Basalt Province. Numerous deep-seated inclusions are contained in lavas. Megacryst association consists of transparent and turbid clinopyroxenes (CPx), ilmenite (Il), orthopyroxene (OPx), olivine (Ol), and biotite (Bt), in order of distribution. Turbid clinopyroxene megacrysts are interpreted as the result of partial melting and recrystallization of transparent megacrysts during their ascent in high-temperature nephelenite magma. Megacrysts are comparable to microlites and phenocrysts in chemical composition and quantitative relation of minerals. The megacryst population has the following chemical features: olivine (mg#=84-97) and orthopyroxene (mg#=86-91) are high in magnesian; orthopyroxene contains chromium (Cr_2O_3= 0.2-0.6 wt%); other megacrysts - clinopyroxene, biotite, ilmenite - are more Fe-rich (CPx - mg#=73-82, Bt - mg#=73-77), Ti-rich (CPx -TiO_2=0,8-2,0 wt%, Bt -TiO_2=7,7-8,2 wt%), and Cr-poor. On the basis of our investigation, we conclude that two conditions must be satisfied for megacryst crystallization: (1) the quantity of megacrysts that are formed must be a considerable part of the melt volume (apparently, more than 50 % by volume); megacrysts are not rare crystals as proposed in the hypothesis that megacrysts are intratelluric phenocrysts; (2) megacryst crystallization does not cause essential alteration of melt composition within deep-seated magma chamber. Such a process is comparable with the hypothesis that megacrysts form from high temperature mineralized fluid circulating in upper mantle weak zones (Kovalenko et al., 1986; Sharkov et al., 1989).

NTRODUCTION

In different parts of the world there are occurences of alkali basalts and ultrabasic foidites that bring megacrysts and xenoliths of deep-seated rocks onto the Earths surface. Deep-seated inclusions are of significant scientific interest because they provide information on mantle rock composition beneath volcanoes and geological processes taking place in the upper mantle. Megacrysts are very large individual crystals. They are usually 1- cm across, but can be up to 10-15 cm across. A few are fragments of gigantic grain rocks (i.e., orthopyroxene megacrysts having less than 1.5 wt% CaO), but most megacrysts have their own origin. We will consider such megacrysts here. Megacrysts have similar features to microlites and phenocrysts. They are usually supposed to be genetically related to host lavas.

An interesting feature of the Chukchi Peninsula is that the deep-seated inclusions are contained only in lavas of alkali-ultrabasic composition, whereas in other Cenozoic provinces deep-seated inclusions are associated with alkali basalts.

GEOLOGICAL SETTING AND COMPOSITION OF HOST LAVAS

The described volcanoes are located on the southern Chukchi Peninsula in the Enmelen and Nunyamuveem River basins (Rabkin, 1954 and Akinin and Apt, 1994). They make up part of the Bering Sea Basalt province (see Fig. 1 from Akinin, this volume). Our team, consisting of V.F. Belyi, V.V. Akinin, J.E. Apt, Yu.A. Kolyasnikov, and S.V. Shchepetov, examined six volcanoes in the summers of 1985-86. Composition of volcanics and deep-seated inclusions are presented in Akinin and Apt (1994).

The investigated territory (Enmelen and Nunyamuveem River basins) is composed mainly of Cretaceous alkali-calc volcanic rocks of the Okhotsk-Chukotsk volcanic belt. There are also ledges of basement, formed by Devonian limestones and schists. Alkali volcanoes are situated around paleozoic rock ledges or near large granite intrusions. This geometry is a result of the tensionsal state of the crust in these districts.

Alkali volcanoes are of Neogene age (4-10 Ma) and are small isolated bodies from several tens m^2 to 6-10 km^2 in area. There are volcanic edifices (with cinder cones, neck remnants, extrusion domes, and dikes) and lava flows. About 97 percent by volume of lavas investigated are represented by nephelinites (olivine melanephelinites and leucite-bearing olivine melanephelinites according to the Russian classification (Bogatikov et al., 1981) and only 3 percent are basanites (olivine tephrites). Deep-seated inclusions are contained only in volcanoes built by nephelinites (leucite-bearing olivine melanephelinites). Thus, in the Chukchi Peninsula we can see examples of megacrysts sourced in lavas of alkali-ultrabasic composition.

The lavas containing deep-seating inclusions have porphyritic textures with 12-20 percent by volume olivine phenocryst (Fo_{89-75}). Groundmasses have micropoikoilitic and microcrystalline textures and consist of 41-49 percent Ti-diopside ($Wo_{49.1}En_{39.8}Fs_{11.1}$ and 2.2-5.2 wt% TiO_2), 10-17 percent Ti-magnetite and ilmenite, 2-

15 percent leucite, 5-10 percent nepheline, 0-3.5 percent plagioclase, and less than 5 percent alkali feldspar and glass. Phlogopite and apatite are accessory minerals.

These lavas are strongly silica-undersaturated (SiO_2=38.6-42.4 weight percent), highly alkali (Na_2O+K_2O= 5.4-8.1 wt%), highly titanic (3-5 wt%) and highly magnesian ($mg\# = 100*Mg/(Mg+Fe^{+2})$=63.0-72.6). They stand out as the most undersaturated among lavas of the Bering Sea Basalt Province as seen in the composition of lavas presented by Akinin (this volume, Tables 1).

DESCRIPTION OF MEGACRYSTS

The megacryst population consists of two types of clinopyroxenes, ilmenite, orthopyroxene, olivine and biotite (in the order of distribution).

Megacrysts occur as single large crystals that are usually angular or subangular, but occasionally some euhedral crystal facets are observed. Clinopyroxene megacrysts often contain gas inclusions 0.1-1 mm in diameter. These inclusions indicate high gas pressure during megacrysts crystallization. Individual crystals, except turbid (dull) clinopyroxene and ilmenite, are optically and chemically homogeneous but differ in composition from each other.

Two types of clinopyroxene megacrysts occur - transparent and turbid (Akinin and Apt, 1994).

Transparent Megacrysts

These are generally (1-4 cm across, sometimes up to 12 cm) and occur in highly vesicular and highly oxidized lavas, cinder, and bombs. They are Na-Al low-Ca augites ($Wo_{37.7}En_{48.6}Fs_{13.6}$; Table 1, numbers 1-9) which are common in alkali basalt provinces in other parts of the world. They are dark brown, homogeneous, and have a charateristic vitreous luster and concoidal fracture. Zones of melting, which contain inclusions of alkali glass, titanomagnetite, and rare olivine occur along cracks or in zones bordering the rim of the crystals.

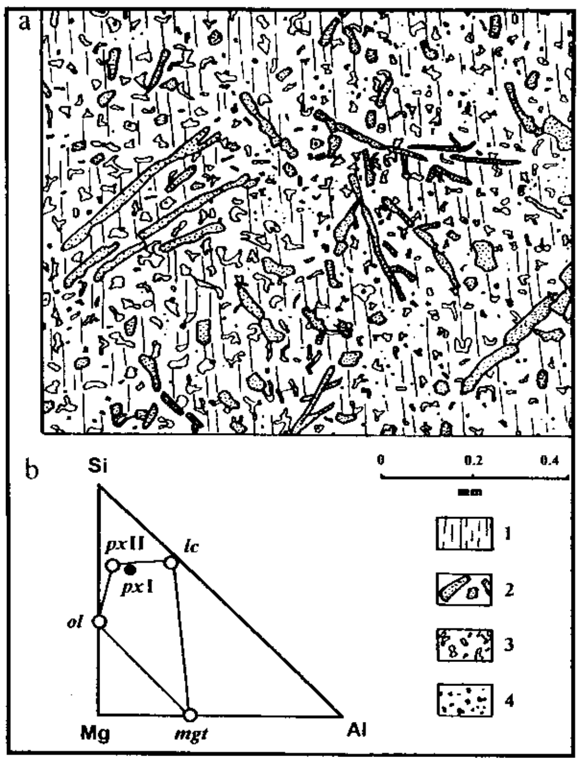

Fig. 1. Internal structure of the turbid clinopyroxene megacryst (a): 1 - clinopyroxene; 2 - olivine; 3 - glass, leucite; 4 - titanomagnetite. Compositions of the megacryst mineral phases (b): *pxI* - whole chemical composition of the turbid megacryst, *pxII* - clinopyroxene of turbid megacryst, *ol* - olivine, *mt* - titanomagnetite, *lc* - leucite

Turbid Clinopyroxene

These megacrysts resemble transparent clinopyroxene megacrysts in chemical composition, but are very different internally and externally. They are grey crystals (from < 1-3 cm) that have an eliptical shape, dull luster, and well-developed cleavage. They generally occur in non-vesicular or weakly vesicular lavas. The megacrysts have a microporphyritic texture: large clinopyroxene crystal (average $Wo_{46.7}En_{42.0}Fs_{11.3}$) contain abundant randomly oriented small inclusions of leucite, glass, titanomagnetite, and needles or whisk-shaped aggregates of olivine (Fig. 1). Clinopyroxene composition is variable and changes within single crystal (Table 1, #'s 16 and 17). Megacryst rims are usually more titanic (Table 1, #11). Newly-formed pinkish-brown titan-diopside, similar in composition to the titan-diopside in the groundmass of the lavas, occurs around megacrysts (Table 1, #12). A transparent core, without inclusions of olivine, leucite, and magnetite, was found in the center of a turbid megacryst.

Olivine Megacrysts

These are generally 0.5-2.5 cm across and consist of fractured, transparent olive-green crystals of rounded shape. They are highly magnesian ($Fo_{87.1-91.0}$, rarely $Fo_{83.6}$), have low Ca (CaO=0.4-0.11 wt%), and high Ni (NiO=0.21-0.32 wt%) (Table 1, #'s 19-24). Some megacrysts have thin (0.01-0.03 mm) rims that are more Fe- and Ca-rich and have less Ni ($Fo_{82-86.2}$, CaO=0.17-0.48 wt%, NiO=0-0.05 wt%).

Table 1 **Representative compositions of minerals from megacrysts**

	Transparent clinopyroxene megacrysts								
Sample	121-B	121-P	123-5	127	132-1	135	135-1	1070	n/No
Mineral	cpx	cpx	cpx	cpx	cpx	cpx	cpx	cpx	cpx
Map No	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
SiO_2	52,00	52,34	51,96	52,60	52,09	52,34	52,52	51,80	50,42
TiO_2	1,16	0,80	1,23	1,03	1,32	0,80	1,14	1,45	1,52
Al_2O_3	6,57	7,28	6,54	7,29	7,93	7,08	7,12	8,20	7,48
Cr_2O_3	0,01	0,01	0,01	0,00	0,01	0,01	0,00	0,01	0,00
FeO*	7,36	6,72	7,46	6,36	8,21	6,66	7,13	7,56	6,96
MnO	0,18	0,09	0,10	0,11	0,08	0,12	0,18	0,15	0,11
MgO	14,60	16,64	14,15	16,35	12,84	16,63	15,08	14,45	12,43
CaO	16,36	14,30	16,86	15,72	16,32	13,83	14,89	14,84	17,68
Na_2O	2,10	1,43	1,64	1,78	2,03	1,54	1,90	2,46	2,34
K_2O	0,01	0,02	0,02	0,02	0,00	0,01	0,01	0,03	0,00
NiO	0,00	0,01	0,01	0,01	0,00	0,00	0,00	0,00	0,00
Total	100,35	99,64	99,98	101,27	100,81	99,02	99,97	100,95	98,94
mg#	78,0	81,5	77,2	82,1	73,6	81,7	79,0	77,3	76,1
n	2	3	2	2	3	3	3	2	1

	Turbid clinopyroxene megacrysts								
Sample	121-7						125-1		127
Mineral	cpx	cpx	cpx	ol	lc	mgt	cpx	cpx	cpx
Map No	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
SiO_2	50,76	50,48	40,94	39,62	59,10	-	50,70	52,20	52,17
TiO_2	1,64	2,32	6,33	0,07	0,16	23,55	2,03	1,42	1,48
Al_2O_3	4,19	4,60	9,59	0,02	23,04	4,42	5,68	3,92	4,55
Cr_2O_3	0,04	0,08	0,03	0,01	0,01	0,29	0,07	0,02	0,00
FeO*	5,68	5,60	7,50	20,54	0,39	63,05	6,78	6,12	6,07
MnO	0,06	0,14	0,14	0,30	0,03	0,55	0,06	0,14	0,11
MgO	14,45	13,99	10,67	39,90	0,16	5,95	12,65	14,86	15,34
CaO	22,35	23,07	22,70	0,23	0,50	-	21,96	21,62	20,95
Na_2O	0,76	0,69	0,65	0,00	0,02	-	1,17	0,66	0,35
K_2O	0,00	0,01	0,00	0,01	16,53	-	0,19	0,06	0,13
NiO	0,00	0,02	0,13	0,03	0,05	0,06	0,02	0,00	0,00
Total	99,93	101,00	98,68	100,73	99,99	97,87	101,32	101,02	101,15
FeO	-	-	-	-	-	43,94	-	-	-
Fe_2O_3	-	-	-	-	-	21,23	-	-	-
mg#	81,9	81,7	71,7	77,6	42,2	19,4	76,9	81,2	81,8
n	1	2	1	4	1	1	1	2	1

Table 1 (continued)

	Orthopyroxenes								Ol
Sample	121-A	126-4	121-4B/8	121-A	131-2	132	1-OPx	1-OPx	125-5
Mineral	opx	opx	opx	opx	opx	opx	opx	opx	ol
Map No	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*
SiO_2	54,20	53,99	54,18	54,48	54,55	55,39	56,41	54,57	40,01
TiO_2	0,25	0,18	0,26	0,12	0,16	0,11	0,07	0,26	0,02
Al_2O_3	5,55	5,19	5,76	5,28	5,28	5,31	4,28	5,69	0,07
Cr_2O_3	0,31	0,47	0,26	0,56	0,42	0,62	0,42	0,20	0,03
FeO*	7,79	6,79	8,12	6,94	6,46	6,06	6,44	8,29	12,31
MnO	0,13	0,11	0,15	0,11	0,08	0,15	0,13	0,11	0,12
MgO	30,10	31,28	30,01	31,50	30,58	33,45	32,99	30,14	47,06
CaO	1,75	1,73	1,69	1,79	1,74	0,56	0,68	1,74	0,10
Na_2O	0,23	0,26	0,26	0,28	0,63	0,01	0,00	0,08	0,06
K_2O	0,01	0,01	0,00	0,01	0,02	0,02	0,00	0,02	0,00
NiO	0,03	0,01	0,00	0,08	0,06	0,08	0,06	0,04	0,21
Total	100,35	100,02	100,69	101,15	99,98	101,76	101,48	101,14	100,00
mg#	87,3	89,1	86,8	89,0	89,4	90,8	90,1	86,6	87,2
n	3	3	2	2	2	2	2	2	3

	Olivines				Biotites		Ilmenites		
Sample	121-5	126	217-1	n/No	121-2	n/No	122-I		
Mineral	ol	ol	ol	ol	bt	bt	il	il	mgt
Map No	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*
SiO_2	41,23	39,38	41,93	41,69	37,78	35,98	-	-	-
TiO_2	0,02	0,03	0,02	0,00	7,61	8,17	40,72	49,29	19,15
Al_2O_3	0,02	0,00	0,09	0,06	15,96	15,39	1,65	0,43	4,60
Cr_2O_3	0,01	0,01	0,00	0,00	0,03	0,00	0,00	0,02	0,06
FeO*	9,38	15,83	9,03	8,62	9,49	8,55	50,97	38,95	64,56
MnO	0,15	0,19	0,28	0,08	0,02	0,00	0,31	0,21	0,23
MgO	50,69	45,01	50,11	48,96	15,96	15,96	5,45	8,67	6,18
CaO	0,04	0,10	0,05	0,06	0,00	0,00	-	-	-
Na_2O	0,01	0,01	0,00	0,00	0,57	0,54	-	-	-
K_2O	0,00	0,00	0,00	0,00	8,78	10,99	-	-	-
NiO	0,21	0,30	0,32	0,00	0,07	0,00	0,00	0,00	0,00
Total	101,76	100,85	101,83	99,47	96,33	95,60	99,10	97,57	94,78
FeO	-	-	-	-	-	-	27,78	28,97	39,16
Fe_2O_3	-	-	-	-	-	-	25,77	11,10	28,22
mg#	90,6	83,5	90,8	91,0	75,0	76,9	25,9	34,8	22,0
n	3	4	5	1	6	1	3	2	2

Note: 11 - megacryst rim; *12* - new-formed outside border; *34* - whole megacryst composition determined using a defocused beam; *35-36* - exsolution lamellae. *n* - quantity of analyses; mg# = 100*Mg/(Mg+Fe^{+2}). Total Fe is expressed as FeO*. Analyses are performed by V.V. Akinin and G.A. Merkulov ("Camebax" microprobe, NEISRI, Magadan). *9, 31, 33* - from (Belov et al., 1984).

Orthopyroxenes

These megacrysts measure 0.5-3 cm across and are fractured, dark brownish or yellowish green, and oval shaped. They are Al-Cr enstatites ($En_{85}Fs_{11.6}Wo_{3.4}$) with high Ca contents (CaO=1.5-1.8%) (Table 1, #'s 19-23, 26). Some megacrysts containing less than 0.7 weight percent CaO (Table 1, #'s 24 and 25) are apparently fragments of very coarse-grained deep-seated rocks which we find as xenoliths. Megacrysts have reaction rims (thikness is 0.05-6.0 mm) caused by incongruent melting. These rims consist of very small crystals of olivine and low-Al clinopyroxene occuring in a leucite or feldspar matrix (Akinin and Apt, 1989); OPx + K_2O-> Ol+ CPx + Fsp (or Lc) + SiO_2, where OPx -opthopyroxene, Ol - olivine, CPx - clinopyroxene, Fsp - alkali feldspar, Lc - leucite.

Fe-Ti oxide megacrysts

These are generally 1-7 cm across and occur as grey crystals with a metallic luster They have an irregular shape with smooth, occasionally resorbed rims. They have parallel exsolution lamellae of thin (5-20 microns) magnetite in ilmenite (Table 1, #'s 35 and 36). Magnetite exsolution lamellae comprise from 25 to 50 percent of the volume of the megacrysts. The total megacryst composition determined using a defocused beam, belongs to ilmenite (Table 1, #34). Only one sample has ilmenite without magnetite. Some exsolution lamellae are bent due to plastic deformation after the lamellae formed. In reflected light, one can see that each megacryst consists of many grains (0.5-1 mm across) and each subgrain has its own orientation of exsolution lamellae. Leucite aggregates (less than 0.3 mm across) are found surrounding some megacrysts. Leucite aggregates also occur as rounded blebs inside a megacryst.

Biotite Megacrysts

These megacrysts (0.5-2 cm across) are light-brown rectangular crystals occuring more commonly in oxidized, highly vesicular lavas and cinders. They are ocassionally found in non-vesicular lavas, but in these lavas they are highly deformed and recrystallized. Megacrysts belong to titaniferous biotites (Table 1, #'s 32 and 33).

After Mercier and Carter's single-pyroxene geothermobarometers (Mercier and Carter, 1975; Mercier, 1976; and Mercier, 1980), we have calculated the following equilibrium conditions of pyroxene megacrysts (Akinin and Apt, 1994): clinopyroxene - T=1200-1325℃, P=16-25 kbar; orthopyroxene - T=1215-1270°C, P=21-29 kbar. Olivine megacrysts were crystallized at P > 10 kbar according to the calculation after barometer of Finnerti and Boyd (1978). It is interesting to note that equilibrium parameters for megacrysts are considerably higher than those of xenoliths of spinel peridotites from the same lavas.

DISCUSSION

The comparison of chemical composition of megacrysts with phenocrysts and microlites, makes it possible to note some general peculiarities showing a genetic relationship of megacrysts with their supporting lavas. Megacrysts of clinopyroxene and mica are compositionally close to microlites in mg#; they contain considerable TiO_2, but almost no Cr_2O_3. Ilmenite and magnetite have approximately the same minimal composition as microlites; abundant MgO and very low Cr_2O_3 content. There is a considerable TiO_2 and Al_2O_3 content in all magnetites.

It is interesting that the megacryst population on the Chukchi Peninsula is comparable with their host lavas both in composition of minerals and quantitative relation among them. Dark mineral percentages are closely related between in megacryst population and volcanics (in brackets): clinopyroxene - 58 percent (63%), olivine and orthopyroxene - 15 percent (20%, only olivine),ilmenite and magnetite - 26 percent (17%), mica - 0.3 percent (less than 1%). These facts support the idea of similarity between the crystallization processes of megacryst and volcanics.

We will now note features of the Chukchi Peninsula megacryst population that distinguish them from the megacryst population in provinces of alkali basalts. The first two features are generally characteristic of the mineralogical peculiarities of ultrabasic versus basic lavas.

(1) All megacrysts are dark minerals. Feldspars, which are the typical representatives of megacryst populations in alkali basalts, are not observed in the Chukchi Peninsula.

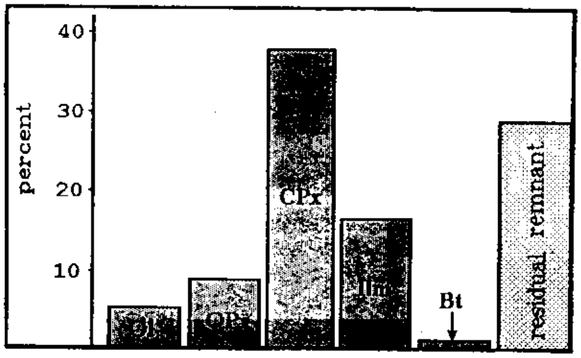

Fig. 2. Supposed quantitative relation among crystallized megacrysts.

(2) They are the most magnesian among megacrysts from different provinces: clinopyroxene - mg#=73-82, opthopyroxene - mg#=86-91, olivine - Fo_{87-91} (sometimes down to Fo_{84}), biotite - mg#=73-77. Transparent clinopyroxenes have higher Ti/Al ratios than augite megacrysts from the Baikal Rift Zone, the Russian Far East, and Mongolia.

(3) The third feature is the presence of two types of clinopyroxene megacrysts in the Chukchi Peninsula. It concerns the secondary transformation of megacryсts, but does not concern the primordial megacryst origin. Nephelinite magma has a higher liquidus temperature than alkali basalt magma and, therefore some clinopyroxene megacrysts recrystallize at high temperatures. Thus forming two types of clinopyroxene megacrysts in the Chukchi Peninsula - transparent ones (primordial) and turbid ones (recrystallized).

Factors pointing to formation of turbid megacrysts from the transparent megacrysts during ascent of high-temperature nephelinite magma are as follows: a) the texture of turbid megacrysts is similar to recrystallized zones in transparent megacrysts, b) the composition of clinopyroxene from the turbid megacrysts and recrystallized zones of transparent megacrists are close; c) there is a relict crystal similar to transparent pyroxene in one of the turbid megacrysts; d) the bulk chemical analyses of turbid megacrysts is close to those of transparent ones; e) the peculiarities of transformation of transparent megacrysts into turbid ones are in agreement with experimental data of Yoder et al., (1969) on melting of low-Ca augites in conditions of low pressure. The recrystallization of transparent megacrysts (CPx1) into turbid ones (CPx2) occurs with the introduction of K and diffusion of Na into the melt CPx1 + $K_2O \rightarrow$ CPx2 + Ol + Lc + Mt + Na_2O (Ol-olivine, Lc - leucite, Mt - titanomagnetite) (Apt and Akinin, 1994).

Megacryst Origin

At the present time there are several views on megacryst formation. The most widespread opinions are that: (1) Megacrysts are the intratelluric phenocrysts of basaltic magma (Kuno, 1964; Irving, 1974; Kepezhinskas, 1979; and others) and (2) Megacrysts are the result of fluid-magmatic crystallization in weak zones of the upper mantle (Kovalenko et al., 1986; Sharkov et al., 1989).

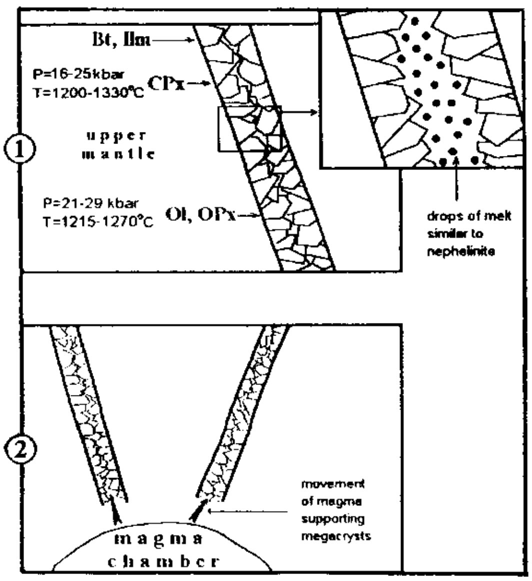

Fig. 3. Supposed model of megacryst formation.

By comparing the Chukchi megacryst composition with the composition of experimental liquidus phases crystallized from melts similar to volcanics of the Chukchi Peninsula, such as the nepheline basanite and olivine nephelinite in Australia (Adam, 1990), one can see the following:

Only olivine and orthopyroxene megacrysts can be intratelluric phenocrysts. They are high-magnesian and orthopyroxene contains Cr (Cr_2O_3=0.2-0.6 wt%). However, clinopyroxene and biotite megacrysts are considerably more Fe-rich, Ti-rich (CPx - TiO_2=0,8-2,0 wt%, Bt - TiO_2=7,6-8,2 wt%) and Cr-poor. Clinopyroxene, biotite, and ilmenite could form, when Mg and Cr abundance decrease in the melt, and Ti and Fe increase; i.e. when the melt is mostly crystallized. Incidentally, data from other provinces also testify to the formation of some megacrysts during the late phase of crystallization. For example, there are a lot of feldspar megacrysts in alkali basalt provinces; but, according to experimental data, at high pressure, feldspars are formed in the last crystallization stage and build matrix (Saltykovsky, 1981).

This investigation suggest that the megacryst formation process have to satisfy two conditions:

(1) The quantity of megacrysts that are formed must be a considerable part of the melt volume (apparently, more than 50% by volume) (Fig.2). Megacrysts are not rare crystals, as they would be according to the hypothesis that megacrysts are intratelluric phenocrysts.

(2) Megacryst crystallization does not cause essential alteration of melt composition in deep-seated magma chamber.

Probably, these conditions can be realized if megacrysts form from a small part of the melt (maybe these are the first drops of melt forming at the time when the melting just begins). Such a process is compatible with the hypothesis that megacrysts form from high-temperature mineralized fluid circulating in upper mantle weak zones (Kovalenko et al., 1986 and Sharkov et al., 1989). Olivine and orthopyroxene megacrysts are formed from the silicate part of high-temperature fluid circulating in upper mantle weak zones and containing the drops of melt similar to nephelinite. Megacrysts of clinopyroxene, ilmenite and biotite are formed during percolating of the fluid into higher horizons of the upper mantle (Fig.3).

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