PETROLOGY OF ALKALI LAVAS AND DEEP-SEATED INCLUSIONS OF ENMELEN VOLCANOES, CHUKCHI PENINSULA

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ABSTRACT

The Enmelen volcanoes in the southern Chukchi Peninsula formed 10 to 4 Ma. Volcanic lavas (olivine melanephelinite 97% and basanite 3%) are the deepest in the Bering Sea province of late Cenozoic alkaline basalts. Melanephelinites contain deep-seated inclusions as xenoliths at three different depth levels, as well as, cumulates and megacrysts. Methods such as mineral thermobarometry and computer modeling were used to reconstruct the petrogenesis as follows: 1) Megacryst crystallization began in highly-mineralized mantle fluid containing the components of the initial melanephelinite melt. The most wide-spread pyroxene megacrysts were formed at T=1200-1325 °C, P=16-29 kb; 2) The processes of melt segregation occurred (fluid degasification); the liquidus of the most primitive olivine melanephelinites has P=30-32 kb, T=1300-1320 °C (for $H_2O \sim 4.5\%$, $CO_2 < 2\%$), $\log fO_2 > -6.3$. The modeled fractional crystallization of clinopyroxene and olivine in a 10 to 25 kb interval, based on the calculated initial magma composition, satisfactorily represents the major component varieties of the volcanic series. 3) The rise of magma and entrainment of xenoliths occurred; the most wide-spread spinel lherzolites have their equilibrium at T=950-1080 °C, P=14-22 kb, $\log fO_2$ (QFM) = -0.47 to +0.33. The plotted geotherm closely resembles the typical oceanic plot.

Basanites make up about 3 percent of the volcanoes and could have formed during a relative rise of an ascending mantle plume.

INTRODUCTION

The occurrences of Late Cenozoic alkalic basalts are known within the Bering Sea area including St. Lawrence, Nunivak and Pribilof Islands, and also from its continental rim in Alaska and Chukotka. These alkalic magma effusive rocks that formed 0-6 Ma are the most significant in the Arctic area. Therefore, in the Bering Sea Province, alkalic basalts of late Cenozoic age are easily recognized (Moll-Stalcup, 1994; Akinin and Apt, 1994). Within this province, as elsewhere in the world, alkalic basalts contain deep-seated inclusions, which makes their study very important for examining mantle magmas and their sources.

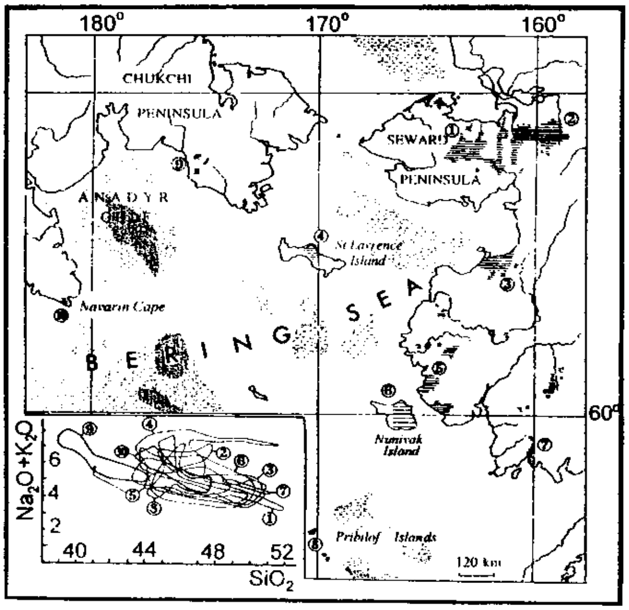

Fig. 1. Location of the Late Cenozoic volcanic fields in Chukchi Peninsula and Alaska (Bering Sea province). Circled figures: 1- Imuruk Lake area; 2- Devil Mountain; 3- St.Michael volcanic field; 4- St.Lawrence Island; 5- Ingakslugwat volcanic field; 6- Nunivak Island; 7- Togiak Basalt; 8- Pribilof Islands; 9 - Enmelen volcanoes; 10- cape Navarin. In the left corner: SiO_2 vs. total alkalies 1 - 8 - after Moll-Stalcup (1994); 9 - Our data. The pattern show Tertiary basins.

The Bering Sea province contains 17 volcanic fields consisting mostly of tholeiitic and alkalic olivine basalt flows. Small basanite and nephelinite fans, flows and maars are less frequent. Volcanic fields do not occur in a line, as is typical of a hot-spot trace, but are instead scattered in the middle of the American plate. Such a mode of occurrence and the particular composition of basalts, serves as a basis for their classification as typical intraplate volcanics. Their formation was presumably related to mantle magmatic and tectonic processes in the Bering Sea, which resulted in depressions being filled with Paleogene and Neogene sediments of thicknesses from 4 to more than 11 km, much like Navarin and St. George Basins. Alkalic basalt fields usually occur on uplifts neighboring such depressions (Fig.1).

The Enmelen volcanoes on the Chukchi Peninsula are of particular interest. Despite insignificant lava eruptions, about 1 km^3, these volcanoes are distinguished by their rock composition (Fig. 1). They consist of olivine melanephelinites (97%) with modal leucite and nepheline and basanites (3%). The origin of such melts is usually attributed to great depths or a high CO_2 partial pressure during the fluid phase, and a low degrees of a partial melting of the garnet-peridotite source, enriched with incompatible elements (Brey and Green, 1977; Frey et al., 1978).

ANALYTICAL AND CALCULATING METHODS

Sample powders were analyzed for major elements by wet chemical methods and also analyzed for five trace elements (Rb, Sr, Ba, Y, Nb) by XRF. Mineral analyses were performed on an three-channel "Camebax" microprobe operating at an accelerating voltage of 15-20 kV, a sample current of 50 nA, and a 3-10 s integration time. The obtained calibration data were tested with a set of reference samples for electron microprobe analysis according to Jarosewich, et al. (1980). For Mg and Fe calibrations, the USNM 2566 (olivine) and USNM 85276 (fayalite) standards were used (Jarosewich et al., 1980). The CaO content of olivine was examined with JXA-5A microprobe operating at an accelerating voltage 20 kV, a sample current of 200 nA, and an integration time of 80 s; the reveal limit is 0.003 weight-percent with a relative error of 10.3 percent.

The obtained results are presented by Akinin and Apt (1994). These data were processed in a DBase IV system involving a set of original computer programs prepared by the author, including thermobarometry calculations and magmatic crystallization modeling. Temperature and pressure data given below represent the mineral thermobarometry as follows: 1) for rock xenoliths - two-pyroxene thermometer (Bertrand and Mercier, 1986) and pyroxene barometer (Mercier, 1980); 2) for pyroxene megacrysts - thermobarometers (Mercier 1976, 1980) previously tested according to Adam (1990); and 3) for Fe-Ti oxide megacrysts - oxygen barometer and thermometer (Andersen and Lindsley, 1988). The oxygen fugacities in the ol+opx+sp mantle assemblage in peridotite was estimated by combining equations (Ryabchikov et al., 1986; Ender and Woerman, 1989; Mattioli and Wood, 1988). The spinel peridotite pressure was calculated according to exchange of Ca between olivine and clinopyroxene (Köhler and Brey, 1990) with precision determinations of CaO in olivines. Crystallization of a hypothetical initial melt was modeled in terms of an algorithm based on the highest phase liquidus temperature calculations. Simultaneously, the liquidus temperatures were calculated using the model of Roeder and Emslie (1970) for olivine, Ariskin et al. (1986) for high-calcium pyroxene, and Nielsen and Drake (1979) for orthopyroxene. The fact that Na was partially involved in the modeled clinopyroxene crystallization, was also considered. High-pressure extrapolation was performed with the involvement of dP/dT (mineral - melt) equilibrium.

GEOLOGICAL SETTING AND PETROGRAPHY

On the Chukchi Peninsula, late Cenozoic basalts occur in the Enmelen and Nunyamuveem River basins (Rabkin, 1954). Thirteen samples of these rocks have K/Ar ages ranging from 10 to 4 Ma, averaging 6.2 Ma (Akinin and Apt, 1994). Underlying rocks are calc-alkalic, mostly Cretaceous andesites, rhyolites, and dacites of the Okhotsk-Chukotsk Volcanic Belt and more seldom, basement rocks including Devonian (?) limestones and biotite-hornblende schists. Intrusive rocks consist of Cretaceous granites.

A flow of massive olivine melanephelinites, with a length of about 11 km, a width of 100 to 1500 m, and a thickness of 5-10 m, occurs in the upper reaches of the Melitveem River. A small separate dike of basanites also occurs in this area. Volcanic lavas contain only bedrock fragments and do not have any mantle inclusions here.

In the Enmelen River basin, there is a set of small plugs and the major Enmelyuveem volcano, that consists structurally of slaggy cones, extrusive domes, and lava flows composed of leucite-bearing olivine melanephelinites. In addition to massive lavas, there are many vesicular and oxidized lava varieties and slags abundant in different deep inclusions. Three lava flows come from the volcano toward the river valleys, whereas the fourth flow, to the east, consists of basanites that do not contain deep inclusions and seem to have originated from another eruption site.

Volcanic rocks are predominantly leucite-bearing olivine melanephelinites (beside clinopyroxene and Fe-Ti oxide, the groundmass contains 10-15 % leucite and less than 10% nepheline) and olivine melanephelinites (beside clinopyroxene and Fe-Ti oxide, the groundmass contains 15-18% nepheline). Twelve to twenty percent of these rocks contain small (1-2 mm) euhedral olivine phenocrysts (Fo_{89}-75) occur in a groundmass consisting of 40-50 percent titan-diopside (TiO_2=1.2-5.2%; $Wo_{49.1}En_{39.8}$ $Fs_{11.1}$), 10-17 percent Ti-magnetite and ilmenite, 5-18 percent nepheline, 2-15 percent leucite, 0-3.5 percent plagioclase (K-bearing An_{24-47}), and less than 5 percent Ca-rich anorthoclase and glass. Phlogopite and apatite are accessory minerals. Abundant deep-seated inclusions from groups I and II (Frey and Prinz, 1978) are present only in leucite-bearing olivine melanephelinites. About 80-90 percent of the inclusions are spinel lherzolites. Other inclusions are usually clinopyroxene megacrysts (7%), ilmenite (3%), gabbro and essexite (1.6%), and orthopyroxene megacrysts (1.1%). The amount of such inclusions as websterite, dunite, harzburgite, clinopyroxenite, rare coarse-grained orthopyroxenite, pyroxene pegmatite, glimmerite, and olivine and biotite megacrysts is less than 1 percent of all inclusions.

Basanites differ from melanephelinites for not containing deep-seated inclusions and megacrysts. They contain 15-24 percent plagioclase ($An_{24\text{-}50}$) and some samples contain phenocrysts of plagioclase, in addition to phenocrysts of olivine and clinopyroxene.

The Enmelen lavas are SiO_2-undersaturated (SiO_2=38.7-44.2%), high-magnesian (Mg#>0.6), high- alkalic (Na_2O+K_2O=4.7-8.1%), and high-titaniferous (TiO_2=2.5-5%) (Table 1). The rocks are poorly differentiated. The nephelinites of Hawaii (Claque and Frey, 1982), East Africa rift-zone (Gerasimovsky and Polyakov, 1974) and Tasmania grabens (Adam, 1990), are similar to the Chukchi lavas, but the latter contain more K_2O and TiO_2. Some melanephelinite occurrences in the Russian Far East have smaller TiO_2 contents, whereas the content of other major elements are similar. Examples are the Sviyagin and Merkushevsky volcanoes located on rigid crustal blocks or a thick crust (Scheka, 1983), and nephelinites of the Kananyga and Viliga Rivers area to the north of the Okhotsk Sea (Ichetovkin et al., 1970).

THE COMPOSITION OF DEEP-SEATED INCLUSIONS

According to their mineralogy, xenoliths are distinguished as belonging to two groups of ultramafites (magnesian and magnesian-ferruginous) and gabbroids. We will describe only three types of upper mantle peridotite xenoliths (a complete description is given in Akinin and Apt, 1994 and Apt, this volume). These types are as follows: 1) mantle xenoliths from the spinel facies depth level; 2) deformed mantle xenoliths from greater depths; 3) mantle cumulates. This classification is based on different rock textures, mineral compositions and thermobarometry data.

Low to depleted Spinel Lherzolites and Harzburgites

Xenoliths of with allotriomorphic-granular textures (after Wilshire et al., 1991), are the most common. These are typical group I xenoliths and consist of olivines ($Fo_{89\text{-}91}$), Cr-bearing orthopyroxenes and clinopyroxenes (mg#=0.89-0.93), and irregular spinel (Al_2O_3=53.6-61%, Cr_2O_3=7.6-24.48%; Table 2). According to available criteria (Frey and Green, 1974), and spinel and clinopyroxene compositions, the Enmelen lherzolites are non-depleted varieties. The most primitive xenolith is the lherzolite sample (No 126-6) that has similar amounts of clinopyroxene and olivine (55.2% ol, 14.9% cpx) to the modeled pyrolite. The high Al_2O_3/CaO ratio (1.62) of sample No 126-6 is comparable to data from the suboceanic upper mantle (Al_2O_3/CaO=1.78; Maaloe and Aoki, 1977). The composition of a hypothetical non-depleted upper mantle beneath the Enmelen volcanoes can be calculated, assuming that different compositions of spinel peridotite xenoliths reflect different degrees of a partial melting of an initially homogeneous mantle, with the addition of possible melt injections from other sites. The lherzolite composition, normalized with reference to 38 percent MgO content with help of the linear regression coefficients of MgO and other major elements (Table 5), is a close approximation to the primitive mantle composition. Amphibole and phlogopite do not occur in peridotite xenoliths and may indicate an insignificant modal metasomatism in the mantle spinel zone.

Deepest Mantle Xenoliths

These have the highest Ca-conteins in olivines and low-Ca clinopyroxenes with initial spinel absent. They are found only in the small Enmelen volcano with the most primitive lavas. It is noteworthy that they are scarce, but co-occur with wide-spread, usual spinel lherzolites.

A strongly deformed lherzolite xenolith has a porphyroclastic mosaic texture and consists of coarse (2-5 mm) olivines ($Fo_{90\text{-}88}$), melted orthopyroxenes ($En_{85\text{-}86}Fs_{10\text{-}11}Wo_{3.7\text{-}4}$), and clinopyroxenes ($En_{54\text{-}61}Fs_{8\text{-}9}Wo_{30\text{-}38}$). These minerals are subject to recrystallization, forming small (<0.5 mm) polygonal olivine ($Fo_{87\text{-}85}$) and leucite aggregates along dislocation zones bounding them. Some sites reveal a secondary, fine assemblage of olivine ($Fo_{87\text{-}85}$)+ plagioclase ($An_{60\text{-}70}$)+picotite (Cr_2O_3=4.3-5.1; mg#=0.77-0.79) that is probably a result of decomposition of clinopyroxene+spinel or garnet under decompression (P<9 kb). The initial assemblage may also represent the mantle area where both spinel and garnet are unstable and Al_2O_3 is totally dissolved in pyroxenes. The existence of such an area (T>1250°C, P=10-20 kb) has been established experimentally (Ringwood, 1981).

Olivine-Pyroxene Cumulate

Olivine websterite has an equigranular mosaic texture and consists of 35 percent orthopyroxene ($En_{83}Fs_{13}Wo_4$), 20 percent clinopyroxene ($En_{57}Fs_{10}Wo_{33}$), 40 percent olivine ($Fo_{86.5}$, CaO=0.16-0.17%) and 5 percent groundmass. Some minerals are euhedral and contain melt inclusions, which testifies to their magmatic genesis.

The groundmass consists of glass and Fe-Ti oxide and spinifex crystals of Ti-augite and differs from the groundmass of melanephelinites by its texture.

Table 1. Major (wt.%) and trace (ppm) element analyses of volcanic rocks from Enmelen volcanoes

Rock Type	olivine melanephelinites			leucite-bearing olivine melanephelinites					basanites	
Sample No	224	219-7m	217-1	126	127	121-4	130-1	135-1	310-10	220
SiO_2	42,33	41,69	41,17	42,03	41,45	39,34	41,63	40,88	44,21	44,04
TiO_2	3,54	3,19	3,66	3,10	3,86	4,79	4,09	4,01	3,94	3,55
Al_2O_3	9,80	10,75	9,40	11,30	12,40	11,60	10,65	11,60	12,15	10,90
Fe_2O_3	4,37	6,18	5,17	3,69	4,75	4,71	3,52	4,81	5,02	3,94
FeO	9,52	7,72	8,91	8,05	7,47	9,05	9,13	8,91	7,19	9,12
MnO	0,19	0,19	0,19	0,15	0,16	0,16	0,14	0,16	0,15	0,17
MgO	11,48	13,13	12,69	14,31	13,70	12,34	12,34	11,84	11,59	11,89
CaO	11,43	9,52	9,46	8,90	9,67	8,20	8,94	8,55	9,60	9,74
Na_2O	3,90	4,00	4,20	3,21	3,20	3,76	3,59	3,75	3,00	3,60
K_2O	2,00	2,10	2,20	2,58	3,00	3,64	2,93	3,04	1,70	1,75
Cr_2O_3	0,050	0,050	0,050	0,070	0,030	0,020	0,020	0,020	0,030	0,060
NiO	0,025	-	0,036	0,032	0,053	0,023	0,023	0,023	0,037	0,025
P_2O_5	0,97	0,85	1,02	0,63	0,68	0,75	0,62	0,42	0,59	0,84
$H2O^+$	0,83	0,17	0,71	0,78	0,64	0,55	0,48	1,00	1,02	0,68
$H2O^-$	0,09	0,07	0,11	0,14	0,06	0,13	0,01	0,28	0,26	0,10
CO_2	0,22	0,05	0,22	0,05	0,05	0,05	0,05	0,05	0,05	0,15
Total	100,75	99,66	99,20	99,02	101,17	99,11	98,16	99,34	100,54	100,56
Rb	30	23	33	44	34	50	44	54	35	28
Sr	802	994	988	689	759	865	755	794	733	872
Ba	711	-	687	684	838	209	661	-	643	713
Y	-	24	24	13	14	19	15	17	19	27
Zr	-	289	309	194	214	278	261	260	225	263
Nb	-	79	64	63	65	77	61	64	49	59
$Fe_2O_3^*$	2,28	2,25	2,30	1,93	1,99	2,25	2,08	2,24	1,98	2,15
FeO^*	11,40	11,25	11,49	9,64	9,96	11,26	10,42	11,22	9,92	10,74
mg#	0,64	0,68	0,66	0,73	0,71	0,66	0,68	0,65	0,68	0,66
Fo	82,00	81,10	84,60	87,20	88,20	72,10	77,10	85,90	77,80	85,00

Note: Fe_2O_3* and FO* - calculated for $Fe_2O_3/FeO = 0.2$; mg# = $Mg/(Mg+Fe^{+2})$; Fo - forsterite minal in olivine phenocrysts.

THERMOBAROMETRY OF DEEP-SEATED INCLUSIONS

The mineral thermobarometry results can be summarized as follows: spinel lherzolite xenoliths are in an equilibrium state at T=930-1075°C (average 1015°C and a standard deviation of 47), P=16-22 kb (Table 3), and $\log fO_2(QFM)^{15\ kb}$ from -0.47 to +0.44. The P-T equilibrium trajectory is similar to the plot of the oceanic geotherm. Deeper group xenoliths have equilibrium conditions at T=1386°C, P=32-33 kb (deformed spinel-free lherzolite) and T=1306°C, P=25.8 kb (olivine-pyroxene cumulate). Pegmatoid pyroxenite (exsolved cpx+opx+sp) in the same group, have equilibrium conditions as follows: 1) T=1384°C and P=30.6 kb calculated for the whole pyroxenite composition are indicative of the pre-exsolution equilibrium of protopyroxene;

2) T=1074°C and P=15.4 kb values calculated on the basis of both ortho- and clinopyroxene lamella compositions reflect the "freezing" of exchange processes after decomposition of the solid solution.

Table 2. Whole-rock wet chemical analyses of xenolithes and microprobe analyses of minerals

Sample	126-6					122B				
Rock	spinel lherzolite					spinel lherzolite				
Symbol	whole	ol	cpx	opx	sp	whole	ol	cpx	opx	sp
SiO_2	43,60	40,60	54,52	55,69	0,00	46,05	40,50	53,08	55,13	0,00
TiO_2	0,13	0,00	0,41	0,10	0,06	0,16	0,00	0,76	0,16	0,18
Al_2O_3	4,83	0,00	6,77	4,52	60,49	4,95	0,00	7,29	4,58	59,88
Cr_2O_3	0,34	0,00	0,69	0,32	8,63	0,40	0,00	0,62	0,27	8,32
Fe_2O_3	1,49	-	-	-	-	1,80	-	-	-	-
FeO	6,90	10,02	2,82	6,18	10,48	5,95	10,10	3,05	6,69	11,52
MnO	0,20	0,07	0,08	0,15	0,14	0,19	0,04	0,10	0,17	0,10
MgO	38,60	50,00	15,21	33,67	21,37	34,63	49,40	15,23	33,15	21,00
CaO	2,97	0,05	19,02	0,61	0,00	5,13	0,06	19,42	0,62	0,00
Na_2O	0,50	0,00	2,05	0,13	0,00	0,40	0,00	1,60	0,03	0,00
K_2O	0,20	0,00	0,01	0,00	0,00	0,10	0,00	0,01	0,00	0,00
NiO	0,24	0,36	0,04	0,10	0,37	0,24	0,35	0,02	0,08	0,28
Total	100,0	101,10	101,62	101,47	101,54	100,0	100,45	101,18	100,88	101,3
mg#	0,909	0,899	0,906	0,907	0,784	0,912	0,897	0,899	0,898	0,765

Sample	126-2						127-3		
Rock	deformed spinelless peridotite						olivine-pyroxene cumulate		
Symbol	whole	ol^1	ol^2	opx^{core}	cpx	opx^{rim}	ol	cpx	opx
SiO_2	47,70	40,67	40,41	54,48	52,88	52,71	40,76	53,03	54,98
TiO_2	0,49	0,01	0,05	0,25	0,36	0,28	0,00	0,64	0,29
Al_2O_3	4,99	0,11	0,15	5,48	6,33	6,82	0,00	6,39	5,29
Cr_2O_3	0,00	0,06	0,08	0,45	0,73	0,15	0,00	0,32	0,31
FeO	9,26	9,53	11,04	5,80	4,46	7,34	13,05	5,92	8,31
MnO	0,15	0,10	0,09	0,07	0,11	0,16	0,10	0,10	0,17
MgO	32,40	49,43	47,05	31,48	20,19	29,26	46,93	18,37	29,91
CaO	4,04	0,16	0,19	1,80	12,81	2,16	0,14	14,90	1,87
Na_2O	0,64	0,08	0,00	0,36	1,27	0,54	0,00	1,26	0,10
K_2O	0,33	0,01	0,00	0,00	0,02	0,01	0,00	0,00	0,00
NiO	0,00	0,24	0,27	0,01	0,00	0,05	0,36	0,05	0,04
Total	100,00	100,40	99,34	100,18	99,16	99,48	101,34	100,98	101,27
mg#	0,862	0,902	0,884	0,906	0,890	0,877	0,865	0,847	0,865

Note: mg# = $Mg/(Mg+Fe^{+2})$; whole-rock analyses normalized to 100%.

For megacrysts, the highest temperature obtained is for transparent (non-melted) clinopyroxene, with average values of T=1257°C (1204-1326), P=21.5 kb (15.9-25.4), n=9. Orthopyroxene megacrysts have a lower average temperature and smaller variations; T=1246°C (1214-1269), P=23.6 kb (21-29.2), n=9. Turbid melted clinopyroxene megacrysts have equilibrium values at T=904-1090°C and P=7.3-22.4 kb. Whole composition, preexsolution parameters for ilmenite megacrysts are T=1028-1060°C and fO_2=-8.4 to -9. Exsolution equilibrium parameters for ilmenite-magnetite megacrysts are T=890-1000°C and fO_2=-9.8 to -12.9.

Table 3. Geobarometry of peridotite xenoliths of Enmelen volcanoes

Sample No	Grain No	CaO wt%	T°C	P,kb	Rock Type
131-3	3-1	0,033	981	27,1	sp lherzolite
131-3	3-2	0,040	981	21,4	sp lherzolite
131-3	3-3	0,040	981	21,4	sp lherzolite
131-3	3-4	0,042	981	19,9	sp lherzolite
130-10	3-14	0,052	998	16,2	sp lherzolite
126-6	3-9	0,052	1053	20,5	sp lherzolite
126-6	3-10	0,053	1053	19,9	sp lherzolite
126-6	3-12	0,080	1053	9,8	sp lherzolite
122B	3-5	0,059	1055	17,5	sp lherzolite
122B	3-6	0,081	1055	10,4	sp lherzolite
131	4-1	0,071	1105	21,9	sp harzburgite
131	4-2	0,071	1105	21,9	sp harzburgite
131	4-3	0,074	1105	20,9	sp harzburgite
126-2	4-4	0,165	1386	32,8	sp-less peridotite
126-2	4-5	0,168	1386	32,2	sp-less peridotite
126-2	4-6	0,162	1386	33,3	sl-less peridotite

Note: CaO - concentration in olivines; T - temperature after thermometer (Bertrand & Mercier, 1986);
P - pressure after barometer (Kohler & Brey, 1990)

According to the equation of Roeder and Emslie (1970), the pseudoliquidus temperature of olivine megacrysts is 1315-1345°C, if it is in equilibrium with the melanephelinite melt (for samples #125-5, Kd=0.34 and #126, Kd=0.5). The calculated temperature values are presumed to be lower or equal to mantle conditions, since the lithostatic pressure is compensated by a high fluid content.

It is important that thermobarometry data obtained indicate megacrysts occur at greater depths than xenoliths of spinel peridotites.

PRIMARY MAGMA EVOLUTION

According to mantle equilibrium conditions, primary magma must have the ratios Mg/(Mg+Fe)=0.63-0.73 or FeO/MgO<1 (Tatsumi et al., 1983), concentration Ni=235-400 ppm (Sato, 1977), and equilibrium with mantle olivine Fo_{90-86}. Among the Enmelen lavas these conditions are best represented in samples #127 and #126 (Table 4).

The highest magnesian phenocrysts of olivine are present in sample #127 - $Fo_{88.7}$ and #126 - Fo_{88}, and are close to equilibrium; Kd=0.3 (Roeder and Emslie, 1970). The Fe_2O_3/FeO ratios in these melts range from 0.15 to 0.2 and are calculated according to Sack et al. (1980) and Maurel and Maurel (1982). Oxygen fugacities are determined by microlites of Fe-Ti oxides using the method of Andersen and Lindsley (1988).

The crystallization temperature values for olivine phenocrysts are calculated in terms of the equation of Roeder and Emslie (1970) and equal 1353 to 1340°C. The pressure at crystallization is probably not higher than 5 kb (Polyakov et al., 1985). Using the equation by Perchuk (1987), which author tested by experiments by Sack et al. (1987) and Adam (1990), the pressure for primitive melts is estimated at 32-30 kb.

The compositional and experimental data (Adam, 1990) available for similar SiO_2-undersaturated basanites and olivine nephelinites are consistent with their derivation from a polybaric partial melting of a garnet lherzolite source enriched with incompatible trace elements. According to lava mineralogy, high pressure melting provides a better explanation of rock genesis than the presence of high volatile concentrations (CO_2+H2O>14%). Many volcanic rocks have ferruginated phenocrysts of olivine (Fo_{85-72}). This may indicate a possible genesis for part of the melanephelinites and basanites under a polybaric fractionation of primary melts. In order to verify this suggestion, a computer model of fractional crystallization was constructed.

Table 4. Composition (wt.%) of primitive magma of Enmelen volcanoes

Sample	127	126	126cpx
SiO_2	41,43	42,97	44,80
TiO_2	3,86	3,17	2,80
AL_2O_3	12,39	11,55	10,60
Fe_2O_3	1,55	1,98	1,80
FeO	10,37	9,88	9,00
MnO	0,16	0,15	0,10
MgO	13,69	14,63	15,10
CaO	9,67	9,10	10,00
Na_2O	3,20	3,28	2,90
K_2O	3,00	2,64	2,30
P_2O_5	0,68	0,64	0,60
mg#	0,702	0,725	0,749
Fo	88,2	87,2	91,4
Kd_{ol-L}	0,31	0,38	0,31
T,°C	1339	1353	1450*
T_{Fo},°C	1335	1326	1363
fO_2	-6,69	-6,20	-5,90
P,kb	32	30	27

Note: 126, 126 - samples of most primitive leucite-bearing olivine melanephelinite, 126cpx - hypotetic composition of primitive melt of Enmelen volcanoes, calculated by modeling of reverse path of fractional crystallization of olivine and clinopyroxene in sample 126 at 15 kb; Fo - average composition of olivine phenocryst; Kd_{ol-L} - distribution coefficient of Fe^{+2} and Mg between olivine and rock; T - pseudoliquidus temperature after geothermometer (Roeder & Emslie,1970); T_{Fo} - the same one for Fo; fO_2 - oxygen fugacity in melt, after R.O.Sack et al. equation (Sack et al., 1980); P - pressure after barometer (Perchuk, 1987). * - for clinopyroxene.

According to the modeling results obtained for the initial sample #126, clinopyroxene is first formed at a pressure of 10 to 32 kb and degree of crystallization of 5 to 30 percent followed by olivine at a pressure of 22 kb. The results of modeling satisfactorily describe the major element variations in this volcanic series. As to the component of Al_2O_3, it is possible that either the crystallization of a small amount of garnet was not considered, or the initial melt might have had another composition, such as sample #126cpx (Table 4), which was obtained by adding clinopyroxene to sample #126.

According to calculations, the formation of basanites occurred at 22-25 kb, and was probably related to a progressive partial melting of a rising mantle plume. This supposition agrees well with a left-hand shift of peritectic reaction under decreased pressure; ol+cpx+L2=gr+opx+L1 (Brey and Green, 1977), where L1 is olivine nephelinite and L2 is alkalic basalt.

Table 5. Composition of undepleted mantle beneath Enmelen volcanoes

No	1	2	3	4
SiO_2	44,51	44,90	45,47	49,80
TiO_2	0,12	0,12	0,20	0,33
Al_2O_3	3,99	4,02	3,99	10,80
FeO	8,02	8,09	7,88	9,04
MgO	38,00	38,33	38,58	17,95
CaO	3,43	3,46	3,52	10,62
Na_2O	0,32	0,32	0,33	1,07
K_2O	0,13	0,13	0,03	0,22
Cr_2O_3	0,36	0,36	-	-
NiO	0,25	0,25	-	-
mg#	0,89	0,89	0,90	0,78

Note: 1 - spinel lherzolite xenolith of Enmelen Volcanoes, normalized by method of lenear regression to MgO=38%; 2 - also, to 100%; 3 - composition of primitive mantle (Jagoutz et al, 1979); 4 - hypothetic (calculated) melt separated under a parcial melting of peridotite xenoliths of Enmelen volcanoes.

CONCLUSIONS

The development of alkalic mantle magmatism is schematically shown in Fig. 2, which shows the summary of calculations made and different experimental results. The consideration of megacryst genesis should precede the interpretation of historic petrology. Factors such as a high compositional homogeneity of megacrysts, their large size, and chemical inequilibrium with host melanephelinites (a non-equilibrious coefficient, Kd_{Fe-Mg}, between crystal and rock), are arguments against their usual crystallization as intratelluric phenocrysts. A more reasonable explanation is the hypothesis of a fluid crystallization of megacrysts, for example, in a mixture of a high-density (~70%) emulsion of CO_2, with suspended sulfide-silicate melt drops (Kovalenko et al., 1986). In an opinion differing from Kovalenko and others, we believe the filtration of this fluid in the mantle spinel zone represents the early generation of the initial melt at greater depths. This concept is supported by the calculated melt generation pressure (30-32 kb or 100-110 km depth), which is higher than the equilibrium pressure for spinel peridotite xenoliths (16-22 kb). The latter do not seem to be a source of melanephelinites in Chukotka and the differences in their composition are probably due to an initial melt of another composition. The hypothetical initial melt is defined in terms of a combination of an equilibrious distribution coefficient, $Kd_{Fe\text{-}Mg}$ of 0.35 at P=20 kb (Takahashi and Kushiro, 1983), and regression coefficients (MgO - other major elements) for spinel peridotite xenoliths from the Enmelen volcanoes.

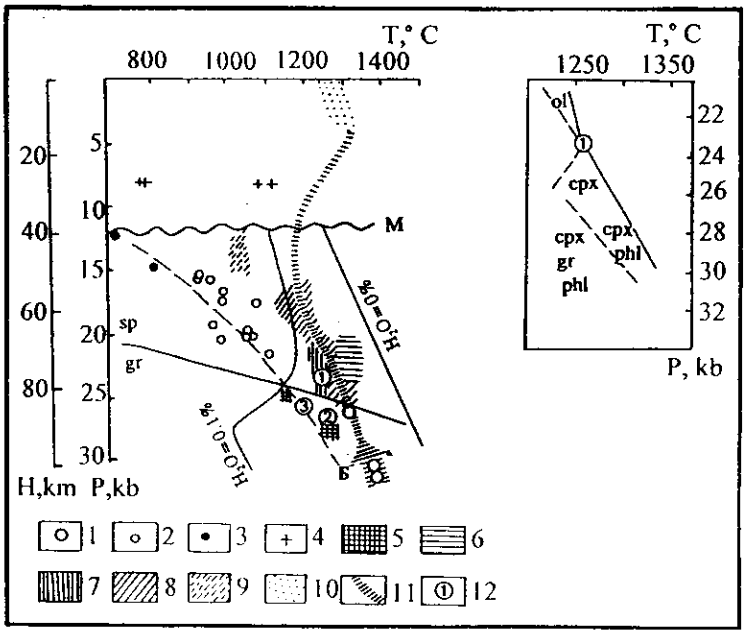

Fig. 2. Scheme of physico-chemical conditions of generation and differentiation of alkaline magma of Enmelen Volkanoes.
Curves: M - crust-mantle boundary; sp-gr - boundary of facies of spinel ang garnet lherzolites for spinel with Cr/(Cr+Al)=0.25; H_2O - pyrolith solidus at water concentrations of 0% and 0.1% (Ringwood, 1981); Б - Baikal Rift Zone geotherm. P-T equilibrium conditions of rock, deep-seated inclusions, megacrysts and phenocrysts from Enmelen leucite-bearing olivine melanephelinites (mineralogical thermobarometry): 1 - high temperature inclusions of magnesian suite (spinel-less lherzolite, pegmatoid pyroxenite, olivine-pyroxene cumulate); 2 - spinel peridotites and clinopyroxenites of magnesian suite; 3 - olivine websterite of magnesian-ferruginous suite ; 4 - gabbroides; 5 - phlogopite megacrysts (experimental data of J.Adam (1990)); 6 - olivine megacrysts; 7 - ortho-pyroxene megacrysts; 8 - clinopyroxene megacrysts; 9 - ilmenite megacrysts; 10 - olivine phenocrysts; 11 - area of generation and evolution of parent magma of Enmelen Volkanoes; 12 - nonvariant equilibrium in nepheline basanite (Adam,1990); figure in circle: 1 - at concentrations of $H_2O=2\%$, $CO_2=2\%$ (see in-set: subliquidus phase relations in nepheline basanite UT- 70489), 2-at $H_2O=4.5\%$,3-at $H_2O=4.5\%$, $CO_2=2\%$

To make these calculations, the highest-magnesian olivine in peridotite - Fo_{91} was used. The obtained melt corresponds to the source melting degree within only about 10 percent and is much different in its composition from primitive olivine melanephelinites of the Chukchi Peninsula (Table 5). According to available thermobarometry data, xenoliths of strongly deformed peridotite and pegmatoid pyroxenite originate at the same depth, where the segregation of initial melt takes place. This is where the separation of melt from fluid is supposed to occur. Thus, the petrologic processes under consideration can be reconstructed as follows: 1) megacryst crystallization in a highly-mineralized mantle fluid containing the components of the primary melanephelinite melt; 2) melt separation from fluid at greater depths in comparison to megacryst crystallization; 3) the rise of melt and the polybaric fractional crystallization and entrainement of xenoliths and megacrysts.

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REFERENCES

Adam, J., 1990. The geochemistry and experimental petrology of sodic alkaline basalts from Oatlands, Tasmania. - J. Petrol. 31 (6): 1201-1223.

Akinin, V.V., and Apt, J.E., 1994. Enmelen Volcanoes, Chukchi Peninsula: Petrology of Alkaline Lavas and Deep-Seated Inclusions. Magadan: NEISRI FEB RAS. 97 p. (in Russian).

Andersen, D.J., Lindsley, D.H., 1988. Internally consistent solution models for Fe-Mg-Mn-Ti oxides: Fe-Ti oxides. - Am. Miner. 73 (7/8): 714-726.

Ariskin, A.A., Barmina, G.S., Frenkel, M.Ya., 1986. Computer simulation of crystallization of basaltic melts the given oxygen fugacity conditions. - Geokhimiya 11: 1614-1627. (in Russian)

Bertrand, P., Mercier, J.-C.C., 1986. The mutual solibility of coexisting ortho- and clipyroxene: toward an absolute geothermometer for the natural system? - Earth and Planet Sci. Lett. 76 (1/2): 109-122.

Brey, G.P., Green, D.H., 1977. Systematic study of liquidus phase relations in olivine melilitite+H_2O+CO_2 at high pressures and petrogenesis of an olivine melilitite magma. - Contr. Min. and Petrol. 61: 141-162.

Clague, D.A., Frey,F.A., 1982. Petrology and trace element geochemistry of the Honolulu Volcanics, Oahu; Implications for the oceanic mantle below Hawaii. - J. Petrol. 23:447- 504.

Ender, A., Woerman, E., 1989. Oxigen fugacity barometer on basic of model system Fe-Mg-Al-Cr-Si-O. - 28th Intern. Geol. Congr. (Abstracts). 1: 451-452.

Frey, F.A., Prinz, M., 1978. Ultramafic inclusions from San Carlos, Arizona: petrologic and geochemical data bearing on their petrogenesis. - Earth and Planet. Sci. Lett. 38: 129-176.

Gerasimovski, I., Polyakov, A.I. 1974. Geochimia of volcanic rocks from East Africa rift zone. - In: East-African rift sistem. M.:Nauka: 5-184. (in Russian).

Ichetovkin, N.V., Silinski, A.D., Fadeev,A.P., 1970. Cenozoic alkali basalts of Kananyga and Viliga Rivers (Ochotsk-Chukotsk volcanic belt). - Geol. and Geophys. 8: 122-127 (in Russian).

Jagoutz, E., Palme, H.,Baddenhausen, H., et al., 1979. The abundances of major, minor and trace elements in the Earth's mantle as derived from primitive ultramafic nodules. - Proc. 10^{th} Lunar and Planet. Sci. Confer. Houston 10: 2031-2050.

Jarosewich, E., Nelen, J.A., Norberg, J.A., 1980. Reference samples for electron microprobe analysis. - Geostandards newsletter 4 (1): 43-47.

Kovalenko, V.I., Solovova, I.P., Naumov, V.B., Ryabchikov, I.D., Ionov, D.A., Tsepin, A.I., 1986. Mantle mineral formation with the carbon dioxide-sulfide-silicate fluid. - Geokhimiya 3: 289-303. (in Russian).

Kohler, T.P., Brey, G.P., 1990. Calcium exchange between olivine and clinopyroxene calibrated as a geothermobarometer for natural peridotites from 2 to 60 kb with applications. - Geochim. et Cosmochim. Acta 54 (9): 2375-2388.

Maaloe, S.,Aoki, K.I., 1977. The major element composition of the upper mantle estimated from the composition of lherzolites. - Contr. Miner. Petrol. 63: 161-73.

Mattioli, G.S., Wood, B.J., 1988. Magnetite activities across the $MgAl_2O_4$ - Fe_3O_4 spinel join with application to thermobarometric estimates of upper mantle oxygen fugacity. - Contr. Miner. and Petrol. 98 (2): 148-162.

Maurel, C., Maurel, P., 1982. Etude experimentale de l'equilibrie Fe^{2+} - Fe^{3+} dans les spineles chromifieres et les liquides silicates basiques coexistancese, a 1 atm. - C.R. Acad. Sci. Paris 295: 209-217.

Mercier, J-C.C., 1976. Single-pyroxene geothermometry and geobarometry. - Am. Miner. 61: 603-615.

Mercier, J-C.C., 1980. Single-pyroxene thermobarometry. - Tectonophysics 70 (1/2): 1-37.

Moll-Stalcup, E.J., 1994. Latest Cretaceous and Cenozoic magmatism in mainland Alaska. - In: Berg, H.C., (Ed.) The Geology of Alaska. - Geol. Soc. of America: The Geology of North America, G-1: 589-619.

Nielsen, R.L., Drake, M.J., 1979. Pyroxene-melt equilibria. - Geochim. et Cosmochim. Acta 43 (8): 1259-1272.

Perchuk, L.L., 1987. Basification as a magmatic replacement. - In: Skethches of physico-chemical petrology. M.: Nauka: 39-64. (in Russian).

Polyakov, A.I., Turkov, V.A., Muravyova, N.S., Nesmeyava, N.S., Ignatenko, K.I., 1985. Physico-chemical conditions of smelting and evolution processes of basaltic magmas in Baikal rift zone. - Geokhimiya 1: 41-58. (in Russian).

Rabkin, M.I., 1954. Alkali and ultrabasic effusives of southern part of the Chukchi Peninsula. - In: Articles simposium of Arctic geology. L.: Vodtransizdat: 210-224. (in Russian).

Ringwood, A.E., 1981. Composition and petrology of the Earths mantle. - M.: Nedra., 584 p. (in Russia).

Roeder, P.L., Emslie, R.F., 1970. Olivin-liquid equilibrium. - Contr. Miner. and Petrol. 29 (4): 275-289.

Ryabchikov, I.D. Uchav, A.V., Ishii, T., 1985. Redox equilibria in the ultramafic rocks from upper mantle of the Yakutian kimberlite province. - Geokhimiya 8: 1110-1123. (in Russia).

Sack, R.O., Carmichael, J.S.E., Rivers, M., Ghiorso, M.S., 1980. Ferric-ferrous equilibria in natural silicate liquids at 1 bar. - Contr. Miner. and Petrol. 75 (4): 369-376.

Sack, R., Walker, D., Carmichael, I., 1987. Experimental petrology of alkalic lavas: constraints on cotectics of multiple saturation in natural basic liquids. - Contr. Miner. and Petrol. 96 (1): 1-23.

Sato, M., 1977. Nickel content of basaltic magmas: identification of primary magmas and measure of the degree of olivine fractionation., 10, 2:113-120.

Scheka, S.A., 1983. Basite-ultrabasite intrusions and inclusions in effusive rocks of Far-East. - M.:Nauka. 167 p. (in Russian).

Takahashi, E., Kushiro, I., 1983. Melting of a dry peridotite at nigh pressures and basalt magma genesis. - Am. Mineral. 68 (9/10): 859-879.

Tatsumi, Y., Sakuyama, M., Fakuyama, H., Kushiro, I., 1983. Generation of arc basalt magmas and thermal structure of the mantle wedge in subduction zones. - J. Geophys. Res. B. 88 (7): 5815-5825.

Wilshire, H.G., McGuire, A., Noller, J.S., Turrin, B.D., 1991. Petrology of lower crustal and upper mantle xenoliths from the Cima volcanic field, California. - J. Petrol. 32 (1): 169-200.