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GEOCHEMISTRY

Basanites of Mt. Khukhch: First Mineralogical–Geochemical Data on the Neogene K–Na Alkaline Magmatism in Western Kamchatka

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Geotectonic reconstruction of the Cenozoic structure of western Kamchatka suggests the wide development of rifting in Paleogene and Neogene in this region[1]. However, magmatic complexes typical of this geodynamic setting are as yet unknown. A Neogene subvolcanic basanite body (Mt. Khukhch) was found in the course of a geological–geochemical study of potassium alkaline magmatism in the Bystraya River basin, western Kamchatka, in 2001. The mineralogic–geochemical study of the rocks and previous data showed that the basanites of Mt. Khukhch are the first reliable evidence of the occurrence of typical within-plate K–Na alkaline magmas in the rear zone of the Kamchatka island-arc system.

The Khukhch basanites compose a small subvolcanic body (60–80 m^2 in area) on the right bank of the Bystraya River (Fig. 1) among the subvolcanic occurrences of Paleogene–Neogene potassium alkaline and subalkaline basaltoids (absarokites, trachybasalts, and shonkinites). The basanite subvolcanic body has intrusive contacts with the enclosing volcanosedimentary sequence of undifferentiated Lower Miocene Viventek and Kuluven formations of the Middle Eocene–Lower Miocene Vayampol Group. Based on the K–Ar age of spatially associated trachybasalts (17–8 Ma) [5] and their geological–stratigraphic position, the Khukhch basanites are considered Middle–Late Miocene rocks.

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The basanites are grayish black and dark gray massive fairly fresh rocks. They have a finely porphyritic texture with numerous euhedral and resorbed phenocrysts of Ol and scarce Cpx among fine-grained microdolerite groundmass. The olivine phenocrysts contain spinel inclusions. Two subsequent crystallization phases of subphenocrysts, microlites, and interstitial grains can be distinguished in groundmass. The first (early) generation of microlites includes subphenocrysts (laths) of Pl, as well as microlites of Cpx and Ti-magnetite (TiMgt). The second (late) generation is represented by thin acicular microlites of apatite, as well as microlites and interstitial grains of nepheline, leucite, low-calcic Pl, and analcime. Based on mineral–petrographic and mass-balance calculations, the average mineral composition of the basanites is as follows: phenocrysts, subphenocrysts, and microlites of Ol (22%), Cpx (34%), Pl (21%), and TiMgt (4%). Interstitial phases consist of Ne (16%), Lc (3%), and Ap and Anc (<1%).

The composition of Al–Cr spinels in olivines is close to picotite and Cr-picotite (Table 1). In the marginal zones of olivines, spinels have higher Fe contents, while ore minerals in microlites are mainly represented by Ti-magnetite. Olivines in phenocrysts evolve from forsterite ($Fo_{88.1–79.4}$) in the core and intermediate parts to hortonolite in rims. Subphenocrysts and microlites ($Fo_{69.6–62.8}$) show further enrichment in Fe. Clinopyroxenes correspond to salites and fassaites. Salites ($Wo_{46.0–47.8}Fs_{10.2–10.7}$) in the phenocryst core are replaced by fassaites ($Wo_{50.1–52.2}Fs_{13.3–15.5}$) in subphenocrysts and mircrolites (Table 1). The Pl laths are composed of K-free bytownites and labradorites ($An_{66–74}Or_0$), while smaller laths are labradorites with a significant content of orthoclase end member ($An_{57–66.6}Or_{1.1–2.1}$). The more acid Pl ($An_{21–50}Or_{4–12}$) of andesine and oligoclase compositions occurs as fine grains in association with interstitial nepheline and leucite. Interstitial nepheline in the groundmass insignificantly varies in composition and corresponds to both carnegieite and nepheline solid

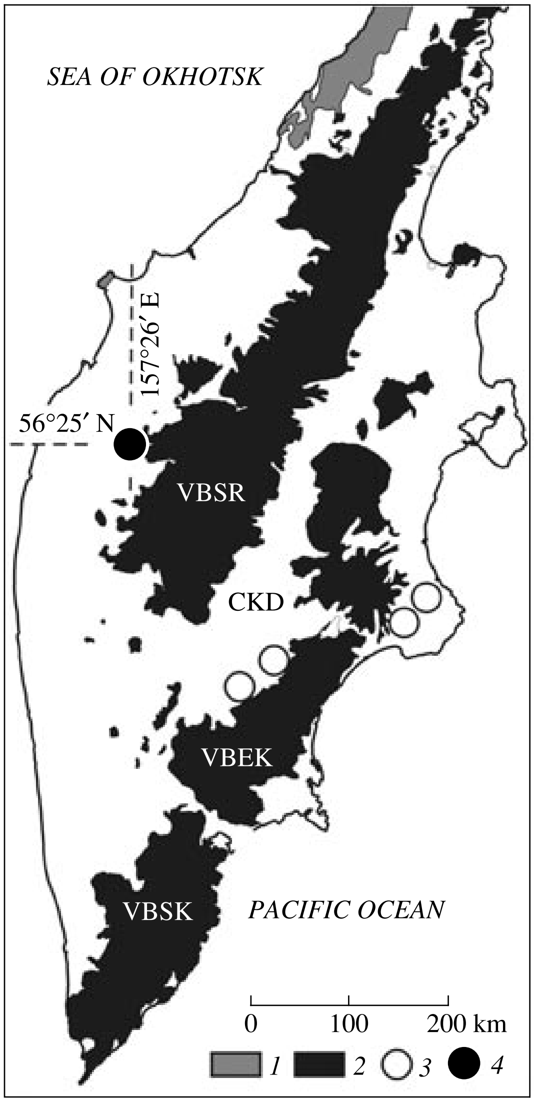

Fig. 1. Location of the basanites of Mt. Khukhch in the scheme of volcanic belts of Kamchatka. (*1*) Upper Paleogene volcanic belt of western Kamchatka; (*2*) Oligocene–Miocene and Pliocene–Quaternary volcanic belts of Kamchatka; (*3*) Middle–Late Miocene subvolcanic bodies and lavas of K–Na alkaline and subalkaline basaltoids of eastern Kamchatka [3]; (*4*) localization of subvolcanic basanite body of Mt. Khukhch, western Kamchatka. Abbreviations: (VBSK) volcanic belts of southern Kamchatka; (VBEK) volcanic belts of eastern Kamchatka; (VBSR) volcanic belts of the Sredinnyi Range; (CKD) Central Kamchatka Depression.

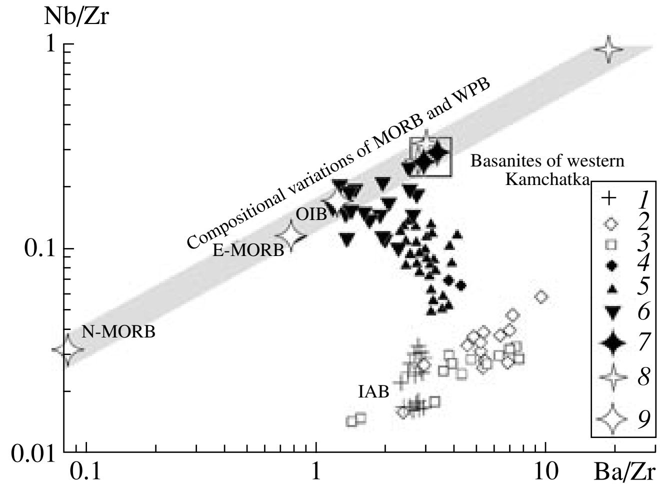

Fig. 2. Nb/Zr–Ba/Zr diagram of the basanites of Mt. Khukhch and basaltoids of various geochemical types. (*1*) Island-arc moderate-K basalts of the volcanic belt of eastern Kamchatka; (*2*) island-arc moderate-K and high-K basalts of the volcanic belt of the Sredinnyi Range, Kamchatka; (*3*) basaltoids of potassium alkaline and subalkaline series of western Kamchatka; (*4*) K–Na-shonkinites of western Kamchatka; (*5*) basalts of K–Na-alkaline basaltic and alkaline–olivine–basaltic series of the Sredinnyi Range; (*6*) basaltoids of K–Na-alkaline and subalkaline series of eastern Kamchatka; (*7*) basanites of western Kamchatka (Mt. Khukhch); (*8*) average compositions of riftogenic alkaline basalts and basanites from the Rungwe province (Tanzania) [4] and Oman [10]; (*9*) average compositions of normal (N-MORB) and enriched (E-MORB) mid-oceanic ridge basalts and oceanic-island basalts (OIB) (after [9]). Compositions of all geochemical types of Kamchatka basalts are based on our original ICP-MS data with supplements from [3, 7, 8].

solutions (Table 1). Data points of Ne in the feldspar projection plane are grouped near the equilibrium curve of these phases. Nephelines in the basanites of western Kamchatka, like those in alkaline basalts from other areas of Kamchatka [2, 3], have elevated contents of SiO_2 and K_2O. Leucites in interstices have nearly ideal composition with minor impurities of Na_2O, CaO, and FeO (Table 1).

Owing to the crystallization of olivine in association with spinel and the subsequent large-scale crystallization of subphencorysts and microlites of Ol, Pl, Cpx, and TiMgt, the compositional variation trend of basanite magma is observed as an increase in alkalinity and alumina content in the residual melt up to the point of the appearance of phonotephrite composition in the groundmass (Table 1).

The Khukhch basanites are ascribed to the basic feldspathoid-bearing alkaline rocks of K–Na series (Na_2O/K_2O = 1.5–1.9). They are characterized by low SiO_2 and elevated MgO, TiO_2, Na_2O, and K_2O contents (Table 2). The rocks have high contents of compatible siderophile (Co, Ni, and Cr), HFSE (Nb and Ta), radioactive (Th and U), and LREE elements and moderate contents of Zr, Hf, and alkali metal, alkali earth, and chalcophile elements (Rb, Ba, Sr, Pb, and Cu). High fractionation of REE (La_N/Yb_N = 10.8–12.6) and values of some indicator trace-element ratios (Ba/Nb = 10–12, Sr/Nb = 17–18, and Ta/Yb = 1.3–1.6) suggest that the basanites of western Kamchatka can be ascribed to within-plate basalts. This is distinctly seen in the Ba/Zr–Nb/Zr diagram (Fig. 2), where data points of basanites show MORB and WPB trends.

Table 1. Average compositions of minerals from basanites of Mt. Khukhch, wt %

Phase	Sp	TiMgt	Ol		Cpx		Pl		Lc	Ne	Gm
	incl	mic	phen	mic	phen	mic	laths	mic	int	int	scan
SiO_2	0.08	0.00	41.41	35.44	52.29	41.55	49.04	57.86	55.23	49.34	47.75
TiO_2	1.04	22.26	0.00	0.04	0.73	4.05	0.08	0.09	0.04	0.03	1.80
Al_2O_3	43.36	1.87	0.00	0.00	3.88	11.24	31.85	25.60	23.75	31.37	20.59
Cr_2O_3	14.44	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO*	24.63	67.63	11.75	37.69	6.46	8.49	0.73	0.52	0.52	0.64	6.16
MnO	0.06	0.62	0.10	0.97	0.03	0.01	0.00	0.00	0.00	0.00	0.00
MgO	15.26	2.27	46.87	24.99	14.73	10.72	0.06	0.03	0.02	0.04	3.82
CaO	0.00	0.23	0.05	0.62	22.55	22.98	14.51	7.05	0.14	0.92	10.21
Na_2O	0.00	0.00	0.00	0.00	0.51	0.37	3.41	6.23	0.19	14.69	6.34
K_2O	0.00	0.07	0.00	0.03	0.00	0.00	0.00	1.62	21.16	2.68	2.80
Total	98.87	95.04	100.18	99.78	101.18	99.41	99.68	99.00	101.05	99.71	99.47
n	4	7	4	5	2	5	8	6	3	7	7

Note: (FeO*) All Fe is given as FeO. (*n*) Number of averaged analyses. Mineral phases: (Sp) spinel, (TiMgt) titanomagnetite, (Ol) olivine, (Cpx) clinpyroxene, (Pl) plagioclase, (Lc) Leucite, (Ne) nepheline, (Gm) groundmass; (incl) spinel inclusions in olivine phenocrysts; (phen) phenocrysts, (sub) subphenocrysts (laths), (mic) microlites, (int) interstitial grains in groundmass. The groundmass composition is based on scanning data. Minerals were analyzed on a Camebax 244 microprobe at the Institute of Volcanology and Seismology, Far East Division, Russian Academy of Sciences (accelerating voltage 20 kV, beam current 40 nA, count time 5 s, and K_α lines; T. M. Filosofova, analyst).

Table 2. Contents of major (wt %) and trace (ppm) elements in the basanites of Mt. Khukhch

Component	PP-2264	PP-2265	Component	PP-2264	PP-2265	Component	PP-2264	PP-2265
SiO_2	43.52	43.80	Rb	41	42	U	1.51	1.48
TiO_2	1.96	1.96	Ba	557	558	La	34.50	34.22
Al_2O_3	14.39	14.55	Sr	890	890	Ce	73.63	72.10
Fe_2O_3	4.73	4.79	Pb	2.99	2.80	Pr	9.09	8.80
FeO	7.18	7.00	Zn	76	72	Nd	33.04	32.44
MnO	0.18	0.17	Cu	42	44	Sm	6.79	6.64
MgO	10.96	11.00	Co	51	50	Eu	1.96	1.89
CaO	9.75	9.89	Ni	245	232	Gd	6.13	6.55
Na_2O	3.30	3.56	Cr	356	343	Tb	0.82	0.96
K_2O	2.11	1.90	V	249	239	Dy	4.56	4.69
P_2O_5	0.67	0.65	Sc	25	30	Ho	0.84	0.93
H_2O	0.80	0.55	Ta	2.90	2.79	Er	2.31	2.31
CO_2	0.23	0.17	Nb	51.0	49.1	Tm	0.29	0.31
Total	99.78	99.99	Zr	167	192	Yb	1.86	2.15
F	440	700	Hf	4.06	4.11	Lu	0.25	0.27
Cs	0.56	0.55	Th	4.43	4.44	Y	21	23

Note: Major elements were analyzed by the XRF method. Iron was separated by titration at the Vinogradov Institute of Geochemistry and Analytical Chemistry (A. K. Klimova and L. P. Koval, analysts). Trace elements were determined by the ICP-MS method at the Analytical Center of the Irkutsk Scientific Center, Siberian Division, Russian Academy of Sciences. Trace elements in sample PP-2264 were analyzed on a high-resolution Element 2 mass spectrometer at the Institute of the Earth's Crust (L. A. Chuvashova, E. V. Smirnova, and V. I. Lozhkin, analysts). Trace elements in sample PP-2265 were analyzed on a quadrupole VG Plasma Quad$^+$ mass spectrometer at the Institute of the Earth's Crust (M. E. Markova and T. A. Yasnygina, analysts). Analyses were controlled with basaltic standards BIR-1, BHVO-1, JB-2, and BCR-2.

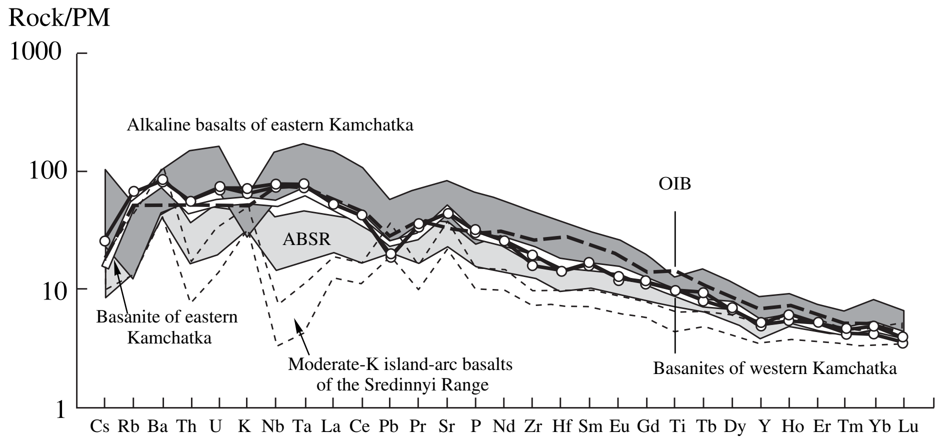

Fig. 3. Distribution patterns of magmatophile elements in the basanites of Mt. Khukhch and basaltoids of various geochemical types. Element abundances (g/t) are normalized to those in the primitive mantle (PM) (after [9]). (ABSR) Ne-normative basalts of alkali basaltic and alkali olivine–basaltic series of the Sredinnyi Range, Kamchatka; (OIB) average compositions of oceanic island basalts (after [9]).

Spidergrams of the Khukhch basanites (Fig. 3) are similar to those of basanites of eastern Kamchatka previously studied by Volynets et al. [3]. The Miocene basanites of western and eastern Kamchatka are similar to basanites of within-continental rifts [10] and OIB. However, the former basanites are characterized by higher contents of Rb, Ba, K, and Sr; and, contents of Zr, Hf, Ti, and HREE are lower, probably, due to the contribution of metasomatized mantle material in the basanite magma.

The similar Middle–Upper Miocene age of basanites from eastern and western Kamchatka [3, 5] indicates the simultaneous manifestation of K–Na alkaline magmatism in both frontal and rear zones of the Neogene island-arc system. The appearance of alkaline basaltic magmatism in these regions was related to the cessation of Oligocene–Early Miocene subduction of the Kula oceanic plate beneath the continental margin of Kamchatka and the development of riftogenesis up to the onset of a new Pliocene–Quaternary subduction. In this period, deep lithospheric fractures and decompressional melting could have generated basic mantle magmas in both frontal and rear zones of the consolidated continental block of Kamchatka. The timing of alkaline basaltic magmatism at Kamchatka coincides with the peak of extension in the marginal seas of the West Pacific successively marked by northward strike-slip dislocations, rifts, and spreading structures [6].

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