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ORIGIN OF CENOZOIC VOLCANIC SERIES OF KOMANDORSKY BASIN FRAMING ACCORDING TO GEOCHEMICAL AND EXPERIMENTAL DATA

(Figs. 4, Tabs. 2)

Abstract: Cenozoic calc-alkaline olivine-bronzite andesites and dacites of South Koryakia (Komandorsky basin framing) are the differentiation products of magnesian andesitic magmas. High crystallization temperatures (1230—1385 °C) obtained in homogenization experiments on melt inclusions in sub-liquidus mineral phases provide the evidence of relative H_2O depletion of initial melt (water content in magma less than 1.5 wt. %). This melt underwent extensive sub-liquidus fractionation indicated by silicic glass inclusions in bronzites and Ca-plagioclases. The observed geochemical characteristics (especially REE systematics) of South Koryakia volcanics are attributed to mixing between within-plate (plume-type) enriched source and depleted oceanic crust represented by eclogites. All the geochemical and experimental data support the idea of anhydrous partial melting of quartz eclogites. This process is related to crustal extension probably due to interaction between rising plume-type diapir and subducted Komandorsky basin oceanic crust.

Резюме: Кайнозойские известково-щелочные оливин-бронзитовые андезиты и дациты Южной Корякии (обрамление Командорского бассейна) являются продуктами дифференциации магнезиальных андезитовых магм. Высокие температуры кристаллизации (1230—1385 °C), полученные при экспериментах гомогенизации на инклюзиях расплава в субликвидусовых минеральных фазах, доказывают относительное обеднение первичного расплава водой (содержание воды в магме меньше чем 1,5 вес. %). Этот расплав претерпел интенсивное субликвидусовое фракционирование, намеченное инклюзиями кремнеземного стекла в бронзитах и Ca-плагиоклазах. Наблюдаемые геохимические характеристики (особенно систематика р.з.э.) вулканитов Южной Корякии приписываются смешиванию внутриплитового (типа плама) обогащенного источника с обедненой океанической корой представленной эклогитами. Все геохимические и экспериментальные данные поддерживают идею безводного частичного плавления кварцевых эклогитов. Этот процесс родственный растяжению коры вероятно ввиду взаимодействия повышающегося диапира типа плама и субдуцированной океанической коры Командорского бассейна.

Introduction

The origin and evolution of calc-alkaline magmas is a problem considered fundamental to the understanding of convergent plate boundaries development. There are three main aspects in the study of island arc magma genesis. The first one involves identification of possible mantle and crustal sources of island arc volcanics, the second one concerns the variability of petrogenetic processes to produce differentiated volcanic suites and the last but not least deals with

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recognition of the past tectonic settings of volcanic series in convergent plate margins.

In the last decade several attempts have been made to discover island arc magma sources utilizing geochemical data (Gill, 1981, 1984; Morris — Hart, 1983). It has been established that three main sources participate in island arc petrogenesis: the MORB-like depleted source, the within-plate (hot--spot) source and sometimes (mainly in mature arcs and continental margins) the crustal component. There is, also, some evidence in favour or the metasomatically enriched sub-continental mantle source (Rogers—Hawkesworth—Parker—Marsh, 1985; Kepezhinskas—Gulko—Efremova, 1987).

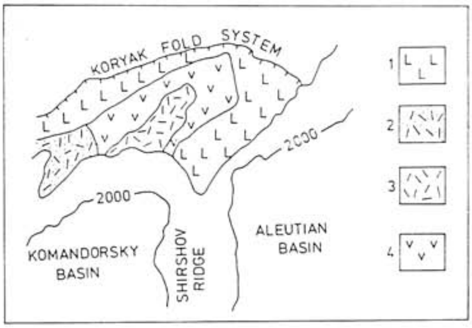

Fig. 1. Simplified geological map of South Koryakia.

Explanations: 1 — Upper Cretaceous oceanic association; 2 — Paleogene island arc association; 3 — Neogene rift association; 4 — Pliocene — Recent plateau-andesites.

The presence of andesitic series in continental fold belts is usually regarded as the evidence of their formation in island arc environment which contradict geological and geophysical data. Some recent works show that low and medium-K series occur both in intraoceanic and continental arcs as well as in the back-arc and intra-arc spreading centers and transform fault — trench — transform fault triple junctions (Kepezhinskas—Gulko—Efremova, 1987). So, there is the necessity of additional geological and geochemical criteria.

This paper concerns the origin of Cenozoic calc-alkaline lavas of South Koryakia. The region to be considered (Fig. 1) lies north of Komandorsky basin. Structurally this is a complex volcanotectonic depression flanked on the eastern and western sides by mountain ranges composed of Cretaceous oceanic and Paleogene island arc sequences respectively (Bogdanov—Fedorchuk, 1987). The volcanic belt consists of large volumes of andesitic flows and various pyroclastics and many monogenetic volcanic fields including small andesitic and dacitic lava flows and rarely dikes and necks. The extension is indicated by parallel dike series as well as by a set of geological and geophysical data (Kepezhinskas, 1985). The volcanic rocks are characterized by the occurence of olivine-bronzite-Ca-plagioclase and two-pyroxene phenocryst assemblages described in details in (Kepezhinskas, 1985; Kepezhinskas—Bakumenko — Usova, 1968). All the lavas show typical calc-alkaline trends on Miyashiro's and AFM diagrams (Kepezhinskas, 1985).

Geochemical characteristics of South Koryakia volcanic rocks

Representative analyses of volcanic rocks are given in Tab. 1. The lavas of South Koryakia belong to medium-K low-Rb calc-alkaline island arc series. They are slightly enriched in Ba, Sr, Li and Cs in relation to intraoceanic arc andesites (e. g. Tonga-Kermadecs and Marianas). The K/Rb ratio ranges from 1160 in basaltic andesites to 330 in dacites following typical calc-alkaline trend (Gill, 1981). Basaltic andesites are characterized by low Ba/Sr ratios similar to that of bulk Western Pacific ocean floor (Stern—Ito, 1983) whereas andesites exhibit high Ba/Sr ratios typical of mantle plume alkali basalts due to general enrichment of Koryakian lavas in LIL-elemets.

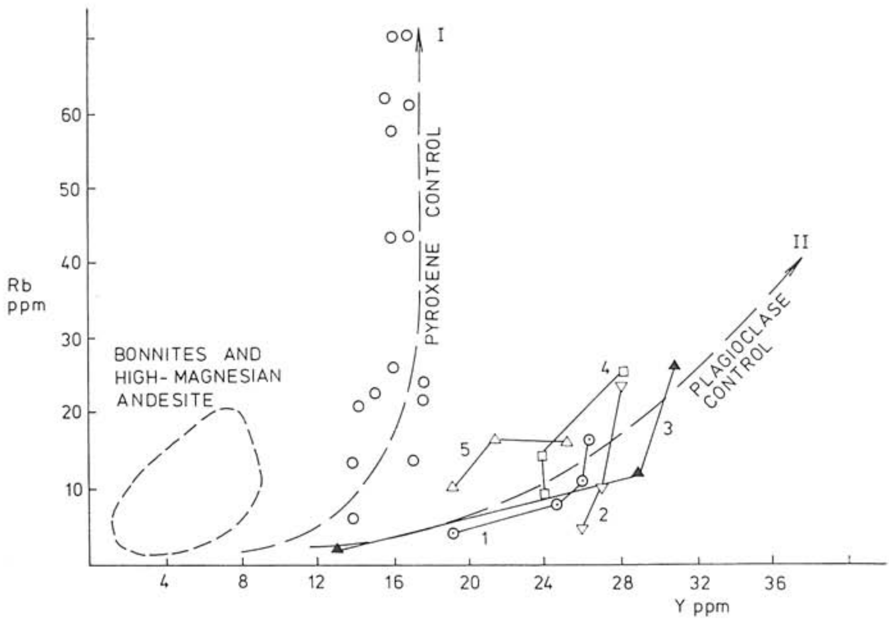

Fig. 2. Rb—Y variation diagram for island arc volcanic series. The explication of trends I and II see in text. Boninites and high-magnesian andesites field from Kepezhinskas et al. (1987).
Volcanic series differentiation trends: 1 — St. Kitts, Lesser Antilles; 2 — Edgecumbe volcanic field, Alaska; 3 — Little Semyachik, Kamchatka; 4 — Java, western Sunda arc; 5 — Sarigan, Marianas. Data from Kepezhinskas et al. (1987); Meijer—Reagan (1981). Open circles: South Koryakia volcanics.

Island arc suites exhibit two principal differentiation trends manifested by the covariation of Rb and Y (Fig. 2). The "boninitic" trend (number I on Fig. 2) with pyroxene control buffering the yttrium concentration suggests the high-magnesian andesitic primary magma composition. The plagioclase control trend (number II on Fig. 2) results from the differentiation of high-alumina basaltic or basaltic andesite magma. The fractionation of calcic plagioclase from these melts leads to the intense Sr enrichment of early-stage plagioclase cumulates

Table 1

Representative major (wt. %) and trace (ppm) element analyses of South Koryakia volcanics

	1	2	3	4	5	6	7	8
SiO_2	50.13	54.14	54.57	55.91	56.75	60.18	60.83	60.98
TiO_2	1.80	1.29	1.29	1.20	0.97	0.92	0.72	0.61
Al_2O_3	16.84	17.01	16.99	18.35	20.45	17.99	15.86	15.46
Fe_2O_3	4.25	2.49	2.37	3.70	2.28	2.56	1.72	2.68
FeO	5.00	5.22	5.41	4.16	4.06	3.88	4.98	4.08
MnO	0.13	0.13	0.13	0.11	0.10	0.10	0.10	0.13
MgO	6.58	6.02	5.94	4.03	2.77	2.52	5.12	4.65
CaO	10.67	8.53	8.13	7.45	7.55	6.38	6.33	6.95
Na_2O	3.17	3.90	3.89	3.90	3.77	3.79	3.15	3.10
K_2O	1.01	1.00	1.00	0.95	1.05	1.48	1.05	1.21
P_2O_5	0.42	0.27	0.28	0.24	0.25	0.19	0.14	0.15
Cr	190	163	162	28	24	61	258	127
Ni	93	86	90	56	27	50	176	110
Co	3	28.8	28.8	26.8	20.6	16.7	25.3	19.0
Ba	310	350	343	267	320	390	340	470
Sr	1120	790	785	556	688	540	440	520
Li	11	—	—	10	—	9.7	—	—
Rb	7.2	9	10	7	11	24	21	18
Cs	4.8	0.27	0.26	2.2	0.41	1.57	1.16	0.64
Zr	161	140	140	140	120	130	110	90
Y	22	—	—	22	—	17	—	—
Nb	1	—	—	—	—	39	—	—
La	11	10	9.7	10.6	9.4	9.9	8.9	9.9
Ce	36	24	24	24	20	22	19	19
Nd	29	14.5	14.1	14.5	13.0	12.8	11.3	10.1
Sm	—	3.82	3.73	4.01	3.49	3.39	3.15	2.56
Eu	1.9	1.31	1.25	1.28	1.33	1.05	0.96	0.82
Gd	5.6	4.3	4.0	4.2	3.7	3.6	3.6	2.9
Tb	—	0.71	0.65	0.71	0.59	0.61	0.60	0.45
Tm	—	0.359	0.324	0.353	0.310	0.291	0.312	0.266
Yb	2.7	2.09	1.95	2.09	1.83	1.84	1.91	1.68
Lu	—	0.311	0.280	0.303	0.275	0.249	0.279	0.256
Hf	—	3.0	3.4	3.1	2.9	3.1	2.9	2.7
Ta	—	0.268	0.262	0.260	0.264	0.262	0.217	0.177

which can be used as additional geochemical indicators of "normal" island arc series. The South Koryakia lavas follow "boninitic" trend with increasing Rb and nearly constant Y accompanied by increasing Nb content and Ba/Nb ratio changing from typically island arc of 30—300 to plume-source Ba/Nb ratio similar to that in Hawaiian enriched basalts (V a r n e, 1985).

The REE pattern in least fractionated olivine-bronzite andesites of South Koryakia are shown on Fig. 3. The REE abundances in these rocks are similar both to those in the primitive andesites of Taupo Volcanic Zone of New Zealand and those in the basalts of Loihi seamount related to Hawaiian mantle plume.

1 st continuation of Tab. 1

	9	10	11	12	13	14	15
SiO_2	61.13	61.52	61.96	62.78	63.42	65.39	66.72
TiO_2	0.76	0.76	0.77	0.55	0.63	0.65	0.66
Al_2O_3	17.26	17.10	17.00	16.36	16.90	16.04	15.73
Fe_2O_3	2.44	1.89	3.20	2.75	1.24	2.77	2.28
FeO	3.46	3.63	2.38	2.56	3.96	2.81	1.99
MnO	0.09	0.09	0.09	0.08	0.09	0.08	0.08
MgO	2.95	3.14	3.00	4.00	2.96	1.27	1.89
CaO	6.60	6.58	5.71	6.53	5.63	5.07	3.95
Na_2O	3.76	3.73	4.17	3.06	3.42	4.12	4.44
K_2O	1.34	1.34	1.55	1.19	1.56	1.64	2.11
P_2O_5	0.21	0.22	0.17	0.14	0.19	0.15	0.15
Cr	55	44	38	127	68	39	34
Ni	68	34	34	112	37	32	16
Co	14	16.4	17.6	19.0	14.6	12.1	10.4
Ba	440	493	542	480	480	440	510
Sr	410	458	658	440	410	368	282
Li	7.2	—	14	—	14	—	16
Rb	23	20	21	20	26	29	43
Cs	2.8	0.88	0.87	0.94	2.9	1.78	2.16
Zr	130	130	130	100	130	150	196
Y	15	—	14	—	16	—	16
Nb	47	—	—	—	35	—	39
La	8.0	13.4	11.5	10.2	13.4	12.6	13.3
Ce	25	27	26	20	26	27	27
Nd	17	12.6	10.8	11.4	13.0	14.1	12.7
Sm	—	3.31	3.01	2.76	3.17	3.32	3.32
Eu	0.9	1.06	0.94	0.93	0.93	0.96	0.85
Gd	2.5	3.5	3.3	3.0	3.4	3.6	3.7
Tb	—	0.59	0.52	0.45	0.55	0.58	0.58
Tm	—	0.304	0.288	0.251	0.288	0.311	0.341
Yb	2.2	1.86	1.77	1.58	1.72	1.95	2.07
Lu	—	0.283	0.265	0.230	0.260	0.290	0.317
Hf	—	3.4	3.5	2.7	3.6	4.2	4.7
Ta	—	0.266	0.307	0.176	0.232	0.349	0.423

Notes: Recalculated to 100 % on a volatile-free basis. Major elements obtained by wet chemical analysis at the Institute of Geology and Geophysics, Siberian Branch of U.S.S.R. Academy of Sciences, analyst — L. S. Zorkina. Cr, Ni, Co, Li, Rb, Cs measured by atomic absorption; Ba, Sr, Y by ICP spectrometry; Zr and Nb by XRF at the Institute of Lithosphere, U.S.S.R. Academy of Sciences, analysts — N. I. Gulko, L. B. Efremova, A. T. Savichev. REE, Hf, Ta determined by instrumental neutron activation analysis at the Institute of Geology and Geophysics, analyst — V. S. Parkhomenko. See Kepezhinskas — Gulko — Efremova (1987) for detailed analytical techniques.

1 — plagioclase cumulate basaltic rocks; 2—5 — olivine-pyroxene andesites; 6—11 — olivine-bronzite andesites; 12—13 — olivine-bearing two-pyroxene andesites; 14—15 — olivine-bearing two-pyroxene dacites.

The similarity between Koryakian andesites and plume-related volcanics is demonstrated by La—Sm and La—Yb inter-element relationships (Fig. 4). There are three main primitive andesite types in subduction zones according to REE systematics (K e p e z h i n s k a s, 1987). The first one is characterized by $(La/Sm)_N$ and $(La/Yb)_N$ ratios close to 1 and low level of practically all lithophile elements (e. g. olivine-pyroxene andesites of Tonga-Kermadecs, New

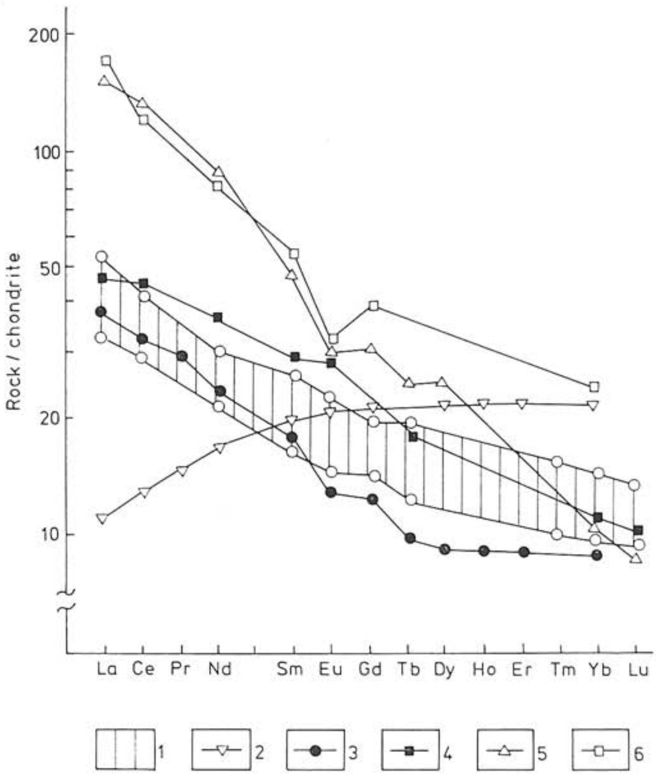

Fig. 3. Chondrite normalized (E v e n s e n—H a m i l t o n—O'N i o n s, 1978) REE concentrations for South Koryakia olivine-bronzite andesites.

Explanations: 1 — South Koryakia andesites field; mean compositions of: 2 — N-MORB (M c L e n n a n—T a y l o r, 1981); 3 — olivine-pyroxene andesite, Taupo Volcanic Zone, New Zealand (C o l e—C a s h m a n—R a n k i n, 1983); 4 — Loihi seamount basalt, Hawaii (F r e y—C l a g u e, 1983); 5 — Vulsini leucite basanite, Central Italy (R o g e r s et al., 1985); 6 — Pacific pelagic sediments (M c L e n n a n—T a y l o r, 1981).

Hebrides and Izu-Bonin arcs) due to partial melting of primordial mantle with chondritic REE pattern and subsequent low-pressure crystallization during magma ascent. The second type andesites represent the melts generated from enriched mantle diapirs chemically similar to within-plate plume source (e. g. Marianas and New Zealand). The increasing $(La\ SM)_N$ ratios in Taupo andesites (up to 3—3.5) are probably due to assimilation of sialic crust. It is important to note the role of long-lived reservoirs in the crustal assimilation model. The contamination of Taupo melts by sialic component (Jurassic greywackes) is additionally fixed both by the presence of metamorphosed sedimentary xenoliths and by the Pb and O isotopic data (B l a t t n e r—R e i d, 1982). The third type exhibit the highest $(La/Sm)_N$ and $(La/Yb)_N$ ratios due to melting of metasomatically enriched source (e.g. Chilean and Colombian Andes). The South Koryakia olivine-bronzite andesites are characterized by $(La/Sm)_N$ and $(La/Yb)_N$ ratios typical of within-plate plume source.

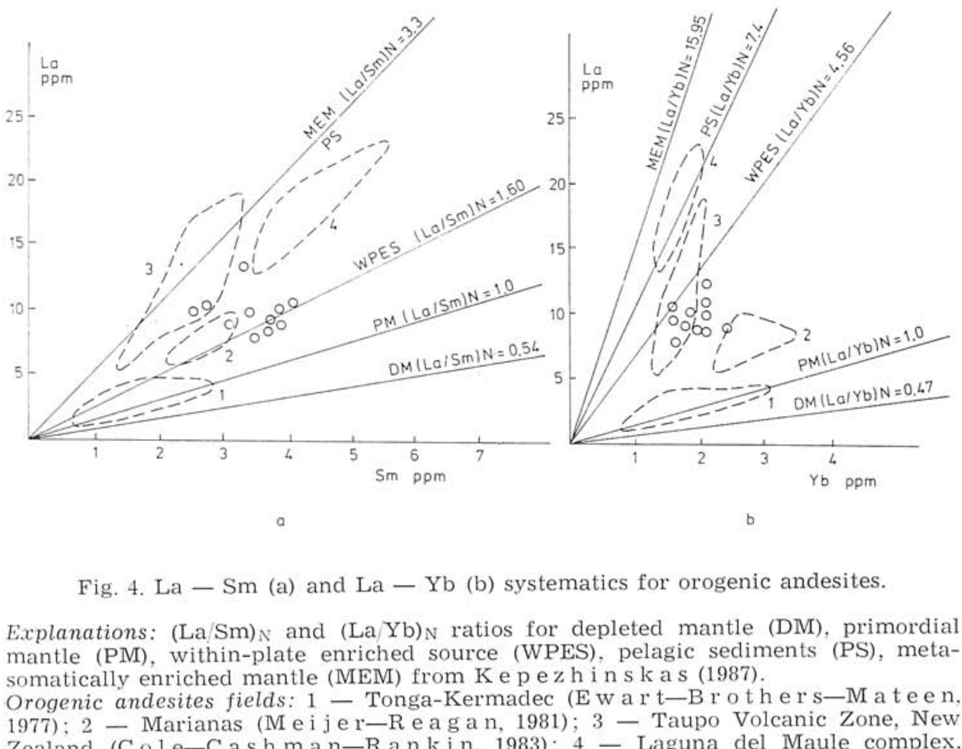

Fig. 4. La — Sm (a) and La — Yb (b) systematics for orogenic andesites.

Explanations: $(La/Sm)_N$ and $(La/Yb)_N$ ratios for depleted mantle (DM), primordial mantle (PM), within-plate enriched source (WPES), pelagic sediments (PS), metasomatically enriched mantle (MEM) from K e p e z h i n s k a s (1987).
Orogenic andesites fields: 1 — Tonga-Kermadec (E w a r t—B r o t h e r s—M a t e e n, 1977); 2 — Marianas (M e i j e r—R e a g a n, 1981); 3 — Taupo Volcanic Zone, New Zealand (C o l e—C a s h m a n—R a n k i n, 1983); 4 — Laguna del Maule complex, Chilean Andes (F r e y et al., 1984). Open circles: South Koryakia andesites.

Conditions of magma generation

A detailed study of phenocryst and glass inclusion chemistry and experimental work on melt inclusions were done in order to determine the conditions of magma generation (K e p e z h i n s k a s—B a h u m e n k o—U s o v a, 1986). The experimental results are shown in Tab. 2. Comparable results based on homogenization experiments on two-pyroxene andesites (Tab. 2) and magmatic geohygrometers calculation have been reported (R o e d d e r, 1984; M e r z-

Table 2

Homogenization temperatures (°C) of melt inclusions in sub-liquidus mineral phases of two-pyroxene andesites

location	plagioclase	orthopyroxene	clinopyroxene
South Koryakia basaltic andesite andesite	 1210—1295 1230—1385	 >1300 —	 — —
Khariuzovsky volcanic massif, Western Kamchatka	1200—1280	>1400	1190—1300
Avachinsky volcano, Kamchatka	1160—1340	—	1200—1250
Mendeleev volcano, Kunashir Is., Kuriles	1290—1380	—	—
Bezimianny volcano, Kamchatka	1345—1350	—	—
Karymsky volcano, Kamchatka	1280—1340	—	—

Data from Kepezhinskas — Bakumenko — Usova (1986).

bacher—Eggler, 1985). The calculation of equilibration temperatures using different plagioclase thermometers (Drake, 1976; Glazner, 1984) show a good correlation between experimental and calculated data especially taking into account the correction factor on Na^+ diffusion in silicate melts.

The microprobe analyses revealed two main types of glass inclusions: the high-Ti magnesian glasses and the silicic low alkaline glasses. The first case indicates the local silicate liquid immisciblity demonstrated by co-existance of unsaturated magnesian glasses with silicic ones in bronzite phenocrysts (Kepezhinskas—Bakumenko—Usova, 1986). The microcrystalline phases in composite inclusions are represented by plagioclases (labrador-andesines), titanomagnetites and Ti-spinels reflecting the crystallization within isolated inclusion. The most common silic glasses represent extensive sub-liquidus fractionation in relatively deep magma chambers. This process is characteristic of orogenic magmas but the South Koryakian residual glasses are less alkaline than those of active continental margin andesites (Kepezhinskas—Bakumenko—Usova, 1986).

The occurence of andesitic magmas usually suggests hydrous melting conditions (Gill, 1981). Evidence for the relative depletion of calc-alkaline magmas in H_2O has been provided (Sobolev, 1979). These data were supported by thermodynamic analyses of corresponding physico-chemical systems (Kadik — Maksimov, 1982) and the direct investigation of melt inclusions in calc-alkaline two-pyroxene andesites (Roedder, 1984; Kepezhinskas — Bakumenko—Usova, 1986). High crystallization temperatures of sub-

-liquidus mineral phases in South Koryakia lavas and the absence of amphibole both in phenocryst and groundmass assemblages preclude any significant participation of H_2O in magma genesis. The P_{H_2O} estimation based on Harris — Anderson's method (Harris — Anderson, 1984) gives the following results: $P_{H_2O} < 1$ kbar and the water content in magma less than 1.5 wt. %.

Only few orogenic magmas could be in equilibrium with peridotite under upper mantle conditions because the partial melting of peridotite under dry conditions leads to the generation of picritic or high magnesian andesitic liquids (Gill, 1981; Tatsumi, 1981). The idea of partial melting of basic material under H_2O-unsaturated conditions is preferable since both clinopyroxene and garnet are liquidus phases of anhydrous andesitic melts at high pressures; so that these magmas could represent partial melts of basaltic eclogites.

Discussion

The data obtained in this study demonstrate the ambivalent geochemical characteristic of South Koryakia volcanics showing their similarity to intraoceanic island arc calc-alkaline series on the one hand to plume-related suites on the other. The observed chemical variations are due to mantle heterogeneity and mixing of different mantle sources, e.g. depleted oceanic type mantle and enriched subcontinental plume-type mantle. Thus, the mixing between MORB-like sediment-contaminated component and OIB component lying in the conventional Sr-Nd-Pb mantle array occurs in the oceanic Vitiaz island arc system including Fiji and the South Fiji back-arc basin for at least last 30 m. y. (Gill, 1984). The South Koryakia calc-alkaline series are also characterized by the enrichment both in LIL and HFS elements. The observed characteristics are attributed to mixing between plume-type enriched source and depleted oceanic crust represented by eclogites. The interaction of high-temperature anhydrous fluid enriched in HFS elements with basaltic eclogites and the subsequent partial melting of mixed parent composition lead to the generation of chemically heterogeneous andesitic magmas. The same model has been proposed for the calc-alkaline andesites of the eastern Aleutian arc (Morris—Hart, 1983). It was based on a plume—pudding model of mantle wedge beneath the arc segment. The interaction between hot chemically enriched diapirs and subducted oceanic crust within the sub-arc mantle and the low-pressure fractionation of anhydrous initial melts in shallow magma reservoirs lead to the formation of differentiated series indicative of initial rifting in the framing of small oceanic basins.

Myers et al. (1985) suggest two stages of lithospheric plumbing systems development beneath convergent plate margins including the early stage of small-scale mantle heterogeneites and mixing of different sources and the late stage with stable chemical gradient in the source — intermediate magma chambers — volcano system due to heat and mass transfer. Our data provide the evidence of the relative immaturity of plumbing systems in South Koryakia closely related to the oceanic lithosphere evolution in the western part of the Bearing Sea region.

Conclusions

1. Cenozoic calc-alkaline olivine-bronzite andesites of Komandorsky basin framing are the differentiation products of high-magnesian andesitic magmas.

2. High crystallization temperatures (1230—1385 °C) obtained in experiments on melt inclusions in sub-liquidus phases provide the evidence of relative H_2O depletion of initial melt (water content in magma less than 1.5 wt. %).

3. The geochemical characteristics of South Koryakia lavas are attributed to mixing between plume-type enriched diapir and depleted subducted oceanic crust.

4. All the geochemical and experimental data support the idea of anhydrous partial melting of quartz eclogites in the presence of juvenile fluid enriched in incompatible elements.

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