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Strontium and Oxygen Isotope Compositions of Late Cenozoic K-Na Alkalic Basalts of the Within-Plate Geochemical Type in Kamchatka

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Abstract – The strontium isotope composition of the Pliocene-Quaternary within-plate K-Na basalts of the basalt-comendite and alkalic olivine basalt series of Kamchatka ($^{87}Sr/^{86}Sr = 0.70313 - 0.70386$, $n = 20$) are found to be identical to the strontium isotope composition of the Quaternary island-arc basalts of the region ($^{87}Sr/^{86}Sr = 0.70304 - 0.70382$, $n = 45$). The strontium is more radiogenic ($^{87}Sr/^{86}Sr = 0.70343 - 0.70512$, $n = 13$) in the lavas of the late Miocene K-Na alkalic basalt series of the within-plate type. The $\delta^{18}O$ values ranging between +5.5 and +6.6‰ in the Pliocene-Quaternary basalts are common for unaltered rocks of mantle origin, whereas the $\delta^{18}O$ values in the late Miocene basalts grow from 6.0 to 12‰ as the H_2O^+ content increases in the lavas. Hypothetical mechanisms are proposed to account for the strontium and oxygen isotope variations in the basalts.

GEOLOGIC SETTING OF THE KAMCHATKAN WITHIN-PLATE BASALTS AND PURPOSE OF THE STUDY

Lavas of the within-plate geochemical type have been discovered, along with island-arc lavas, by Volynets (Volynets *et al.*, 1984, 1987, 1990a, b; Volynets, 1993) among the Late Cenozoic volcanic rocks of Kamchatka. The lavas are subalkalic or alkalic rocks with elevated concentrations of lithophile trace elements. Although the contents of some of the elements (Rb, Ba, Be, F, and some others) in these lavas are comparable to their contents in the lavas of the island-arc shoshonite-latite series, these lavas fundamentally differ from all island-arc lava varieties by their considerably higher Nb, Ta, and Ti concentrations and the lower values of their K/Ti, K/Nb, Zr/Nb, La/Ta, Th/Ta, and other analogous ratios.

The within-plate basalts have been found in various volcanic belts of Kamchatka, are of different ages, and have been grouped into a few volcanic series: the K-Na alkalic basalt (N_1^3) and K-Na alkalic olivine basalt (N_2) series in eastern Kamchatka, the K-Na alkalic olivine basalt (Q_3^3–Q_4) and K-Na basalt-comendite (N_2–Q_1) series in the Sredinnyi Range, and the K alkalic basalt (N_1^3–N_2) series in western Kamchatka. All these series, except the last one, are considered in this paper. Significantly, the emplacement of within-plate lavas in eastern Kamchatka preceded the formation of the eastern island-arc volcanic belt, whereas within-plate lavas were emplaced simultaneously with island-arc lavas in the Sredinnyi Range volcanic belt during the intermediate and final phases of its development.

The lavas of the K-Na alkalic basalt series are identical to nepheline-normative alkalic basalts of oceanic islands and continental rifts in terms of their trace element distributions. The lavas of the K-Na alkalic basalt and basalt-comendite series exhibit a number of the more or less distinctive features of island-arc lavas; for example, they display some deficiencies in Nb and Ta relative to K and La in spider diagrams (Volynets *et al.*, 1990b; Volynets, 1993). The concentrations of alkalis, titanium, and trace elements in the basalts of these series vary perceptibly with the magnesium content of the rocks: the concentrations of incompatible elements decrease and the contents of compatible elements increase as the magnesium content increases, even though the distribution patterns in spider diagrams for basalts of different series do not change (Volynets, 1993).

In addition to the above areas, basalts similar to the rocks of the K-Na alkalic basalt series of Kamchatka have been found in the Kamchatka Isthmus in the Apuka Formation, which is Pleistocene in age (Volynets *et al.*, 1990b). Koloskov, a coauthor of this paper, identified the rock as leucite basanite. Associated with this rock were non-island-arc xenoliths of

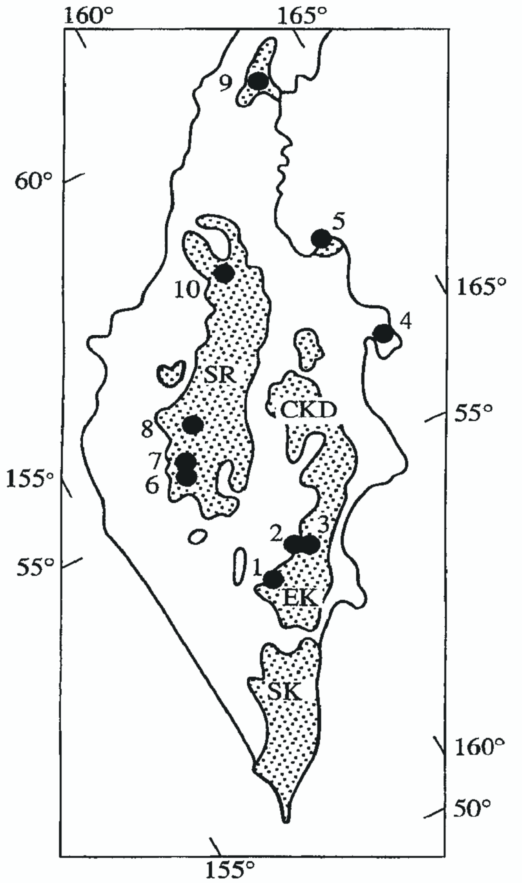

Fig. 1. Location of sample sites.

1 – Bakening Volcano, Avachinskii Range; 2 – Stepanov and Khrustalnyi Creeks, Valaginskii Range; 3 – Mt. Ploskaya and Mt. Stol, left side of the Levaya Zhupanova River; 4 – Pervaya Perevalnaya River, Cape Kamchatskii Peninsula; 5 – Nachiki Volcano, Ozernoi Peninsula; 6 – Belogolovskii Volcano; 7 – Icha flood basalt zone; 8 – Dol Geologov flood basalt zone; 9 – Valovayam River, Kamchatka Isthmus; 10 – Tekletunup Volcano. Stippled areas are volcanic belts: SR – Sredinnyi Range, CKD – Central Kamchatka Depression, EK – Eastern Kamchatka, SK – Southern Kamchatka.

dunite-lherzolite composition and megacrysts of high-Na clinopyroxene and picroilmenite (Koloskov *et al.*, 1992).

The earlier petrological model, offered by Volynets (1993) for the origin of non-island-arc lavas in Kamchatka, assumed that mantle plumes rose from an undepleted mantle and interacted with a MORB-type depleted mantle material in the upper lithosphere. Differences in the geochemistries of the rock series were explained by the varying degree of interaction and the different extents to which the mantle wedge material had been reworked metasomatically by fluids operating in the subduction zone.

The purpose of this strontium and oxygen isotope study in the Kamchatkan within-plate alkalic and subalkalic basalts was to test the above model, search for other potential magma sources (e.g., crustal material), and compare the island-arc and within-plate lavas of Kamchatka. For the purpose of comparison, the strontium isotope composition was determined in several samples of alkalic basalts from the Kamchatka Isthmus and the Koryak Plateau, and the authors' unpublished data on strontium isotope compositions in Kamchatkan island-arc basalts were employed.

METHODS OF STUDY

Strontium isotope measurements were performed at the Laboratory of Isotope Geochemistry and Geochronology at the Institute of Geology, Moscow, using a MAT-260 mass spectrometer and the technique described in *Geokhimiya Izotopov* ... (1983) (30 measurements), and at Cornell University, USA, using a TIMS mass spectrometer (six measurements). Precision was 0.00005 and 0.00004, respectively. The samples used for oxygen isotope analyses were decomposed with ClF_3. Oxygen isotope composition was measured using a MI-1201V mass spectrometer. The $\delta^{18}O$ values are given in ‰ SMOW. Accuracy was ±0.2‰.

RESULTS

The sample sites are shown in Fig. 1, and the results of measurements are shown in the table. The samples of Quaternary rocks were absolutely fresh in a petrographical sense, and the Pleistocene rock samples showed occasional chloritization of dark-colored minerals. However, the late Miocene rocks were markedly altered and contained chlorite, analcime, and occasional albite, serpentine, and carbonate. Nevertheless, most of the samples of each age group contained modal nepheline. The H_2O^+ content, an important indicator of rock alteration, was 0 - 0.63 wt % in the Quaternary basalts, 0.08 - 0.84 wt % in the Pliocene, and ranged from 1.62 to 7.14% in the late Miocene basalts.

As seen in the table and Fig. 2, some ranges of the Sr isotope ratios in the basalts of geochemically different series overlap. However, the lavas of the alkalic basalt series (N_1^3) contain a markedly more radiogenic strontium in comparison with the within-plate basalts of the K-Na alkalic basalt and basalt-comendite series and the Quaternary island-arc basalts. Generally, their $^{87}Sr/^{86}Sr$ ratios are similar to the values of the K-Na alkalic basalts from oceanic islands and continental rifts (Faure, 1986). Although low Sr isotope ratios have been reported for nepheline-normative basalts from such structures, e.g., from St. Helena Island (Chaffey *et al.*, 1989) and the Kamchatka Isthmus (the table), these instances are the exceptions rather than the rule.

The Sr isotope ratios in the basalts of the basalt-comendite and alkalic olivine basalt series are identical

Strontium and oxygen isotope compositions in Late Cenozoic within-plate K-Na alkalic basalts of Kamchatka

No.	Sample number	Location	Na_2O	K_2O^+	H_2O	K_{Mg}	$^{87}Sr/^{86}Sr$	$\delta^{18}O$
Alkalic olivine basalt series								
Sredinnyi Range (Q_3^3–Q_4)								
1	6341	Icha Zone	3.67	1.34	0.50	60.9	0.70332*	–
2	6429	"	3.32	1.41	0.07	61.6	0.70336*	–
3	6409	"	4.16	1.95	0.00	56.3	0.70361	–
4	6805	Dol Geologov	3.00	1.89	0.33	69.4	0.70328*	–
							0.70337	–
5	6849/1	"	3.79	1.22	0.00	68.4	0.70327	–
6	6732	"	4.00	1.85	0.25	59.5	0.70330*	–
7	6771	"	4.50	1.85	0.36	49.5	0.70313*	–
8	1019/1	Tekletunup V.	3.53	1.85	0.12	62.6	0.70357*	5.7
							0.70366	–
Eastern Kamchatka (N_2)								
9	N-291	Ozernoi Pen.	4.39	2.15	0.84	55.3	0.70349	6.5
10	4090/2	Mt. Ploskaya	2.80	1.74	0.82	50.2	0.70341	–
11	S-19	Mt. Stol	2.75	1.54	0.72	45.1	0.70333	–
12	S-22	"	2.75	1.60	0.68	46.2	0.70353	–
13	93-63	Stepanov Cr.	3.30	1.80	0.80	42.7	0.70351	–
14	6323-2	Avachinskii Range	3.50	1.58	0.26	62.6	0.70380	6.6
15	V-48-6	"	1.07	0.24	0.00	–	0.70356	–
16	92-23	"	3.40	1.62	0.08	62.5	0.70328	–
Basalt-comendite series								
Sredinnyi Range (N_2–Q_1)								
17	6254	Belogolovskii V.	3.60	1.73	0.40	56.4	0.70328	5.5
18	6257	"	4.48	2.40	0.27	46.2	0.70329	6.2
Alkalic basalt series								
Cape Kamchatskii Peninsula (N_1^3)								
19	7590	Pereval'naya R.	3.49	2.70	7.14	–	0.70394	–
20	7594	"	3.63	1.52	2.41	–	0.70343	–
21	7605	"	4.00	0.90	3.02	–	0.70425	12.2
Valaginskii Range, eastern slope (N_1^3)								
22	112	Zverinyi Cr.	2.50	1.40	1.69	72.5	0.70362	6.0
23	7893	Stepanov Cr.	2.58	1.29	1.62	73.0	0.70452	6.9
24	2575/3	"	2.49	1.14	2.65	68.3	0.70388	6.2
25	7637	"	4.00	1.96	3.94	72.0	0.70363	9.0
26	4078/4	"	3.53	1.80	4.24	65.9	0.70442	10.4
27	3177/1	"	5.04	2.21	2.46	60.7	0.70452	8.4
28	93-57	"	3.74	1.21	2.29	68.0	0.70417	6.9
29	3166	Khrustal'nyi Cr.	3.11	1.49	2.29	73.9	0.70402	8.0
30	2138/2	"	4.93	1.90	4.55	63.4	0.70442	8.5
31	93-64	"	4.48	1.45	5.17	62.0	0.70512	8.9
Kamchatka Isthmus (Q_1)								
32	3523	Valovayam R.	2.65	1.49	0.50	68.3	0.70317	–
33	8710	"	3.68	2.21	0.14	62.3	0.70296	–
Karyak Plateau, Cape Navarin (Q_1)								
34	749	Cape Navarin	3.55	1.71	0.63	70.8	0.70342	–

Note: The data marked by an asterisk were obtained at Cornell University, USA; the others, at the Institute of Geology, Moscow. No. 15 is a black pyroxene inclusion in basalt (No. 14); the other samples are basalts or basanites. $K_{Mg} = MgO/[MgO + 0.85(FeO + 0.9Fe_2O_3)]$. The Na_2O, K_2O, and H_2O contents are in wt %; K_{Mg}, in at. %; $\delta^{18}O$, in ‰.

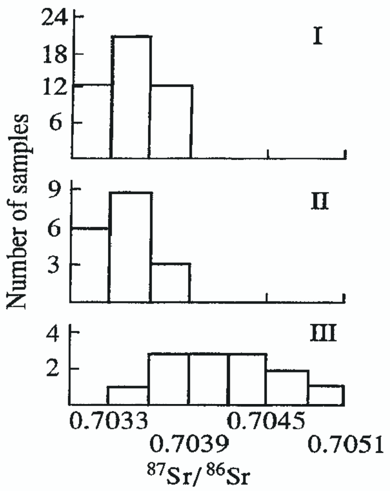

Fig. 2. Frequency distribution of $^{87}Sr/^{86}Sr$ values in the Late Cenozoic basalts of Kamchatka.

I – Quaternary island-arc basalts (45 analyses); II – Pliocene-Quaternary basalts of the basalt-comendite and alkalic olivine basalt series (20 analyses); III – late Miocene basalts of the alkalic basalt series (13 analyses).

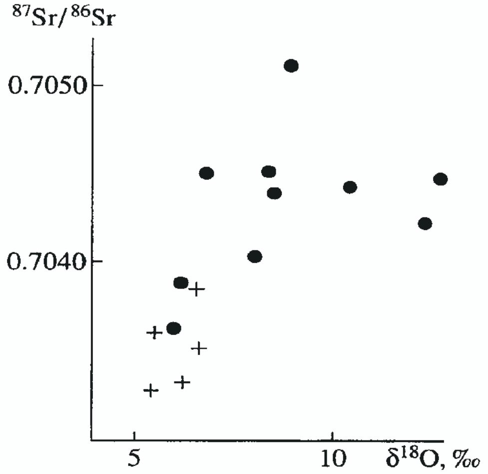

Fig. 3. Correlation between the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values in the rocks of the alkalic basalt series (dots) and in the basalts of the alkalic olivine basalt and basalt-comendite series (crosses).

to the values of the Quaternary island-arc basalts and range between 0.70304 and 0.70382, according to Vinogradov *et al.* (1986), Bailey *et al.* (1987), Churikova and Sokolov (1993), Kerstig and Arculus (1993), and our yet unpublished data. In this respect, the important evidence is the similarity between the $^{87}Sr/^{86}Sr$ ratios of the island-arc moderately potassic series (0.70332 and 0.70334) and the values of the K-Na alkalic basalt series (0.70332, 0.70336, and 0.70361), which occur together in the Icha areal cinder-cone zone on the Sredinnyi Range. Similar values have been obtained for the K-Na alkalic basalts of the Navarin Complex in the Koryak Plateau (Fedorov *et al.* (1993) and the table).

The oxygen isotope composition in the lavas of the alkalic basalt series (N_1^3) varies: the $\delta^{18}O$ values range from 6.0 ± 0.5‰, which is the value common for unaltered rocks of mantle origin (Taylor, 1968), to 10.4 - 12.2‰ in the rocks considerably enriched in heavy oxygen. In contrast, the $\delta^{18}O$ values in the basalts of the alkalic olivine basalt and the basalt-comendite series are fairly uniform and fall within a range of 5.5 - 6.6‰, which is accepted for unaltered rocks of mantle origin (see the table). Similar values (5.4 - 6.2‰) have been reported for the Quaternary island-arc basalts of the Kuril Islands (Pokrovskii and Zhuravlev, 1991).

DISCUSSION OF RESULTS

The studied basalt samples showed a positive linear correlation between the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values (Fig. 3). This relationship may have resulted from the mixing of two sources with different Sr and O isotope compositions. The mixing of two sources with different isotopic compositions usually produces a hyperbolic pattern. However, when different elements have close concentrations in both sources, the mixing hyperbola transforms to a straight line (Taylor, 1980). In our case, one of the source materials might have $\delta^{18}O \leq 5.5‰$ and $^{87}Sr/^{86}Sr \leq 0.703$, and the other might have $\delta^{18}O \geq 9‰$ and $^{87}Sr/^{86}Sr \geq 0.705$. The former can be interpreted as a mantle source, and the latter, as a crustal source. The possible materials of the crustal source might be the Cretaceous-Paleogene volcanic and volcano-sedimentary deposits that underlie the Neogene-Quaternary sequence (or older metamorphic rocks in the Sredinnyi Range); waters saturating the rocks of the sequence; or circulation waters, probably of marine origin.

To specify the crustal source is a fairly difficult task. The high $\delta^{18}O$ values might have been produced by the contamination of magma by the sedimentary (or acid metamorphic) component of the rock sequence or by sea water or its derivatives. Obviously, these processes might result in a notable increase of the Sr isotope ratios in the lavas. However, the contamination of primary alkalic magmas by the volcanogenic-sedimentary rocks of the Cretaceous-Paleogene basement can hardly account for geochemical differences between the lavas of the alkalic basalt series (with high $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values) and the lavas of the alkalic olivine basalt series (with low $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values), e.g., for the above-mentioned considerable increase of Ti, Nb, and Ta concentrations in the former. It cannot explain the similar differences in the lavas of the alkalic basalt series either. It seems more likely, therefore, that the crustal source was sea water containing crustal

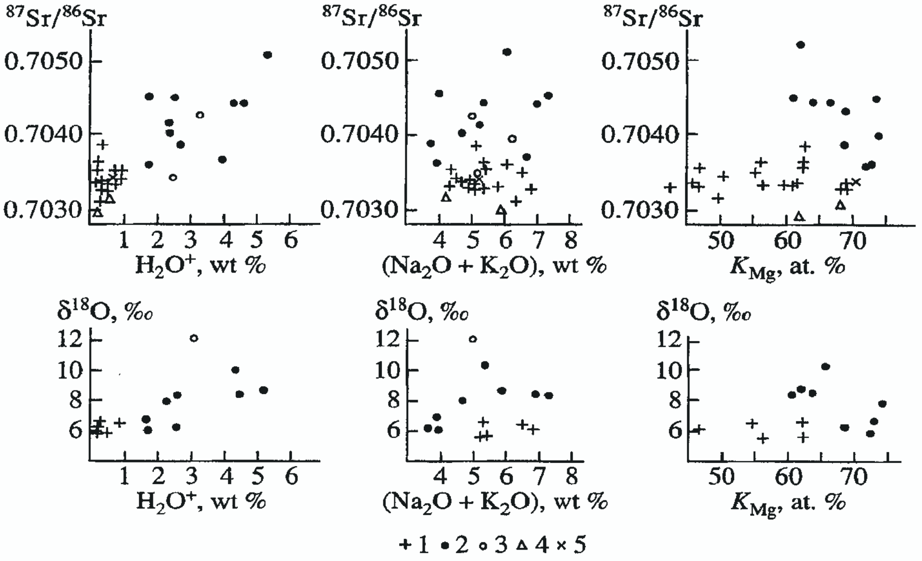

Fig. 4. Correlations between $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values in the lavas against their water and alkali contents and K_{Mg}.
1 – alkalic olivine basalt series; 2, 3 – alkalic basalt series: 2 – Valaginskii Range, 3 – Cape Kamchatskii; 4 – Kamchatka Isthmus; 5 – basanites, Cape Navarin.

components that assimilated during the reaction with the surrounding rocks.

At the same time, a different interpretation can be offered for the results of this isotope study. This interpretation is based on the existence or absence of a correlation between the Sr and O isotope ratios and the petrochemical characteristics of the lavas. As seen in Fig. 4, the $\delta^{18}O$ values in the lavas of the alkalic basalt series (N_1^3) are directly proportional to the contents of H_2O^+ and alkalis and inversely proportional to the magnesian coefficient. The $^{87}Sr/^{86}Sr$ values in the lavas of this series vary in the same manner with the alkalis content and the magnesian coefficient, but they do not show any regular variation with H_2O^+. The $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values in the lavas of the alkalic olivine basalt series do not show correlation with any of the concerned petrochemical parameters. Therefore, the results for the alkalic basalt series (N_1^3) alone can be interpreted in the context of the mixing model.

The growth of the heavy oxygen concentration with the increasing water content, which was observed in the lavas of this series, might be related to the deposition of clay minerals during the low-temperature hydrothermal alteration of the lavas (*Geokhimiya Isotopov* ..., 1983). However, this process cannot be invoked to account for the growth of the $^{87}Sr/^{86}Sr$ values with the increasing alkalinity and decreasing Mg mole fraction of the basalts. First, as was mentioned above, there is no positive correlation between the $^{87}Sr/^{86}Sr$ values and the H_2O^+ contents in the lavas. Second, the lavas, which are comparable in trace element abundances and Sr isotope ratios, may differ notably in the extent of secondary alterations. Examples are Sample 3177/1, which contains nepheline in the groundmass, and the more altered Samples 4078/4 and 2138/2, which contain analcime and albite in the groundmass (the table). Third, the more alkalic and less magnesian basalts differ from the less alkalic and more magnesian rocks in that they are higher not only in Rb, Ba, and Th, the elements that are highly mobile in water, but also in less mobile La and Sr, and even in inert Nb and Ta [mobility sequence after Tatsumi *et al.* (1986)].

It appears that the correlations between the Sr isotope compositions and the petrochemical parameters of the alkalic basalt lavas (N_1^3) can be interpreted in terms of the mixing model for magmas produced by the partial melting of an enriched (or primitive) mantle plume and the depleted mantle enclosing it (Volynets, 1993). In this interpretation, the relatively low-magnesian basalts (K_{Mg} = 60 - 65%), which are enriched in Sr, LREE, Ti, Nb, and Ta and have higher Sr isotope ratios (0.7044 - 0.7050), are regarded as pure mantle plume derivatives. The more magnesian lavas (K_{Mg} = 70 - 75%) with lower lithophile trace element abundances and lower Sr isotope ratios (0.7034 - 0.7039) are regarded as mixing products.

Another possible explanation for the Sr isotope variations and the geochemical peculiarities of the late Miocene lavas of the alkalic basalt series is that the extent of the partial melting of the enriched mantle plume increased from the more to the less alkalic magmas (Mineev *et al.*, 1992). This interpretation agrees with the positions of the rocks in the sequence: the more alkalic lavas occur in the lower intervals, and the less alkalic occur in the upper intervals.

CONCLUSION

The Late Cenozoic alkalic and subalkalic basalts of within-plate volcanic series of Kamchatka showed different Sr and O isotope compositions. The compositions in the lavas of the K-Na alkalic olivine basalt and basalt-comendite series are identical to those of the island-arc volcanic series, whereas the lavas of the K-Na alkalic basalt series contain more radiogenic strontium and more heavy oxygen. The results of this study suggest two hypothetical interpretations. One of them assumes that the observed Sr and O isotope variations of the basalts were caused by the contamination of mantle magmas with crustal constituents (for example, sea water), and their geochemical peculiarities were caused by the mixing, partial melting, and magmatic differentiation of mantle material. According to the second hypothesis, the isotopic and chemical variations of the basalts are interrelated and were caused by processes that operated in the mantle: the interaction of partial melts from undepleted mantle plumes with MORB-type depleted mantle magmas or the varied partial melting of plume materials.

In order to choose an interpretation that is more realistic a more comprehensive study and the investigation of other isotope systems (Nd, Pb) are needed.

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REFERENCES

Bailey, Y.C., Larsen, O., and Frolova, T.I., Stronium Isotope Variations in Lower Tertiary-Quaternary Volcanic Rocks from the Kurile Island Arc, *Contrib. Mineral. Petrol.*, 1987, vol. 95, no. 2, pp. 155 - 156.

Chaffey, D.Y., Gliff, R.A., and Wilson, B.M., Characterization of the St. Helena Magma Source, Magmatism in the Oceanic Basins, Saunders, A.D. and Norri, M.Y., Eds., *Geol. Soc. Spec. Publ.*, 1989, pp. 257 - 276.

Churikova, T.G. and Sokolov, S.Yu., Magmatic Evolution of the Ploskie Sopki Volcano, Kamchatka: Strontium Geochemistry, *Geokhimiya*, 1993, no. 10, pp. 1439 - 1447.

Faure, G., *Principles of Isotope Geology*, New York: Wiley, 1986.

Fedorov, P.I., Koloskov, A.V., and Lyapunov, S.M., Geochemistry and Petrology of Late Cenozoic Volcanic Rocks from Cape Navarin, Eastern Koryak Plateau, *Geokhimiya*, 1993, no. 9, pp. 1294 - 1296.

Geokhimiya Izotopov v Ofiolitakh Polyarnogo Urala (Isotope Geochemistry in the Arctic Urals Ophiolites), Peive, A.V. and Vinogradov, V.I., Eds., Moscow: Nauka, 1983.

Kersting, A.B. and Arculus, R.J., Constraints on the Contribution of Source Components to the Magma Genesis of the Kamchatka Arc: Multi-Isotope Approach, *IAVCEI Gen. Assembly Abstr.*, 1993.

Koloskov, A.V., Fedorov, P.I., Golovin, D.I., and Lyapunov, S.M., New Data on Late Cenozoic Volcanism on Cape Navarin, Koryak Plateau, *Dokl. Akad. Nauk SSSR*, 1992, vol. 323, no. 5, pp. 904 - 907.

Koloskov, A.V., Flerov, G.B., Ponomarev, G.P., and Bogoyavlenskii, S.O., A New Type of Mafic-Ultramafic Inclusions in Volcanic Rocks of Kamchatka, *Dokl. Akad. Nauk SSSR*, 1988, no. 3, pp. 676 - 679.

Mineev, S.D., Bogdanovskii, O.G., Veksler, I.V., and Karpenko, S.F., Problems of Isotope Systematics: Low-Degree Melting Effect, *Geokhimiya*, 1992, no. 12, pp. 1385 - 1394.

Pokrovskii, B.G. and Zhuravlev, D.Z., New Data on Isotope Geochemistry in the Lavas of the Kuril Island Arc, *Geokhimiya*, 1991, no. 3, pp. 415 - 419.

Tatsumi, Y., Hamilton, D.L., and Nesbit, R.W., Chemical Characteristics of Fluid Phase Released from a Subducted Lithosphere and Origin of Arc Magmas: Evidence from High-Pressure Experiments and Natural Rocks, *J. Volcanol. Geotherm. Res.*, 1986, vol. 29, nos. 1 - 4, pp. 293 - 309.

Taylor, H.P., The Oxygen Isotope Geochemistry of Igneous Rocks, *Contrib. Mineral. Petrol.*, 1968, vol. 19, no. 1, pp. 1 - 71.

Taylor, H.P., The Effect of Assimilation of Rocks by Magmas: $^{18}O/^{16}O$ and $^{87}Sr/^{86}Sr$ Systematics in Igneous Rocks, *Earth Planet. Sci. Lett.*, 1980, vol. 47, no. 2, pp. 243 - 254.

Vinogradov, V.I., Grigor'ev, V.S., and Pokrovskii, B.G., Oxygen and Strontium Isotope Compositions in the Rocks of the Kuril-Kamchatka Island Arc: A Key to Some Geochemical Interpretations, *Evolyutsiya Sistemy Kora-Mantiya* (Evolution of the Crust-Mantle System), Moscow: Nauka, 1986, pp. 78 - 103.

Volynets, O.N., Petrology and Geochemical Classification of Volcanic Rocks in a Recent Island-Arc System, *Dr. Sci. (Geol.) Dissertation*, Moscow: Mosk. Gos. Univ., 1993.

Volynets, O.N., Anoshin, G.N., Puzankov, Yu.M., and Parkhomenko, V.S., Geochemical Classification of the Late Cenozoic Basalts of Kamchatka (Based on Neutron Activation Analyses), *Dokl. Akad. Nauk SSSR*, 1987, vol. 293, no. 3, pp. 685 - 688.

Volynets, O.N., Popolitov, E.I., Patoka, M.G., and Anoshin, G.N., Two Series of High-Alkali Lavas in the Late Cenozoic Volcanic Zone of the Sredinnyi Range, Kamchatka, *Dokl. Akad. Nauk SSSR*, 1984, vol. 274, no. 5, pp. 1185 - 1188.

Volynets, O.N., Puzankov, Yu.M., and Anoshin, G.N., Geochemistry of the Neogene-Quaternary Volcanic Series of Kamchatka, *Geokhimicheskaya Tipizatsiya Magmaticheskikh i Metamorficheskikh Porod Kamchatki* (Geochemical Classification of the Igneous and Metamorphic Rocks of Kamchatka), Novosibirsk: Tr. IGiG SO RAN, 1990b, no. 390, pp. 73 - 114.

Volynets, O.N., Uspenskii, V.S., Anoshin, G.N., *et al.*, Late Cenozoic Within-Plate Basalts of Eastern Kamchatka, *Dokl. Akad. Nauk SSSR*, 1990a, vol. 313, no. 4, pp. 955 - 959.