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ALEXANDER M. BORSUK* — ANDREI A. TSVETKOV* — DMITRI Z. ZHURAVLEV** — IGOR V. CHERNYSHEV**

MAGMATIC EVOLUTION OF THE KOMMANDORSKIE ISLANDS IN THE ALEUTIAN ISLAND ARC

(Figs. 7, Tabs. 5)

Abstract: Three different magmatic associations manifesting the three successive stages of the Aleutian Island arc evolution are distinguished and studied on the Kommandorskie Islands in its westernmost segment. These are: 1) basalt-Na-rhyolite (P_3); 2) basalt-dolerite, subalkaline (N_1^{1-2}); 3) diorite-granodiorite (N^3_2). A detailed petro-geochemical and radiological data, including $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ isotopic ratios, are presented for all of them. Plio-Pleistocene volcanics of andesite association (N^3_2—Q_4) which are abundant within the east-central segment of the Aleutian arc are completely lacking in the Kommandorskie Islands. Problems of magma genesis in light of Nd, Sr isotopes and REE patterns are discussed. It is shown that all the Kommandorskie parental melts were of mantle origin and their sources remained isotopically homogeneous throughout the whole geological history of the Aleutian arc. Nd and Sr isotopic trends indicate the substantial crustal contamination of basaltic melts formed during the early evolutional stages of the Aleutian Island arc with practically negligible involvement of sediments covering the downthrusting oceanic slab. We believe that the differences in magmatic evolution of the western (the Kommandorskie Islands) and the east-central (the Aleutian Islands and Alaska Peninsula) segments of the Aleutian arc are determined by two factors: 1) lateral compositional heterogeneity and differences in thickness of the arc crust related to the transition from oceanic into continental type; 2) variations in depths of magmatic sources defined in turn, by relative rates of plate convergence, thickness and inclination of oceanic slab during subduction.

Резюме: В самой западной части Коммандорских островов выделяются и изучаются три разные магматические ассоциации, проявляющие три последовательные стадии эволюции алеутской островной дуги: 1) базальт-Na-риолитовая (P_3); 2) базальт-долеритовая, известково-щелочная (N_1^{1-2}); 3) диорит-гранодиоритовая (N_2^3). Для всех представлены детальные петро-геохимические и радиологические данные, включая изотопные отношения $^{143}Nd/^{144}Nd$ и $^{87}Sr/^{86}Sr$. Плио-плейстоценовые вулканиты андезитовой ассоциации (N_2^3 — Q_4), которые часто встречаются в пределах восточно-центральной части алеутской дуги, полностью отсутствуют на Коммандорских островах. Обсуждаются проблемы генезиса магмы в свете изотопов Nd, Sr и образцов редкоземельных элементов. Показано, что все коммандорские первичные расплавы были мантийного происхождения и их источники остались плутонически гомогенными через целую геологическую историю алеутской дуги. Изотопные тенденции Nd и Sr показывают существенную коровую контаминацию базальтовых расплавов образованных во время ранних эволюционных стадий алеутской островной дуги с практически незначительным включением осадков, покрывающих нисходя-

* Dr. A. M. Borsuk, Dr. A. A. Tsvetkov, Department of Petrology, Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Academy of ciences of the U.S.S.R., Staromonetny per. 35, 109 017 Moscow.

** Dr. D. Z. Zhuravlev, Dr. I. V. Chernyshev, Laboratory of Isotopic Geochronology, Institute of Geology of Ore Deopsits, Petrography, Mineralogy and Geochemistry, Academy of Sciences of the U.S.S.R., Staromonetny per. 35, 109 017 Moscow.

щую океаническую плиту. Мы думаем, что различия в магматической эволюции западной (Коммандорские острова) и восточно-центральной (Алеутские острова и Аляшский полуостров) частей алеутской дуги определяются двумя факторами: 1) латеральной композиционной неоднородностью и отличиями в мощности дуговой коры связанной с переходом океанического в континентальный тип; 2) вариациями в глубинах магматических источников определенных по очереди, относительными скоростями конвергенции плиты, мощностью и наклоном океанической плиты во время субдукции.

Introduction

A fundamental problem of creation and evolution of continental crust can undoubtedly by considered as one of the most important in the up-to-date petrology. One of the widely accepted and from our point of view sufficently well-argumented concept is that continental crust is formed at active continental margins or close to them and aftewards undergoes some complex transformations with the decisive role played by juvenile material in form of magmatic melts and fluxes. Each new stage of such crustal transformation is manifested by appearance of a compositionally specific magmatic associations (magmatic formations). Thus the latter could be used as tracers of successive tectono--magmatic stages in the evolution of the Earth lithosphere.

That is why the overgrowing interest of the world-wide Earth scientists community is attracted to geological and petrological investigations in island arcs as parts of perioceanic mobile belts including radiological dating and petro-geochemical comparative analysis of various magmatic associations composing them.

In this paper magmatic rocks of the Kommandorskie Islands in the westernmost flank of the Aleutian arc will be described in detail. For the first time in that region the authors distinguished and studied three spatially and temporally descrete magmatic associations, which have counterparts in other segments of the Aleutian arc. Patterns of magmatic evolution within ensimatic and ensialic parts of the Aleutian arc are then briefly discussed.

Geological and tectonical setting

The Aleutian island arc 3200 km long and 125—235 km wide (average 165 km) with 1200 km radius of curvature is one of the greatest island arcs of the Pacific. It has a clear-bended shape and stretches out from Alaska and Kenai Peninsulas in North America nearly to Kamchatka being separated from the latter by a deep (more than 3000 m) and wide (more than 200 km) channel (Fig. 1). To the south sweeps the Aleutian Trench with depths often exceeding 7000 m and to the north — the Bering Sea Basin with depths over 4000 m. The eastern part of the Aleutian islands comprising Umnak, Unalaska, Unimak and Bogoslov is set within the American continental shelf while its central part is bisected by submarine Bowers Ridge with depths less than 1000 m.

Kommandorskie Islands are in the westernmost flank of the Aleutian arc. There are four of them: Bering, Medny, Toporkov, Arii Kamen. The first two are the largest, correspondingly 85 and 54 km on longer axis. The islands are stretched according to the arc strike and are build mainly of Paleogene-Neogene

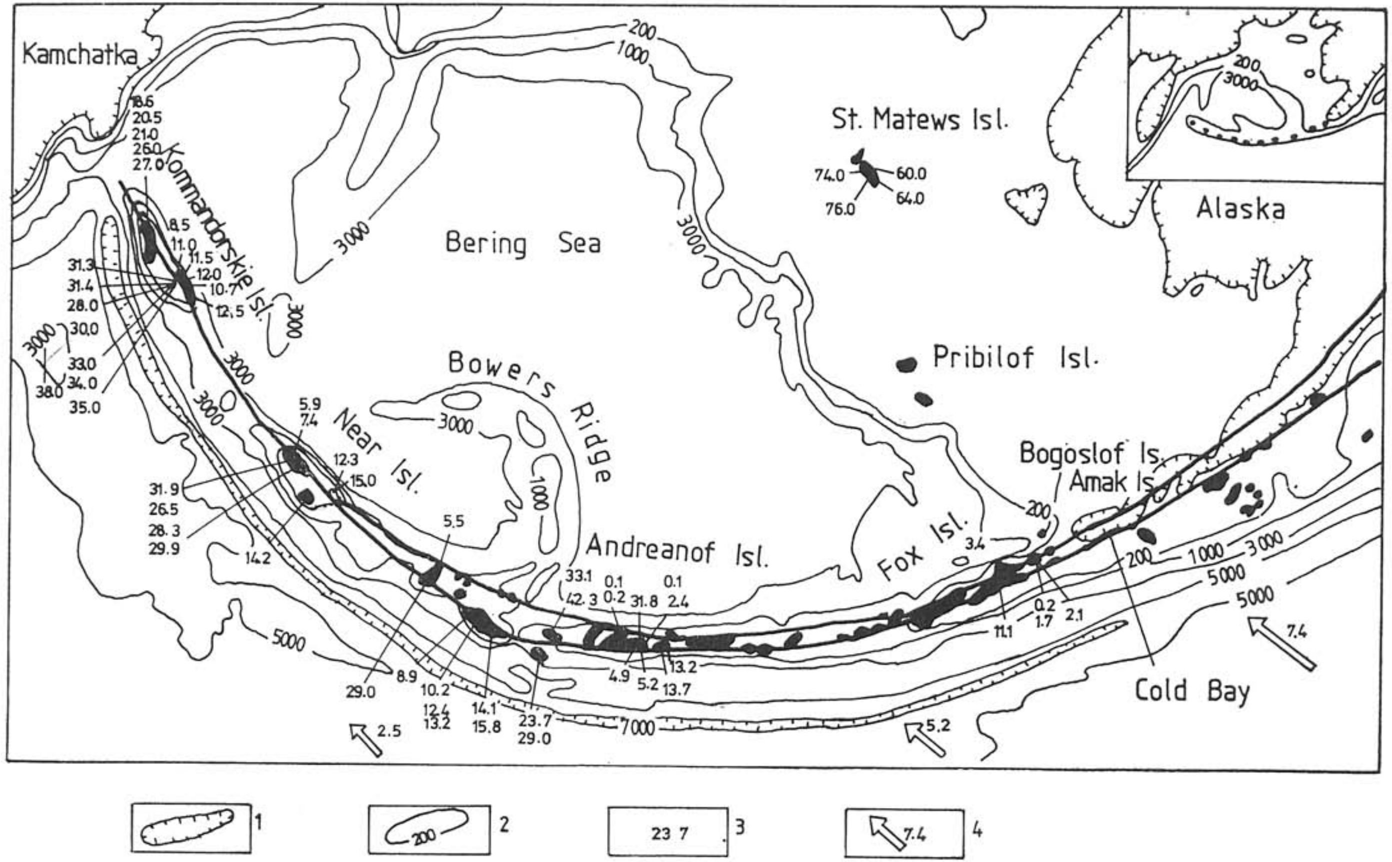


Fig. 1. Schematic map of the Aleutian Island arc. Information from Scholl et al. (1975); De Long et al. (1975, 1978); Schmidt (1978); Borsuk et al. (1982).

Explanations: 1 — Aleutian Trench; 2 — isorates (m), 3 — K/Ar ages (m. y.); 4 — directions and rates (cm/year) of Pacific plate motion (Kay et al., 1981). Miocene (upper line) and Quaternary (lower line) volcanic fronts are shown by solid lines.

volcanic-sedimentary rocks dissected by a series of transversal faults with a magnitude of displacement usually less then 100—200 m (Zhegalov, 1964; Schmidt, 1978).

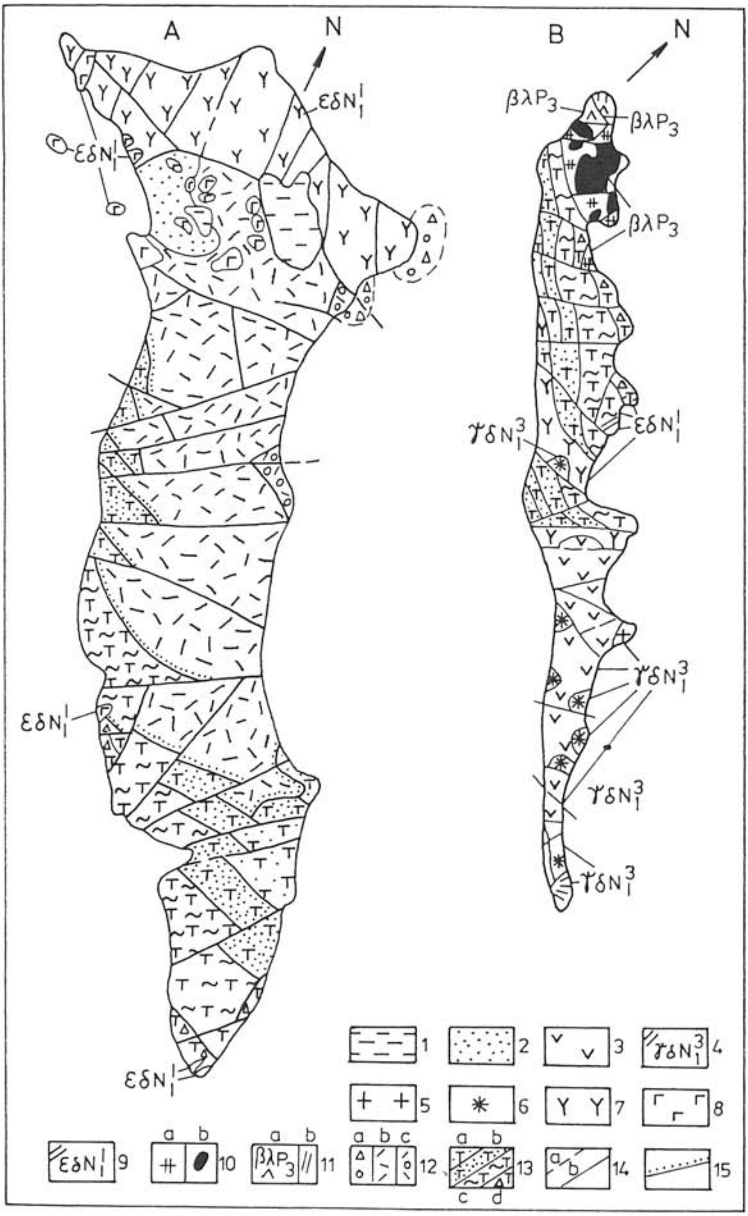
The geological structure of the Kommandorskie Islands and adjacent areas was described and discussed by Morozewich (1912, 1925); Puscharovski (1963); Zhegalov (1964); Egiazarov (1969); Kazakova (1976); Schmidt (1978); Sergeev et al., (1983). In these works most of the attention was drawn to stratigraphy and tectonics, while the papers summarizing petrological and geochemical data on igneous rocks have appeared only recently (Borsuk—Tsvetkov, 1980; Tsvetkov, 1982; Borsuk et al., 1982).

Total thickness of the crust beneath Kommandorskie Islands reaches 20—25 km (Schmidt, 1978). No "granitic-metamorphic layer" is distinguished there, though its existence at the eastern flank of the Aleutian arc in the vicinity of Kodiak Island and further eastward under Alaska Peninsula, is a well established fact (Scholl et al., 1975). Recent radiological dating of Kommandorskie Islands igneous rocks together with information provided by linear magnetic anomalies of the adjacent oceanic floor suggest that the formation of the Aleutian submarine ridge began in Late Cretaceous — Early Paleogene time, though it seems likely that the initial deep-seated fault which lately became a magmatic feeder channel was formed even earlier - in Lover Cretaceous time (Scholl et al., 1975). Current geophysical research has evidenced that the acoustic basement to the north and to the south of Kommandorskie Islands is oceanic crust, apparently, of Late Cretaceous age from the Bering Sea side and of Paleocene or somewhat older age from the Pacific side (Naugler—Rea, 1970).

It should be emphasized that the Aleutian ridge within its Kommandorskie segment was also formed on the oceanic crust, fragments of which represented by peridotitic, pyroxenitic, gabbroic, and jasperitic inclusions are sometimes found in the initial tholeiitic basalts of the Kommandorskie Islands (Tsvetkov—Schmidt, 1982). Rather well-preserved radiolarian microfauna in jasperitic rocks from Bering Islands was dated by Schmidt (1978) as Upper Cretaceous. Suprunenko (1976) having summarized DSDP Leg 19 results showed that the occurrence of shallow-sea sedimentary facies among Middle-Late Eocene deposits of Meiji guyot proves that the latter was not yet completely submerged at 38 m. y. b. p. It seems likely that the data 38 m. y. corresponds to the time boundary when Eastern Kamchatka and submarine Obruchev Rise still composed uniform morphostructure. Later a considerable subsidence of the oceanic floor took place, apparently, related to the formation of a deep-seated fault which in turn could be counted as an embryo of the Aleutian Trench.

Fig. 2. Map of Kommandorskie Islands magmatic associations. Compiled by Tsvetkov, included are data of Schmidt.

Explanations: A — Bering Island, B — Medny Island. 1 — recent lacustrine deposits; 2 — Quaternary diluvial-proluvial deposits; diorite-granodioritic volcano-plutonic association ($\lambda\delta N^3_1$); 3 — andesitic and andesite-dacitic lavas; 4 — dykes; 5 — granodioritic intrusions with aplitic veins; 6 — tonalitic and quartz-dioritic intrusions; basalt-dolerite subalkaline association ($\varepsilon\delta N_1^{1-2}$); 7 — subalkaline basalts, 8 — trachy-



basaltic and teschenitic sills; 9 — trachybasaltic and teschenitic dykes; basalt-Na--rhyolite association ($\beta\lambda P_3$); 10 — Na-rhyolitic and Na-rhyodacitic lavas and pyroclastics (a), hypabyssal intrusions (b); 11 — basaltic lavas and pyroclastics (a), dykes (b); sedimentary and volcano-sedimentary rocks; 12 — polyfacial deposits of Nickolskaya suite; 13 — Kommandorskaya series: A — Preobrazhenskaya suite, B — Gavanskaya suite, C — Gavrilovskaya suite, D — Poludennaya suite; 14 — faults: a — traced, b — assumed; 15 — unconform stratigraphic boundaries.

Table 1

K/Ar ages of Kommandorskie Islands magmatic rocks

Magmatic association	Island	Rock	K, %	Ar^{40} ng/g	Ar^{40} rad. / Ar^{40} tot.	Age, m. y.	Location
Diorite-Granitoid	Medny	Andesite				8.6 ± 0.3	Dyke, South Eastern Pt., 10/6—78*
	Medny	Dacite				10.7 ± 0.8	Lava flow, Glinka Cove, 9/1—78*
		Dacite	1.25 ± 0.3	1.1 ± 0.1		12.0 ± 2	Same, 9/2—78
	Medny	Biotite-hornblende tonalite	1.92 ± 0.04	1.15 ± 0.15	3; 5	8.5 ± 2.5	Stock, Kuropatkin Mt., 13/12—77
	Medny	Biotite-hornblende granodiorite	1.92 ± 0.03	1.5 ± 0.2	13; 21	1.0 ± 3	Stock, Cherny Pt., 11/6—77
	Medny	Aplite	4.32 ± 0.04	3.5 ± 0.3	27; 32	11.5 ± 2	Vein, Cherny Pt., 11/7—77
	Medny	Biotite-hornblende granodiorite	1.53 ± 0.03	1.4 ± 0.2	16; 19	12.5 ± 3	Stock, Cherny, Pt., 11/6—77, 8/1—78
		Biotite	6.74 ± 0.05	5,4 ± 0.3	11; 21	12 ± 2	
		Alkali Feldspar	5.27 ± 0.04	4.4 ± 0.3	14; 39	12 ± 2	
Basalt-Trachydoleritic	Bering	Trachydolerite	1.68 ± 0.03	1.8 ± 0.2	12; 15	16 ± 3	Lava dome, Nicovalnya Mt., 404—77
	Medny	Subalkaline basalt				18.6 ± 0.6	Dyke, Sulkovski Pt., 3/19—78*
	Bering	Teschenite	1.54 ± 0.03	2.3 ± 0.2	21; 26	21 ± 3	Sill, Nikolskoye, 406—77
	Bering	Trachybasalt	1.51 ± 0.03	2.6 ± 0.3	19; 29	25 ± 4	Lava flow, North-Western Pt., 414—77
	Bering	Trachydolerite	2.27 ± 0.03	3.3 ± 0.3	20; 30	21 ± 3	Sill, Gaunts Pt., 415—77
	Bering	Trachydolerite	1.51 ± 0.03	2.2 ± 0.2	26; 26	20.5 ± 3	Sill, Svinye Mt., 13/6g—77
	Bering	Teschenite				27 ± 0.8	Dyke, Monati Pt., 17/3—78

1st continuation of Tab. 1

Basalt-Plagiorhyolitic	Medny	Plagiorhyolite	1.68 ± 0.03	3.5 ± 0.3	21; 28	30 ± 4	Lava flow, Kotenok Pt., 7/2—77
	Medny	Plagiorhyolite	1.50 ± 0.03	3.0 ± 0.3	18; 25	28 ± 4	Stock, Rhyolitic Ridge, 5/2—77
	Medny	Plagiorhyolite				31.3 ± 0.9	Lava flow, Preobrazhenskaya cove, 2/10—78*
	Medny	Plagiorhyolite				31.4 ± 1.6	Same, 2/11—78*
	Medny	Plagiorhyolite	1.67 ± 0.03	4.0 ± 0.4	25; 28	34 ± 4	Stock, Rhyolitic Ridge, 4/2—77
	Medny	Plagiorhyolite	2.14 ± 0.04	4.9 ± 0.4	47; 53	33 ± 4	Same, 4/1—77
	Medny	Basalt	1.35 ± 0.03	2.9 ± 0.2	32; 33	31 ± 3	Dyke, Sulkovski Pt., 3/14—78

Nearly similar radiological values — 38—40 m. y. are believed to represent the time of generation of the Kurile Trench (S u p r u n e n k o, 1978).

In a whole the results of geological and petro-geochemical investigations of Kommandorskie Islands magmatic rocks including their radiological dating (Tab. 1), led us to the definition of three spatially and temporally discrete magmatic associations: 1) basalt-Na-rhyolite (P_3); 2) basalt-dolerite subalkaline (N_1^{1-2}); 3) diorite-granodiorite (N_1^3—N_2^1). Their spatial distribution is shown on a map of magmatic formations (Fig. 2). Chemical analyses of rocks and rock-forming minerals are presented in Tables 2—5.

Basalt-Na-rhyolite association

Time limit when the Aleutian Trench and the adjacent ridge were formed is specified by basalt-Na-rhyolite association. It is of a bimodal type and comprise basalts, Na-rhyolites and Na-rhyodacites. Spatial distribution and volumes of basic and acid members significantly varies. Dredging at the slopes of the Kommandorskie Islands showed wide occurrence of basalts contrary to the subaerial parts of the islands were Na-rhyolites distinctly predominate.

Basalts make up lava flows, layers of tuffs and tuff-breccia cut by numerous basaltic dykes and a few stocks (up to 1000 m^2) of medium-grained gabbronorites and gabbro. Occurring in basalts are inclusions of ultrabasic rocks: spinel peridotites and pyroxenites (T s v e t k o v—S c h m i d t, 1982).

Basalts are usually porphyric in texture. Phenocrysts (30—40 vol. %) are: plagioclase (An_{60-65}), augite ($Ca_{38-40}Mg_{45-49}Fe_{12-14}$, $f^* = 20$—24) and bronzite (see Tab. 2). During alteration feldspar is often replaced by carbonates,

Table 2

Clinopyroxenes from Kommandorskie Islands magmatic rocks

	Basalt-plagiorhyolitic association						
	Basalts					Plagiorhyolites	
	1	2	3	4	5	6	7
SiO_2	52.61	52.98	53.56	53.06	53.19	52.05	52.23
TiO_2	0.27	0.33	0.21	0.25	0.25	0.11	0.10
Al_2O_3	3.50	4.02	3.12	2.63	3.23	1.47	1.53
FeO	7.79	7.50	7.02	8.90	8.18	5.00	5.78
MnO	0.19	0.16	0.19	0.27	0.22	0.15	0.12
MgO	17.05	15.78	15.27	16.36	15.25	18.21	18.10
CaO	17.97	18.41	18.27	18.54	18.55	22.29	21.39
Na_2O	0.33	0.33	0.35	0.21	0.23	0.25	0.24
Total	99.83	99.68	98.09	100.26	99.25	99.53	99.49
Si	1.93	1.95	1.99	1.95	1.96	1.95	1.91
Al (IY)	0.07	0.05	0.01	0.05	0.04	0.05	0.09
Al (VI)	0.09	0.12	0.13	0.06	0.10	0.01	—
Ti	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe	0.24	0.23	0.22	0.28	0.27	0.15	0.18
Mn	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mg	0.92	0.88	0.87	0.90	0.84	0.95	0.96
Ca	0.71	0.73	0.73	0.73	0.75	0.85	0.84
Na	0.02	0.02	0.03	0.01	0.02	0.04	0.02
$CaSiO_3$	37.9	39.7	40.1	38.2	40.3	43.5	42.4
$MgSiO_3$	49.2	47.8	47.8	47.1	45.2	49.0	48.5
$FeSiO_3$	12.8	12.5	12.1	14.6	14.5	7.5	9.1
f	20.7	20.7	20.2	23.7	24.3	13.6	15.8

chlorite, epidote and zeolites. Groundmass is usually completely chloritized and includes, besides microliths of plagioclase and clinopyroxene numerous needles of green hornblende. Magnetite, ilmenite and apatite are common accessories. Cavities in amygdaloidal basalts and in volcanoclastic rocks are filled with calcite, quartz, zeolites and chlorite with sometimes found dendrites of native copper. Basaltic dykes and small intrusive bodies also contain magnesian hornblende indicative of a hydrous conditions in primary silicate melt.

Major-element analyses along with distribution patterns of Co, Ni, Cr, V, Sr and Zr show close correspondence of Medny Island initial basic rocks with initial tholeiitic basalts of modern island arcs, such as Tonga-Kermadek, or Marianas (Meijer, 1982; Ewart—Bryan, 1973; Gill, 1970), though epimagmatic processes caused a considerable variability in concentrations of Fe^{2+}, Fe^{3+}, Mg, Ca and Na. With respect to basaltic and gabbroic rocks of the

* Fe index, $f = \frac{Fe^{2+} \cdot 100}{Fe^{2+} + Mg^{2+}}$ at. %

1st continuation of Tab. 2

Basalt-trachydoleritic association								
Subalkaline basalts						Subalkaline gabbro		
8	9	10	11	12	13	14	15	16
53.56	53.74	53.87	52.29	50.99	51.26	52.52	52.03	52.44
0.24	0.21	0.19	0.31	0.55	0.38	0.31	0.39	0.25
2.36	1.99	2.18	3.93	3.55	2.77	2.72	3.55	2.28
5.90	5.61	5.32	7.30	11.55	10.80	8.39	6.40	8.40
0.20	0.18	0.20	0.22	0.31	0.32	0.19	0.22	0.22
16.70	16.66	16.87	16.16	15.15	16.56	16.37	15.63	15.88
21.35	21.29	21.70	19.96	17.95	17.42	18.80	18.72	18.27
0.24	0.25	0.26	0.36	0.53	0.50	0.14	0.05	0.23
100.55	99.93	100.59	100.50	100.58	100.01	99.52	99.11	98.03
1.95	1.97	1.96	1.91	1.88	1.89	1.94	1.93	1.97
0.06	0.03	0.04	0.09	0.12	0.11	0.06	0.07	0.03
0.05	0.06	0.05	0.08	0.03	0.01	0.06	0.09	0.07
0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
0.18	0.17	0.16	0.22	0.36	0.33	0.26	0.26	0.26
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.90	0.89	0.89	0.88	0.83	0.91	0.90	0.88	0.89
0.83	0.84	0.86	0.78	0.71	0.69	0.75	0.75	0.75
0.02	0.02	0.02	0.02	0.04	0.04	0.01	0.01	0.02
43.5	44.2	45.0	41.5	37.4	35.8	37.9	39.6	39.5
47.1	46.8	46.6	46.8	43.7	47.2	44.1	46.6	46.8
9.4	8.9	8.4	11.7	18.9	17.0	13.9	13.8	13.7
16.7	16.0	15.2	20.0	30.3	26.6	22.4	22.8	22.6

subsequent magmatic stages the basic members of the basalt-Na-rhyolite association have minimal ammounts of REE ($\sum$ REE = 14.35—28.53 ppm), are enriched in HREE, and just as in other LIL elements, closely resemble initial tholeiites of Jakes—Gill (1970). Most distinctly this tendency reveals for the Kommandorskie 3/14—78 basalt (Fig. 3) the REE pattern of which practically coincides with that of Eua, Tonga (Ewart et al., 1977; Kay, 1978). At the same time Kommandorskie basalts differ from MORB (e. g. East Pacific Rise) by lower $\sum$ REE typical of the island arc tholeiitic series.

Acid members of the association are represented by Na-rhyolites and Na-rhyodacites. They occur as numerous thick (50—70 m) and relatively short (1—3 km) lava flows, layers of lava-breccias, tuffs, tuff-breccias, tuff-conglomerates, also make some large hypabyssal stocks, microlaccoliths, domes, sills and dykes cutting the volcanics.

Na-rhyolites and Na-rhyodacites contain phenocrysts of partly albitized plagioclase (An_{44-48}) — 15—25 %, resorbed quartz — 10—15 % and sparse clinopyroxene — 1—2 %. The latter compositionally varies from augite ($Ca_{43}Mg_{49}Fe_{8}$, f = 13.1) to ferro-augite ($Ca_{51}Mg_{28}Fe_{21}$, f = 43.6). Sometimes plagio-

2nd continuation of Tab. 2

Trachybasalts, trachydolerites, teschenites								
17	18	19	20	21	22	23	24	25
52.64	51.26	51.38	51.98	52.08	48.62	49.31	53.28	53.59
0.37	1.14	1.19	1.15	1.01	2.01	1.79	0.35	0.54
2.40	3.97	3.66	3.45	3.60	5.28	5.17	1.70	2.33
10.00	6.86	6.70	6.96	6.60	9.31	9.09	8.55	8.63
0.32	0.16	0.15	0.15	0.15	0.22	0.21	0.52	0.52
15.14	15.08	15.77	15.02	15.05	13.02	13.13	14.36	14.43
17.95	32.14	21.10	21.95	21.72	20.14	20.69	19.13	19.14
0.17	0.25	0.54	0.21	0.55	0.68	0.57	0.33	0.33
99.02	100.86	100.49	100.87	100.76	99.45	100.11	98.22	99.51
1.97	1.88	1.88	1.91	1.91	1.82	1.84	2.00	2.00
0.03	0.12	0.12	0.09	0.09	0.18	0.16	—	—
0.07	0.05	0.04	0.06	0.06	0.06	0.07	0.08	0.10
0.01	0.03	0.03	0.03	0.03	0.06	0.05	0.08	0.03
0.31	0.21	0.20	0.21	0.20	0.29	0.28	0.27	0.28
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.86	0.82	0.86	0.83	0.82	0.73	0.73	0.81	0.80
0.74	0.87	0.83	0.86	0.85	0.81	0.83	0.74	0.77
0.01	0.01	0.04	0.01	0.04	0.05	0.04	0.02	0.02
38.4	43.7	43.9	45.3	45.5	44.3	45.1	40.7	41.6
44.9	43.1	45.5	43.7	43.9	39.9	39.7	44.5	43.2
16.7	11.0	10.5	11.0	10.7	15.8	15.2	14.8	15.1
21.7	20.4	18.9	20.2	19.6	28.4	27.7	25.0	26.7

clase grains are surrounded by rims of K-Na feldspar ($Or_{35-48}Ab_{42-59}An_{5-8}$). Felsitic, sometimes vitrophyric, groundmass (60—70 %) contains small impregnations of magnetite, pyroxene, biotite, apatite, sphene and zircon. Biotite is low in Ti (TiO_2 = 0.16—0.24 %) and has a high Fe-content (f = 56—61).

The Kommandorskie Na-rhyolites differ from calc-alkaline rhyolites of Nockolds (1954) in lower ammounts of K_2O and higher Na_2O. At the same time, as compared with ophiolite plagiogranites (e. g. Troodos) they are enriched with alkalies, especially with K_2O. REE abundances in Na-rhyolites are significantly higher than in basalts spatially associated with them and approach REE contents in Troodos plagiogranites (av. 52.5 % ppm), though the latter are more HREE enriched (Troodos: av. $\sum REE_{Ce}/\sum REE_{Y} = 1.4$; Kommandorskie Islands: average $\sum REE_{Ce}/\sum REE_{Y} = 4.34$). At the same time the Kommandorskie Na-rhyolites have lower $\sum$ REE than most of the continental granites and granodiorites in which $\sum$ REE usually varies within the range 200—2500 ppm (Emmermann et al., 1975). It is interesting to note that with respect to REE, major and minor element abundances, the Kommandorskie Na-rhyolites closely resemble the first acid members of island arc tholeiitic series (Tonga, Marianas, 3rd continuation of Tab. 2

Diorite-granitoid association	
Andesites	
26	27
53.23	52.39
0.29	0.37
1.41	1.54
8.77	9.00
0.46	0.60
14.49	14.79
19.15	19.16
0.27	0.35
98.52	98.43
2.00	1.98
—	0.02
0.08	0.06
0.01	0.01
0.28	0.29
0.01	0.01
0.84	0.83
0.78	0.78
0.02	0.03
41.0	41.0
44.2	43.7
14.7	15.3
25.0	25.9

Explanations: 1–13 – Northern part of Medny Is.: 1–3 basaltic tuff, 3/4—78; 4–5 – basaltic lava, 3/15—78; 6—7 — plagiorhyolitic lava, 7/2—77; 8—13 — basaltic and subalkaline basaltic dykes, 3/2—78, 3/3—78; 14—17 — subalkaline gabbro, stock, Zhirovaya Cove, Medny Is., 1/1—78; 18—21 — trachybasaltic lava, trachydoleritic sill and dykes, northern part of Bering Is., 405, 406, 415;22—23 — teschenitic sill, 19/3—78, Nickolskoye, Bering Is.: 24—27 – andesitic lava, 10/15—78, southern part of Medny Is. *Additionally determined:* Cr_2O_3: in column 1 — 0.12 %, in col. 2 — 0.15 %, in col. 3 — 0.09 %, in col. 22 — 0.15 %, in col. 23 — 0.15 %.

Fiji, etc.) as well as the first acid volcanics formed within intracontinental orogenic belts (the Caucasus, the Urals, etc.).

The earliest magmatic events in the central part of the Aleutian arc corresponding to the basalt-Na-plagiorhyolite association in time, composition and geological setting are known for many islands: Attu and Agattu ("basement" formation), Amchitka (Krugloi Point, Amchitka, Banjo Point formations), Adak and Ilak (Andrew Lake, Finger Bay formations), Rat (Rat, Ganners Cove formations). On many places they produced basaltic pillow lavas and tuffs, which just as Kommandorskie basalts, have undergone greenstone metamorphism. However, the rock-forming pyroxenes in these rocks, relative to

Table 3

Hornblends, biotites and olivines from Kommandorskie Islands magmatic rocks

	Basalt-plagiorhyolitic association				Basalt-trachydolerite association			
	Biotite				Olivine		Hornblende	
	1		2		3	4	5	
SiO_2	55.21		58.73		40.35	39.46	48.95	
TiO_2	0.24		0.16		—	—	1.88	
Al_2O_3	9.94		10.25		0.15	0.05	4.15	
FeO	17.07		15.45		11.58	12.64	10.04	
MnO	—		—		0.28	0.16	0.22	
MgO	7.49		5.59		47.00	46.80	12.48	
CaO	0.30		0.27		0.19	0.14	19.19	
Na_2O	0.21		0.08		—	—	0.39	
K_2O	8.40		8.18		—	—	—	
Total	98.86		98.71		99.55	99.75	97.30	
	Cations per 12 0				Cations per 4 0		Cations per 24 0	
Si	4.18	4.18	4.45	4.45	1.00	1.00	7.72	8.00
Al (IV)	—		—		—	—	0.28	
Al (VI)	8.89		0.92		—	0.01	0.49	
Ti	0.01		0.01		—	—	0.23	
Mg	0.84	2.82	0.63	2.54	1.76	1.74	2.93	5.00
Fe	1.08		0.98		0.24	0.24	1.32	
Mn	—		—		—	0.01	0.03	
Ca	0.02		0.02		—	—	3.23	
Na	0.03	0.86	0.02	0.83	—	—	0.12	3.35
K	0.81		0.79		—	—	—	

the Kommandorskie, are significantly Fe-enriched and contain more Al_2O_3, TiO_2 and CaO ($Ca_{43-46}Mg_{36-40}Fe_{17-19}$, f = 29—34) (De Long et al., 1975). Geochemical differences of Kommandorskie and central Aleutian basic rocks are also defined by means of REE patterns which being practically similar in relation to chondrites differ in total REE abundances (Kay et al., 1982).

It should be also noted that related to basic volcanics at central Aleutians are also known intermediate and acid magmatic bodies. The example are Hidden Bay and Finger Bay layered gabbro-granodioritic plutons dated within 30—35 m. y. interval (Citron et al., 1980; Kay et al., 1983). All these features show the continually differentiated character of the basalt-Na-rhyolite association in the central part of the Aleutian arc.

Within eastern segment of the arc basalt-Na-rhyolite association counterparts with Unalaska formation (Drewes et al., 1961). It consists of fine-grained

1st continuation of Tab. 3

		Diorite-granitoid association				
Hornblende		Hornblende	Biotite			
6	7	8	9	10	11	12
49.12	51.39	55.93	42.66	41.18	38.47	38.87
1.24	0.92	0.89	2.91	3.53	4.34	4.76
8.04	7.41	4.54	13.00	13.73	18.99	13.59
11.75	11.93	10.89	12.19	12.45	15.23	16.41
—	—	0.61	—	—	0.31	0.28
16.23	15.74	17.46	16.11	16.89	15.75	15.63
10.91	11.36	11.53	—	—	0.14	0.09
1.88	1.70	0.94	0.80	1.16	0.11	0.12
0.32	0.29	0.32	8.18	8.54	9.73	9.70
99.38	100.75	100.11	95.85	97.53	98.09	99.45
Cations per 24 0			Cations per 12 0		Cations per 12 0	
6.86 } 8.00	7.09 } 8.00	7.28 } 8.00	3.17 } 4.00	3.03 } 4.00	2.85 } 4.00	2.85 } 4.00
1.14	0.91	0.72	0.88	0.97	1.75	1.15
0.17	0.30	0.01	0.30	0.22	0.07	0.02
0.13	0.09	0.09	0.16	0.16	0.24	0.26
3.33 } 5.00	3.23 } 5.00	3.58 } 5.34	1.78 } 3.00	1.86 } 3.00	1.72 } 3.00	1.70 } 3.00
1.37	1.38	1.25	0.76	0.76	0.95	1.00
—	—	0.07	—	—	0.02	0.02
1.63	1.67	1.70	—	—	0.01	0.01
0.52 } 2.20	0.45 } 2.17	0.25 } 2.00	0.12 } 0.90	0.17 } 0.94	0.02 } 0.95	0.02 } 0.94
0.05	0.05	0.05	0.78	0.79	0.92	0.91

Explanations: 1—2 — plagiorhyolites, 7/7—77; 3—4 — trachydolerites, 409/77; 5 — teschenites, 19/3—78; 6; 7; 9—10 — tonalites, 12/17—77; 8—11 — granodiorites, 11/6—77; 12 — aplites, 11/7—77.

intermediate or acid pyroclastics alternating with dacitic, andesitic and basaltic lavas cut by numerous compositionally similar sills, dykes and small stock-type bodies. Generally, the basalts of the eastern Aleutians differ dramatically in major (Mg, Fe, Na, K) and trace-element (Co, Ni, Cr, Sr, Zr) concentrations from tholeiitic basalts of intraoceanic islands arcs, e. g. Eua, Tonga (Ewart—Bryan, 1973) as well as from the Kommandorskie initial basalts.

Nearly synchronous to the Kommandorskie — Aleutian basalt-Na-rhyolite association numerous plutonic bodies of gabbro-quartz diorite-granite association were formed on Kodiak Island and Alaska Peninsula. Compositionally they vary from gabbros, quartz diorites and granodiorites, to monzonites, granites and adamellites while their age scatters within 38—26 m. y. time range (Reed—Lanphere, 1969).

Table 4

Whole rock chemical analyses of Kommandorskie Islands magmatic rocks

	Basalt-plagiorhyolitic association												
	Basalts				Plagiorhyolites							Subalakline basalts	
	1	2	3	4	5	6	7	8	9	10	11	12	13
	3/7-78	Sh-1	3/14-78	5/1-78	7/2-77	5/4-77	5/5-77	6/22-77	6/4-78	2/10-78	2/11-78	14/3-77	7/2-78
SiO_2	45.28	45.73	47.47	49.55	67.95	68.13	68.67	72.02	75.16	75.61	78.06	44.70	49.78
TiO_2	0.56	1.02	0.82	1.06	0.05	0.38	0.45	0.47	0.22	0.40	0.34	0.62	1.23
Al_2O_3	17.54	19.29	18.35	14.96	13.70	12.13	12.21	12.33	13.71	12.11	11.41	16.25	16.72
Fe_2O_3	3.02	4.59	6.11	7.10	1.92	1.81	2.53	1.23	0.78	1.74	2.10	9.10	4.03
FeO	6.84	3.76	1.73	5.96	2.43	1.06	2.86	2.74	0.17	0.65	0.47	3.95	3.08
MnO	0.09	0.28	0.15	0.22	0.11	0.07	0.08	0.035	0.08	0.07	0.05	0.17	0.12
MgO	12.25	6.75	6.38	5.60	1.84	0.88	2.59	1.91	0.28	0.37	0.44	5.38	7.04
CaO	5.01	9.67	8.94	8.40	4.19	3.08	1.95	1.02	0.22	1.03	0.90	11.39	8.82
Na_2O	2.46	3.33	3.13	2.88	4.31	3.57	4.24	3.93	5.83	5.10	5.17	2.69	3.70
K_2O	0.45	0.43	1.17	0.55	2.07	1.23	1.97	1.24	2.11	0.96	0.29	0.75	0.88
H_2O^-	1.84	1.81	3.10	3.02	0.14	3.64	0.68	0.04	0.15	0.26	0.31	0.82	2.40
H_2O^+	5.09	2.45	1.89	0.94	0.94	4.09	1.29	3.27	0.24	0.49	0.59	1.32	1.57
P_2O_5	0.01	0.09	0.18	0.10	0.10	0.04	0.10	0.12	0.05	0.08	0.06	0.27	0.32
CO_2	0.08	0.36	0.61	0.06	—	—	0.20	0.11	0.10	0.16	0.09	—	0.32
Total	100.75	99.56	100.20	100.53	99.75	100.18	99.89	100.52	99.10	99.03	100.28	—	100.17

1st continuation of Tab. 4

	Basalt-trachydoleritic association										
	Subalk. gabbro	Trachybasalts, trachydolerites			Teschenites						
	14	15	16	17	18	19	20	21	22	23	24
	13/1-78	19/10-78	415/77	13/6g-77	19/1-78	1/1-78	B-1	17/3-78	19/18-78	20/1-78	9/7-78
SiO_2	50.10	44.23	49.15	50.30	49.20	50.16	52.50	53.60	53.77	53.91	54.70
TiO_2	0.69	1.00	1.67	1.46	1.74	0.71	2.95	1.15	1.23	2.17	0.92
Al_2O_3	16.43	19.00	15.65	16.04	16.55	18.50	14.77	16.77	13.67	16.96	15.57
Fe_2O_3	5.08	7.52	4.65	4.94	4.90	3.97	4.68	4.57	6.15	4.17	4.91
FeO	4.46	1.51	3.12	2.69	2.73	5.05	3.57	2.09	2.56	1.42	1.97
MnO	0.14	0.14	0.17	0.12	0.11	0.14	—	0.07	0.09	0.07	0.12
MgO	6.49	4.83	4.89	6.86	5.39	5.37	5.37	6.30	6.57	4.13	5.85
CaO	8.21	8.95	6.77	8.81	8.15	8.86	8.06	6.69	7.83	5.24	4.84
Na_2O	3.79	3.32	4.67	3.45	4.14	3.11	4.46	3.77	4.48	5.40	5.11
K_2O	0.48	1.28	2.66	1.83	1.92	2.45	2.86	1.37	3.56	2.06	3.28
H_2O^-	2.59	2.09	1.35	0.58	0.65	0.61		1.35	0.92	1.06	0.25
H_2O^+	1.59	4.82	2.96	1.52	3.03	1.79	0.93	1.55	0.79	2.35	0.93
P_2O_5	0.10	0.09	0.81	0.64	0.62	0.10	0.68	0.59	0.70	1.18	—
CO_2	0.21	0.66	1.02	0.49	0.38	0.20		0.23	0.49	—	0.33
Total	100.39	99.54	99.54	100.90	100.38	—	100.83	100.20	—	99.84	99.78

2nd continuation of Tab. 4

	Diorite-granitoid association											
	Quartz diorites tonalites		Granodiorites		Aplite	Andesite-basalts		Andesites				Dacite
	25	26	27	28	29	30	31	32	33	34	35	36
	12/17-77	13/12-77	8/2-78	11/6-77	11/7-77	10/3-78	10/14-78	11/4-78	10/15-78	10/6-78	9/3-78	9/1-78
SiO_2	62.60	63.90	63.78	64.83	76.59	53.52	55.02	58.64	58.76	61.44	61.84	67.57
TiO_2	0.42	0.46	0.45	0.50	0.08	0.35	0.71	0.58	0.74	0.50	0.53	0.46
Al_2O_3	17.05	17.04	17.29	15.84	12.07	17.95	17.99	17.10	15.47	16.53	17.09	15.62
Fe_2O_3	2.21	1.47	3.88	1.66	0.37	2.36	8.42	5.40	4.58	4.19	3.17	2.90
FeO	2.05	2.10	1.61	2.44	0.57	4.92	3.89	1.08	2.38	1.52	1.50	0.13
MnO	0.049	0.10	0.05	0.10	0.02	0.17	0.21	0.09	0.10	0.07	0.04	0.03
MgO	2.99	2.42	2.26	2.54	0.09	4.30	3.85	3.38	2.47	2.76	2.64	0.12
CaO	5.42	4.73	4.95	4.47	0.82	8.51	8.67	7.50	5.60	4.83	5.35	4.37
Na_2O	4.03	4.60	4.66	4.19	4.07	2.99	3.70	3.37	4.22	4.19	4.28	3.94
K_2O	1.78	2.02	1.90	2.26	5.12	1.38	0.98	0.28	1.32	2.14	2.05	1.76
H_2O^-	0.32	0.02	0.09			0.12	0.65	1.74	0.76	0.74	1.34	0.84
H_2O^+	1.13	0.88	0.39	0.46	0.23	1.35	0.47	0.91	3.33	1.78	0.31	0.55
CO_2	—		0.08	0.76	—	—	0.12	0.04	—	0.19	0.09	0.23
P_2O_5	0.19	0.11	0.13	0.12		0.17	0.20	0.09	0.17	0.12	0.21	0.14
Total	100.40	99.98	101.52	100.26	100.38	99.50	104.77	100.24	99.98	100.00	100.44	99.66

Additionally determined: in column 1 — 0.03 F_2, 19.9 Li, 8.2 Rb, 3.9 Cs, 70.7 Ni, 39.3 Co, 205.2 Cr, 302.5 V, 152.1 Sr, 22.5 Ba; in col. 5 — 0.02 F_2; in col. 8 — 7.9 Li, 36.5 Rb, 1.8 Cs, 23.6 Ni, 393 Co, 102.5 Cr, 128.8 V, 211.3 Sr, 411.8 Ba; in col. 14 — 0.03 F_2; in col. 18 — 0.01 % F_2; in col. 20 — 0.10 % F_2; in col. 24 — 0.01 F_2.

REE and trace elements in Kommandorskie Islands magmatic rocks

	Basalt-plagiorhyolitic association						Basalt-trachydoleritic association		
	Basalts			Plagiorhyolites			Subalk. gabbro	Subalkaline basalts	
	1	2	3	4	5	6	7	8	9
	3/14-78	Sh-3	5/1-78	2/10-78	2/11-78	6/4-78	1/1-78	3/2-78	5/3-78
La	1.37	0.38	2.75	8.72	9.80	17.80	2.16	6.26	5.43
Ce	3.93	1.27	7.51	22.60	23.00	37.40	5.35	13.70	12.10
Nd	3.06	1.29	7.14	15.20	15.70	25.30	4.50	10.40	10.50
Sm	1.14	0.48	2.59	4.04	4.18	5.33	1.50	2.80	2.60
Eu	0.54		0.93	1.03	1.05	0.823	0.585	0.802	0.866
Gd	—	0.80	—	3.99	4.77	4.76	2.00	—	2.79
Tb	0.275		0.592	0.704	0.701	0.83	0.306	0.425	0.42
Dy	2.47	1.00	3.87	3.97	4.10	5.04	1.73	2.83	2.80
Yb	1.34	0.92	2.72	2.62	2.89	4.13	1.23	1.95	1.61
Lu	0.227		0.426	0.398	0.444	0.678	0.205	0.321	0.267
Σ REE	14.35	6.24*	28.53	66.3	66.6	102.09	19.57	39.49	39.38
$\Sigma\ REE_{Ce}/\Sigma\ REE_{Y}$	1.96		2.34	3.97	3.77	5.28	2.23	5.48	3.50
La/Ce	0.34	0.28	0.37	0.39	0.43	0.48	0.40	0.46	0.45
La/Yb	1.02	0.41	1.01	2.33	3.39	4.31	1.76	3.21	3.37
Co	39.0		39.70	2.92	2.68	0.382	27.1	34.10	38.80
Ni	50.0		18.07	7.85	7.85	7.86	21.22	31.43	41.64
Cr	28.15		29.10	2.20	1.91	1.66	28.60	56.70	56.90
Sr	229.6		230.0	105.0	100.0	100.0	259.0	306.0	408.0
Cs	0.95		1.20	0.18	0.15	0.05	0.779	0.135	0.22
Sc	42.80		50.70	10.40	9.91	6.43	36.90	38.80	40.10
Sb	0.10		0.20	0.235	0.16	0.146	0.082	0.14	
Zr	56.35		69.00	114.00	118.00	141.00	49.00	81.10	38.00
Ta	0.07		0.15	0.121	0.11	0.230	0.03	0.06	0.48
Tn	0.20		0.26	0.17	1.07	2.12	0.427	1.12	0.886
U	0.183		0.193	4.50	1.95	1.60	0.515	0.893	1.41
Hf	1.27		1.43	3.43	3.44	4.81	0.772	1.88	1.44
Ba	134.30		100.00	215.00	100.00	428.0	984.0	110.0	100.0
Rb	6.00		10.00	10.00	10.00	10.00	33.40	14.00	10.00
K	0.49		0.5	0.663	0.50	1.98	1.91	0.66	
K/Rb	833		500	663	500	1880	572	471	
Rb/Sr	0.03		0.04	0.09	0.1	0.10	0.13	0.05	0.02
La/Ta	19.57		18.33	72.07	89.09	77.99	72.00	104.33	11.31
Hf/Th	6.35		5.50	2.93	3.21	2.27	1.81	1.67	1.63

1st continuation of Tab. 5

Basalt-trachydoleritic association		Diorite-granitoid association					Andesitic association	
Teschenites		Tonalites		Granodiorite	Dacite	Andesite-basalt	Andesite-basalt	Andesite
10	11	12	13	14	15	16	17	18
3/19-78	17/3-78	10/6-78	Sh-1	8/2-78	9/1-78	10/14-78	AB-21	AB-23
13.70	42.50	8.91	8.91	8.02	9.85	10.50	12.30	10.70
33.40	103.00	19.10	20.74	16.80	22.50	22.50	29.30	26.30
19.20	60.60	10.00	10.44	8.91	12.00	16.60	19.70	16.70
3.69	11.00	2.10	2.23	2.00	2.68	0.403	5.31	4.13
1.15	2.95	0.702		0.656	0.768	1.23	1.51	1.01
2.73	7.31	1.68		1.80	1.92	4.03	6.03	4.50
0.336	0.854	0.273		0.271	0.334	0.598		
1.94	3.34	1.50	1.67	1.41	2.07	3.49	6.09	4.35
0.859	0.969	0.919		0.883	0.983	2.13	3.44	2.38
0.130	0.141	0.157		0.137	0.172	0.337		
77.14	232.66	45.34	43.99*	40.89	53.28	61.92	83.68	70.07
19.38	13.95	7.67		6.93	7.53	4.23	3.90	4.72
0.41	0.41	0.47	0.43	0.48	0.44	0.47	0.42	0.41
15.95	43.85	6.69		9.08	10.02	4.93	3.58	4.49
29.00	32.30	12.80		10.50	12.40	20.60		
153.23	267.18	28.29		14.93	16.50	7.86		
168.00	3.52	37.70		14.30	20.20	4.62		
1500.0	540.0	618.0		657.0	746.0	652.0	331.0	308.0
0.0501	0.12	0.14		0.18	0.248	0.17		
18.20	18.80	10.40		8.41	8.66	24.30		
	0.058	0.12		0.062	0.108	0.11		
	230.00	58.30		98.80	89.00	72.00	159.00	171.00
0.162	0.386	0.312		0.312	0.240	0.047		
0.931	4.17	1.88		1.73	1.55	0.979		
0.69	2.40	1.04		1.39	1.25	1.11		
2.14	5.17	1.27		2.53	2.36	1.84		
460.00	756.00	268.00		272.00	200.00	280.00	388.00	473.00
10.00	32.60	15.20		15.00	12.70	11.70	22.00	51.20
0.60	2.94	1.71		1.58	1.41	0.79	0.8528	1.29
600	901	1125		1053	1110	682	387	251
0.01	0.06	0.02		0.02	0.02	0.02	0.06	0.17
84.57	110.10	28.55		25.71	41.04	223.4	—	—
2.29	1.24	1.21		1.46	1.52	1.88	—	—

2nd continuation of Tab. 5

Ocean		Ophiolites	Island Arcs			Continent	
Tholeiitic basalt East Pacific Rise (Kay, 1978)	Tholeiitic basalt, Vema Fracture zone (Kay — — Hubbard, 1978)	Troodos plagiogranites (Kay — — Seneshal, 1976)	Tholeiitic basalt, Tonga (Kay — — Hubbard, 1978)	Andesite Marianas (Taylor et al., 1973)	Andesite Hakone, Japan (Fujimaki, 1973)	Granite Schwartzwald (Emmermann et al., 1975)	Granite Susamirski massif (Tsvetkov, 1983)
1.95	2.92	3.90	1.38	2.60	5.88	55.0	72.16
6.50	9.66	11.70	3.73	5.90	20.73	82.0	138.16
5.61	9.60	10.70	3.34	5.70	16.24	45.0	50.28
1.92	3.40	4.33	1.19	1.90	4.27	6.0	14.96
0.77	1.25		0.45		1.222	1.2	
		6.90	1.56	3.20	4.92		13.64
				0.80		0.72	3.52
2.80	5.50	9.10	1.85	2.10	5.50	3.9	12.76
1.72	3.10	5.87	1.53	2.20	2.76	2.8	8.36
	0.457				0.422	0.37	
21.27*	35.89*	52.50*	14.58*	24.40*	61.94*	196.99*	313.84*
3.02*	2.48*	1.40*	1.95*	1.94*	3.18*	20.91*	7.19*
0.30	0.30	0.33	0.37	0.44	0.28	0.67	0.52
1.13	0.94	0.66	0.90	1.18	2.13	19.60	8.63

* Somewhat lower values due to not determined Eu, Tb, Lu; Analyst: L. Zubkova.

Basalt-dolerite subalkaline association

On the Kommandorskie Islands the rocks of this magmatic association are represented by subalkaline basaltic or trachybasaltic lava flows and sheets, less often by sills and dykes of trachybasalts, subalkaline dolerites and gabbro, or teschenites (Borsuk—Tsvetkov, 1980).

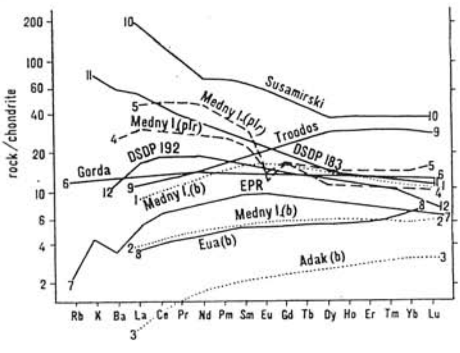


Fig. 3. REE distribution patterns for rocks of Kommandorskie basalt-Na-rhyolite association. The results presented in Figs. 3, 4, 5 are normalized to Leedy chondrite. *Explanations:* 1—2 — Medny Island basalts, 5/1—78, 3/14—78; 3 — tholeiitic basalt of Adak, Sh-3, sample of D. W. Scholl; 4—5 — Medny Island Na-rhyolites, 2/11—78, 63/4—78. *Standards:* MORB-type basalts; 6 — Gorda Ridge (Kay—Hubbard—Gast, 1970); 7 — East Pacific Rise (Kay—Hubbard—Gast, 1970); Island arc tholeiitic basalts: 8 — Eua, Tonga (Ewart et al., 1974), ophiolites: 9 — Troodos plagiogranites (Kay—Senechal, 1976); Continent: 10 — Susamirski granitic batholith in Kurgisia (Tsvetkov, 1983); alkaline and subalkaline basalts from seamounts (Kay—Gast, 1973): 11 — Site 183, DSDP; 12 — Site 192, DSDP.

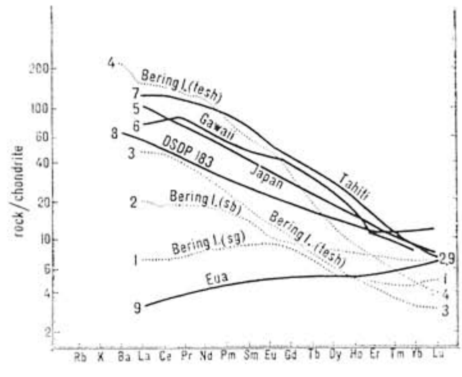


Fig. 4. REE distribution patterns for rocks of Kommandorskie basalt-dolerite subalkaline association.
Explanations: 1 — subalkaline gabbro, 1/1—78; 2 — subalkaline basalt, 3/2—78; 3—4 — teschenites, 3/19—78, 17/3—78. *Standards:* alkaline and subalkaline basalts from Pacific Island arcs and intraoceanic islands: 5 — Japan (Onuma et al., 1968), Hawaii (Schilling—Winchester, 1969); 7 — Tahiti (Schnetzler—Philpotts, 1968); 8 — Bay of Alaska seamount, site 183 DSDP (Kay—Gast, 1973); 9 — Eua tholeiitic basalt, Tonga (Ewart—Bryan, 1973).

Typical Kommandorskie subalkaline basalts are always massive porphyric rocks with a compact fabric. Phenocrysts assemblage: zonal labrador (An_{49-65}), augite or titan-augite ($Ca_{36-45}Mg_{43-47}Fe_{9-19}$, f = 15—30) and high-Mg olivine (Fo_{88}). The groundmass consists of plagioclase and clinopyroxene microliths and specs of brown biotite set in a glassy matrix filled with titanomagnetite micrograins. Amygdales and inter-mineral spacing are filled with analcime also abundant in the glassy matrix.

Teschenites countain well shaped titan-augite phenocrysts ($Ca_{44-45}Mg_{39-40}$ Fe_{15-16}, f = 28—29), more Fe-enriched than clinopyroxenes of subalkaline basalts, small grains of red-brown amphibole (barkevikite) and biotite in a faintly crystalline matrix of plagioclase (An_{35-49}) anorthoclase, augite, quartz, titanomagnetite and apatite.

Basalt-dolerite subalkaline association of the Kommandorskie Islands is of a continually differentiated type. Its whole rock chemistry varies gradually from close to subalkaline flood basalts to average subalkaline gabbros and teschenites (Soloviev, 1970). K_2O content permanently rises and in some subalkaline dolerites and teschenites exceed 3 wt. % due to appearance of modal anorthoclase. Meanwhile the bulk Fe-content rises slowly and varies within 8—9 wt. %, whereas TiO_2 exceeds 1 %. Teschenites — the most alkali--rich rocks, contain significantly higher ammounts of Co, Ni, Cr, V, Sr than typical oceanic subalkaline and alkaline basalts (Engel et al., 1965).

REE patterns for the most magnesian members, the least volumetrically abundant within the association, are slightly enriched with transitional REE (average $\sum$ REE = 19.6 ppm; $\sum REE_{Ce}/\sum REE_{Y} = 2.2$), whereas more alkali-rich rocks — subalkaline basalts, trachybasalts, trachydolerites and teschenites, being similar in $\sum$ REE, are already strongly enriched with LREE (average $\sum_{Ce}/\sum REE_{Y} = 8.1$). Total REE ammounts in teschenites reach 232 ppm and are the highest among all the Kommandorskie igneous rocks. Similar REE patterns are typical of subalkaline basaltic rocks of Japan (Onuma et al., 1968), Hawaii (Schilling — Winchester, 1969), Tahiti (Schnetzler — Philpotts, 1968) and seamounts in the Bay of Alaska (Kay et al., 1970; Kay — Gast, 1973) whose REE values are even higher, exceding 300—400 ppm (Fig. 4).

Temporal relations and petro-geochemical features of the Kommandorskie Islands subalkaline rocks show a gradual increase in alkalinity of magmatic melts. This can be due probably to dry fractionation of 20 % Pl, 10 % Cpx, 5 % Ol, 10 % Mt (mode of phenocryst occurrence in the Kommandorskie subalkaline basalts) from a parental picrobasaltic liquid at moderate depths within basaltic minerals stability field (Borsuk et al., 1982).

Subalkaline basic rocks from Kommandorskie Islands definitely cannot be considered for members of island arc shoshonitic series which are characterized by significantly higher ammounts of Sr, Ba and $^{87}Sr/^{86}Sr$ isotopic values (Gill, 1970; Jakes — Gill, 1970). Distinctions between subalkaline basaltic and shoshonitic series are quite evident in pyroxene compositions and their evolutional trends (Joplin, 1968, Tsvetkov et al., 1982).

Of all the Aleutians, subalkaline basalts are known only on Kanaga Island, they contain inclusions of dunites and peridotites (De Long et al., 1975) whilst true petrographic analogues of the Kommandorskie teschenites are not yet found.

Diorite-granodiorite association

On the Kommandorskie Islands rocks of this magmatic association make up stocks, small laccolith-type bodies, dykes and lava flows.

Granodiorites, composing intrusive bodies (up to 10 km^2) are massive hypidiomorphic rocks consisting of plagioclase (50—55 %), alkali feldspar (5—7 %), hornblende (15—20 %), biotite (2—5 %) and quartz (15—20 %). Among common accessories (1—2 %) are zircon, magnetite and apatite. The latter often makes rims on magnetite. Quartz diorites and tonalites composing microlaccoliths and dykes, differ from granodiorites in their porphyric fabric, lack of alkali feldspar and higher modal ammounts of quartz (up to 25 %) and biotite (up to 10 %).

Plagioclase in granodiorites and tonalites is oligoclase-andesine (An_{17-43}). It is often zonal, the outer zones represented by oligoclase (An_{17-20}) while the central - by andesine (An_{36-43}). Or-content also rises from cores to rims of the grains (average 2.1; Or — core; 4.2 Or — rim). With respect to phenocrystal plagioclase in Na-rhyolites of basalt-rhyolite association the one in granodiorites and tonalites has twice as much Sr and similar distribution of Cr, V, Ba, Zr and Cu. K-Na feldspar in granodiorites corresponds to high anorthoclase-cryptopertite. Amphibole is represented by a common hornblende (f = 25.9). Fairly common is apparent unequilibrity of large amphibole phenocrysts shown in their opacitization and substitution by biotite. Biotite is of two kinds: primary and secondary, the latter replacing hornblende. Its Fe-index in tonalites (f = 29—30) is somewhat lower than in granodiorites (f = 33). Epidote and chlorite are present in small quantities.

Granodiorite and tonalite bodies are often cut by aplitic veins, up to 1 m thick. Aplites are massive fine-grained rocks composed of K-Na feldspar ($Or_{75}Ab_{25}$) — 30—35 %, andesine-oligoclase (An_{13-37}) — 25—30 %, quartz — 35—40 % and biotite — 2—5 %. The latter, when compared with biotites from granodiorites and tonalites, appear to be enriched with Fe and Ti (f = 37; TiO_2 = 4.76). Laser microanalysis reveales considerable increase in Co, Ni, Cr and Cu contents in hornblendes and biotites within the plutonic suite: tonalites — granodiorites — aplites, while concentrations of V, Sr, Ba, Zr, remain nearly constant (B o r s u k et al., 1982). There is also a gradual increase in Ti-content of biotites in rocks of successive magmatic associations: from basalt-Na-rhyolite to basalt-dolerite subalkaline and diorite-granodiorite.

Volcanic rocks of diorite-granodiorite association represented mainly by andesitic and andesite-dacitic lavas are found to be in close spatial association with tonalitic and granodioritic intrusion and can be accounted as their volcanic analogues (see Tab. 5). Andesites consist of plagioclase (An_{55-60}), clinopyroxene ($Ca_{40-41}Mg_{43-44}Fe_{14-15}$, f = 25—26) and orthopyroxene (bronzite) phenocrysts and green hornblende in semicrystalline matrix. Groundmass clinopyroxene is usually lower in FeO and Al_2O_3. Some flows contain strongly cataclased Mg-rich olivine.

According to major and trace element distribution patterns rocks of diorite--granodiorite association are near V i n o g r a d o v's average values for andesite-diorite group (V i n o g r a d o v, 1962). Whereas regarding Ba (with respect) they are closer to basic rocks. With respect to initial Na-rhyolites the association is enriched with Sr (100—105 and 652—746 ppm correspondingly). REE abundances in quartz diorites, tonalites, granodiorites and their volcanic counterparts (average $\sum REE_{Ce}/\sum REE_{Y}$ = 6.6) closely match those of other island arcs calc-alkaline rocks, e.g. Japan and Solomons (Fig. 5).

Rocks similar in age and composition to the described above are widely spread in the Aleutian Islands especially on Attu, Agattu, Semichi, Kiska, Adak, Amchitka, Kagalashka and Unalaska where they are represented by andesitic, dacitic, sparsely basaltic lavas and large granodioritic plutons like Kagalashka

Pluton and Captain's Bay Pluton on Unalaska Island with K/Ar ages of 8—15 m.y. (De Long et al., 1978; Citron et al., 1980).

On the origin of the Kommandorskie magmatic rocks in light of Sr, Nd isotopes and REE patterns

The problem of island arc magma generation and evolution in spite of recently somewhat diminished number of alternative hypotheses is still among

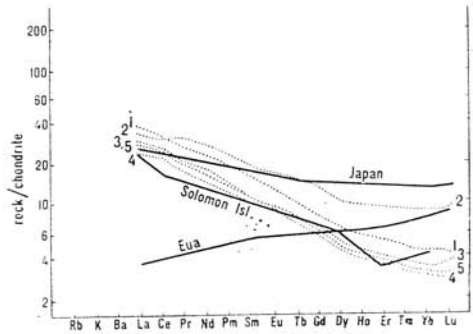


Fig. 5. REE distribution patterns for rocks of Kommandorskie diorite-granodiorite association.
Explanations: 1—2 — Medny Island andesitic lavas, 9/1—78, 10/15—78; 3 — Medny Island tonalite, 10/6—78; 4 — granodiorite Medny Island, 8/2—78; 5 — Kagalashka Island tonalite, Sh-1, sample of D. W. Scholl. By solid lines are shown andesite from Guadalkanal, Solomons (Jakes—Gill, 1970), andesite from Hokkaido Japan (Masuda et al., 1975), tholeiitic basalt from Eua, Tonga (Ewart—Bryan, 1973).

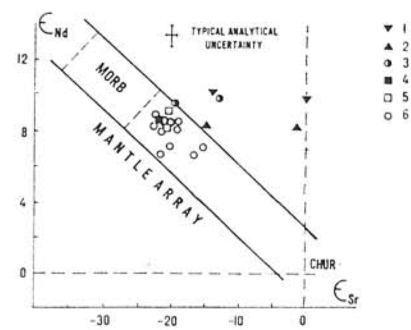


Fig. 6. ϵ Nd — ϵ Sr diagram for Kommandorskie and Aleutian magmatic rocks.
Explanations: Kommandorskie Islands: basalt-Na-rhyolite association (28—35 m. y.): 1 — Na-rhyolites; 2 — basalts; basalt-dolerite subalkaline association (18—25 m. y.); 3 — subalkaline basalts, diorite-granodiorite association (8.5—15 m. y.); 4 — granodiorites. Aleutian Islands (McCulloch—Perfit, 1981): diorite-granodiorite association (0—5 m. y.); 6 — andesites and basalts.

widely discussed ones in modern petrology. At the same time it is quite evident that if the problem of magmatic sources in active oceanic and continental margins would be solved it will make a fundamental contribution in constraining universal petro-geochemical models of generation and transformation of the Earth lithosphere. Covariation of Nd and Sr isotopes especially after discovering a negative covariation between $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios for magmas of mantle origin (De Paolo — Wasserburg, 1976) has become an effective tool in research done on magmatic sources in island arcs.

In the Aleutian island arc the most detailed isotopic and geochemical studies were carried out for Pliocene-Quaternary andesitic association (Kay et al., 1978; McCulloch — Perfit, 1982). Within Kommandorskie segment $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios recently were determined for all the three older magmatic associations (Zhuravlev et al., 1983).

The obtained results are plotted on a Nd-Sr diagram (Fig. 6). The isotopic characteristics of Nd and Sr in igneous rocks of the Kommandorskie magmatic associations are located mainly in the field comprising those of ensimatic island arcs and ensimatic parts of active continental margins (Marianas, New Britain, South Sandwich, Ecuador) (Fifth international . . . 1982).

High $^{87}Sr/^{86}Sr$ values in rocks of the initial magmatic stage causing horizontal shifting of ∈ Sr on the diagram to the right of the mantle array and not accompanied by likewise shifting in ∈ Nd can possibly be described as a result of isotopic exchange with seawater (∈ Sr = + 64). Such process is now studied in detail (Vinogradov — Buyakaite, 1980).

Theoretically there are only two possible ways of seawater Sr to contaminate island arc magmatic melts: 1) through involvement during subduction of a water-bearing sediments or hydrothermally altered basalts of the oceanic crust layer 2, i.e. contamination within magmatic sources; 2) by regional hydrothermal-metasomatic alteration of already crystallized magmatic rocks (propylitization in initial island arc magmatism of altered oceanic crust of water-saturated

The available data seem to favour the second assumption for contamination within magmatic sources would hardly provide considerable variability of ∈ Sr but rather lead to more of less preservation of these values for the same petrographic rock type. Moreover, if preservation of ∈ Sr is caused by participation in initial island arc magmatism of altered oceanic crust of water-saturated pelagic sediments, characterized by high REE ammounts, than there should be a noteable covariation of ∈ Sr and ∈ Nd for rocks of basalt-plagiorhyolitic association which however is not discovered. Among the additional evidence is a direct correspondence between the degree of alteration of the tholeiitic basalts and plagiorhyolites and their $^{87}Sr/^{86}Sr$ values (Borsuk et al., 1982). Thus unpropilitized tholeiitic basalts would probably plot within the mantle array on a ∈Sr — ∈Nd diagram.

One of the major features of basalt-plagiorhyolitic association is a considerable upward shifting of ∈Nd for plagiorhyolites towards higher values (up to +10) in comparison with tholeiites basalts (∈Nd + 8.2) and calc-alkaline basalts, andesites, dacites and rhyolites of diorite-granitoid and andesitic associations (∈Nd + 6.5 — + 9). This fact is of extreme importance for constraining the process of generation of the first island arc acid melts and definitely indicates the involment of crystalline part of the oceanic crust (∈Nd + 10 and higher). Indeed, the results of REE mass-balance calculations clearly show that they could be derived by mixing of initial tholeiite-basaltic liquids with 25—30 % melts from oceanic crust layer 2 (Tsvetkov, 1983).

All the isotopic compositions for diorite-granitoid and andesitic associations fall within the mantle array. Again it should be noted that changes in the crustal structure of the Aleutian basement from oceanic type (Kommandorskie Islands + Central Aleutians) into a continental one (Eastern Aleutians + Alaska) do not make any influence on Nd and Sr isotopic patterns. This indicates the minimal degrees, on absence of crustal contamination either of sialic or mafic components during later stages of the Aleutian island arc development, contrary to the initial one when such a process seems to be quite efficient. Indeed, petrographically similar and synchronous initial basalts from the western and the eastern segments differ in major and trace element abundances. Thus the rocks of Unalaska Island (eastern segment) differ from the Kommandorskie probably due to the contamination of the primary melts by a pre-Cenozoic sialic constituent in the structure of the eastern Aleutian basement. In our opinion the above mentioned features are due to the existence throughout the whole period of the island arc evolution of a uniform magmatic feeder systems. The rocks enclosing feeder channels became progressively depleted in magmatophile elements with time and finally got isotopically equilibrated with melts ascending from the mantle.

As concerned the fate of sediments of genesis of island arc magmas the available data is contradictory (Arculus — Johnson, 1981). On the one hand high K, Ba, Sr, U, Rb and other LIL-element contents in island arc igneous rocks seem to indicate their considerable involvement into magma generation (Kay, 1980; McCulloch — Perfit, 1981), but on the other hand, currently obtained isotopic values significantly constraint volumetric percentage of sediments participating in melting reactions often up to negligible quantities (Arculus — Johnson, 1981). Thus, e. g. Rb, Ba, and REE distribution patterns for 3/14—78 Kommandorskie initial tholeiitic basalt (see Tab. 5) are in perfect correspondence with a model, proposing its origin by melting of 99.875 % of depleted peridotite (harzburgite) and 0.125 % of pelagic sediment (Tsvetkov, 1983). However, the low $^{87}Sr/^{86}Sr$ value in this sample limits maximal values of involved sediments to the first hundreds of a percent.

Presented results of the Kommandorskie Islands isotopic studies led us to the following conclusions: 1) all the parental magmatic melts were of mantle origin; 2) magmatic sources throughout the whole Aleutian Island arc remained isotopically homogeneous for the whole period of its evolution (for more than 30 m.y.); 3) crustal contamination of magmatic melts played a significant role only during initial stage of the island arc development, during subsequent stages effectiveness of such process was conciderably diminished; 4) oceanic sediments were practically not involved in magma generation during the initial evolutional stage. There is strong doubt whether its role increased during the later stages; 5) distinctive variability of $^{87}Sr/^{86}Sr$ isotopic ratios in rocks of similar petrographic type is most probably due to propylitization; 6) variability of $^{87}Sr/^{86}Sr$ isotopic ratios unless other isotopic systems being taken into consideration do not provide irrefutable evidence of magmatism sources unhomogeneity.

Magmatic evolutional patterns of ensimatic and ensialic segments of the Aleutian Island Arc: a comparison

Analysing all the available data on different segments of the Aleutian island arc we shall try now to summarize their evolutional patterns. Schematic comparative diagram is presented in Fig. 7. We used published data on magmatism of the eastern part of the Aleutians and Alaska in Kay (1977, 1978, 1980); Citron et al., (1980); Marsh (1976, 1982); Marsh — Leitz (1980); Drewes et al., (1961); Perfit et al., (1980); Burk (1965); Byers (1961) etc.

The initial evolutional stage throughout the whole Aleutian island arc including Alaska Peninsula is characterized by basalt-Na-rhyolite association. However, while within ensimatic Kommandorskie west-central Aleutian seg-

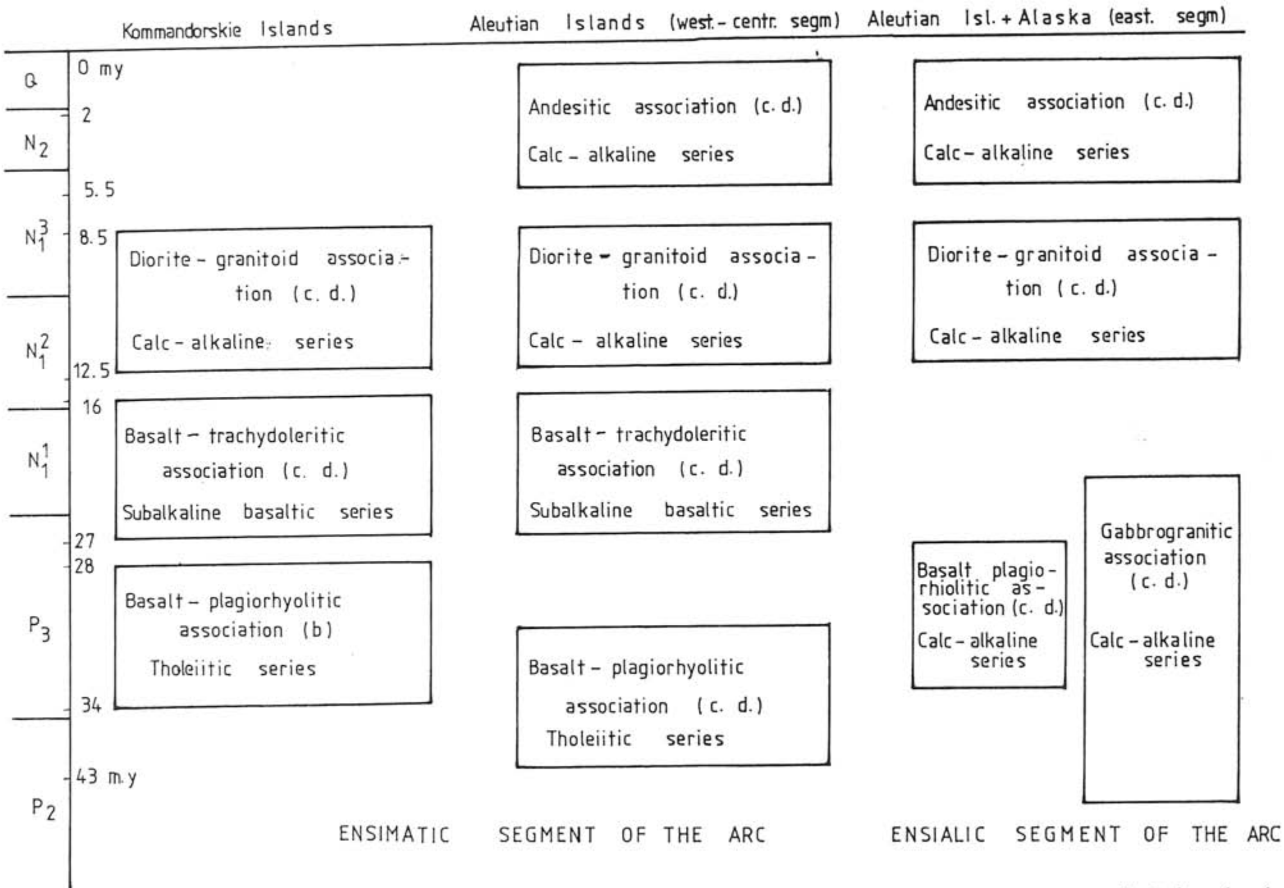


Fig. 7. Magmatic evolutional patterns of ensimatic and ensialic segments of the Aleutian Island arc (compiled by A. A. Tsvetkov).

Explanations: b — bimodal, c. d. — continually differentiated magmatic associations.

ment it belongs to tholeiitic series and often of a bimodal type, in ensialic eastern segment of the arc and in Alaska it is already continually differentiated and belongs to calc-alkaline magmatic series. Along the arc axis there is also a noteworthy variations in volumes of acid and basic members of the association: Kommandorskie Islands rock assemblage tholeiitic basalt-Na-rhyolites (volumetric ratio acid versus basic rocks is approximately 1 : 3); Adak Island, Central Aleutian Islands rock assemblage: basalts, gabbro, dolerites, granodiorites, quartz-diorites — the same ratio is already nearly 1 : 5; Unalaska, Unimak Island, Alaska Peninsula, eastern Aleutian Islands rock assemblage: basalts, basaltic andesites, andesites, intermediate and acid rocks of normal type including granites and syenites — the ratio is 3 : 1. It should be also emphasized that along with basalt-Na-rhyolite association ensialic part of the arc — especially Alaska Peninsula is characterized by synchronous emplacement of the "Alaskan batholith" lacking at Kommandorskie and west-central Aleutian Islands.

Next evolutional stage is represented by the basalt-dolerite subalkaline association which belongs to a subalkaline basaltic series. General alkalinity, mode of differentiation and volumes of erupted material substantially decrease in eastern direction. At the same time, subalkaline basalts, trachybasalts, subalkaline dolerites and teschenites so typical and abundant on Kommandorskie Islands, further eastern are replaced by basalts of normal alkalinity, dolerites and gabbros, while in Alaska and adjacent Aleutian Islands in ensialic part of the arc this magmatic association is not discovered.

Most intensive volcanic and plutonic activity occurred close to Middle-Upper Miocene boundary when the rocks of diorite-granodiorite volcano-plutonic association were intruded along the crest of the entire island arc. The predominating rock types are tonalites, quartz diorites and comagmatic andesites, andesite-dacites while the role played by basic rocks is much less significant; the latter only being differentiated of parental andesite-basaltic melts. The association within ensimatic and ensialic segments actually showes no petro-geochemical distinctions and corresponds to calc-alkaline series.

Current tectono-magmatic stage following the Pliocene one is characterized mainly by calc-alkaline volcanism (andesite association). Its rocks are compositionally similar to recent calc-alkaline volcanics from many Pacific island arcs and active continental margins (e. g. Kuriles, Japan, Cascades, Chile) which are mostly unaffected by differences in crustal structure and thickness. In the eastern part of the Aleutian back-arc zone there are some small-scale manifestations of subalkaline basaltic magmatism (Bogoslov Island) lacking within the rest of the Bering Sea side of the arc. Again, the lowest, with respect to normal basalts, $^{87}Sr/^{86}Sr$ ratios in Bogoslov subalkaline lavas, just as in Kommandorskie Miocene subalkaline volcanics, alongside with petro-geochemical data presented in Arculus et al., (1976) seem to indicate the lowermost location of their magmatic sources, supporting previously distinguished phenomena (Kuno, 1968).

Thus the evolutional patterns of magmatism within different parts of the Aleutian Island arc are definitely specific due in our opinion, to one major reason: lateral variations in composition and thickness of the Earth crust caused by its transition from oceanic type into continental one. For ensialic part of the arc the main factor controlling the trends of magmatic evolution seems to be "old sialic basement" which, alike newly formed continental crust in ensimatic island arcs, either contaminates mantle magmatic melts or gives rise to independent crustal acid melts. That is probably why enseialic island arcs (e. g. the Lesser Kuriles, New Zealand, etc.) often lack magmatic rocks (magmatic associations) of the initial tholeiitic series while those of calc-alkaline series are spread extremely wide.

Acknowledgements: We thank Professor D. W. Scholl, USGS, Menlo Park and Professor R. W. Kay, Cornell University who donated us rock samples from the Aleutian Islands that made possible a comparative study of the Kommandorskie and the Aleutian magmatism. Professor D. W. Scholl is also thanked for providing analytical determinations for some typical Kommandorskie igneous rocks. The research was funded by the USSR Academy of Sciences.

APPENDIX 1. SAMPLES LOCATION:

Basalt-Na-rhyolite magmatic association

3/7—78 Fine-grained propilitized lithocristalloclastic basaltic tuff, Kotenok Pt., Northern Part of Medny Is.
111—1 Small vekded hyalobasaltic breccia, North-Western Pt., Medny Is. (Schmidt, 1978).
3/14—78 Basaltic lava flow with rare ultrabasic xenoliths, Sulkovski Pt., Medny Is.
5/1—78 Basaltic xenodyke in Na-rhyolites, Peschanaya Cove, Medny Is.
3/5—78 Basaltic dyke, Sulkovski Pt., Medny Is.
7/2—77 Na-rhyolite from stock soitward of Kotenok Pt., Medny Is.
5/2—89 Na-rhyolite lava flow, Peschanaya Cove, Medny Is.
5/4—77 Propilitized Na-rhyolite from stock in Peschanaya Cove, Medny Is.
5/5—77 Fresh Na-rhyolite lava flow, the same locality.
6/22—77 Propilitized Na-rhyolite from stock, Matvei Pt., Medny Is.
6/4—78 Glassy Na-rhyolite lava, Trofimovski Cove, Medny Is.
2/10—78; 2/11—78 Na-rhyolite lavas, Preobrazhenskaya Cove, Medny Is.
Sh—3 Propilitized basalt, Finger Bay formation, Adak Is. (Collection of D. W. Scholl).

Basalt-dolerite subalkaline association

14/3—78 Subalkaline basaltic lava flow, Northern part of Bering Is.
7/2—78 Subalkaline basaltic dyke, Gladkovskaya Cove, Medny Is.
13/1—78 Subalkaline gabbroic stock, Arii Pt., Medny Is.
19/10—78 Trachybasaltic lava flow, Northern part of Bering Is.
415/77 Subalkaline dolerite sill, Vhodnoi Reef Pt., Bering Is.
13/6g—78 The same, Scinyi Mt, Northern part of Bering Is.
19/1—87 Teschenitic sill, Nickolskoye, Bering Is.
1/1—78; 9/7—78 Teschenitic dykes, Zhirovaya Cove, Medny Is.
B—1 "Beringitic" dyke, Dykaya Cove, Bering Is. (Zheglov, 1964).
17/3—78 Teschenitic dyke, Monati Pt., Southernmost Bering Is.
19/18—78 Teschenitic sill, Caunta Pt., Northern Is, Bering Is.
20/1—78 Teschenitic dyke, Nickolskoye, Bering Is.
3/2—78; 3/3—78 Subalkaline basaltic dykes, Sulkovski Pt., Northern part of Medny Is.
3/19—78 Teschenitic dyke, the same locality.

Diorite-granodiorite association

12/17—77 Biotite-hornblende tonalite, Kuropatkin Mt., Medny Is.
13/12—77 Quartz diorite, Glinka Cove, Medny Is.
8/2—78; 11/6—77 Granodiorites, Cherny Pt., Medny Is.
11/7—77 Aplitic veinlet in granodiorite, Cherny Pt., Medny Is.
10/29—78; 10/14—78 Andesite-basaltic lava flows, Southern part of Medny Is.
11/4—78 Andesitic lava flow, the same locality.

10/6—78; 10/15—87 Andesitic dykes South Eastern Pt., Medny Is.
9/136—78 Andesitic lava flow, Glinka Cove, Medny Is.
9/1—78 Dacitic lava flow, the same locality.
Sh—1 Tonalite, Kagalasha Is. (Collection of D. W. Scholl).

APPENDIX 2. ANALYTICAL METHODS

Microprobe analyses were done on "Cameca" housed in the Institute of Ore Deposits Geology, Petrology, Mineralogy and Geochemistry of the USSR Academy of Sciences in Moscow (IGEM). Analyses were done at 20 kV with a current of 50 mA. All elements were counted for 70 seconds. Analyst M. V. Tsvetkova. Analyses were refined using a special correcting programme PUMA based on ZAF method for Canon CX-1 computer. A Unified IGEM collection of standards was used. Standards were obtained from the Fersmanian Mineralogical Museum and Mineralogical Museum of IMGRE Institute in Moscow. Standards used were chromdiopside B-6, shrolomite S-68, spessartine K-50, albite K-48, aegirine S-38, olivine B-14, adular K-34, magnetite S-135, rutile S-103.

Major elements were determined by X-ray spectroscopy conventional wet chemical analysis technique and trace elements by quantitative emission analysis in chemical laboratories of IGEM. REE, along with some whole rock and trace element analyses were done in USGS laboratories (Menlo Park California) using instrumental neutron activation, X-ray fluorescence and emission spectroscopy techniques. Analysts B. Lai, S. Ramage, D. Mc Cown, R. Knight (USA), D. Knyaseva, E. Lomaiko, L. Zubkova, G. Esikova (USSR).

K/Ar age determinations were carried out on a special IGEM argon device and MI-1201 mass-spectrometer by isotope dilution technique. With the addition o. Ar^{38} as a spike, potassium was determined by flame spectrophotometry. Radiological ages were calculated using constants recommended by International Subcommission on Geochronology at the XXV International Geological Congress: $\lambda_K = 0.581 \, . \, 10^{-10}$ years^{-1}, $\lambda_\beta = 4.962 \, . \, 10^{-10}$ years^{-1}, $^{40}K = 0.01167$ at. %. Analyst M. M. Arakeljanz. Several determinations were done USGS lab. in Menlo Park under supervision of Dr. L. Silberman.

Sr and Nd isotopic analyses were done in IGEM by D. Zhuravlev using mass-spectrometer MI-1320. The typical analytical uncertainty was 0.005 % for Nd and 0.007 % for Sm ($2\sigma_{mean}$). Nd was measured as Nd^+ on triple filament assembly using Re filaments. The results were fractionation corrected to $^{150}Nd/^{144}Nd = 0.238619$ (Wasserburg et al., 1981). Six isotopes of Nd (143—150) were measured at ion intensities of ^{144}Nd 3—10 x 10^{12} A. The measured $^{145}Nd/^{144}Nd$, $^{146}Nd/^{144}Nd$ and $^{148}Nd/^{144}Nd$ ratios differ frome those of J. Wasserbug (Wasserburg et al., 1981) not more than by 0.004 %. Measured $^{143}Nd/^{144}Nd$ ratio for BCR-1 was 0.511836 ± 26 and falls within the data of the leading isotope laboratories.

Sr was measured on a single filament, Tα. The results were normalized to $^{87}Sr/^{86}Sr$ for SRM-887 0.71022. The measured value was 0.71030 ± 2 (average of 17 analyses, $2\sigma_{mean}$).

$$\varepsilon \, Nd = \frac{(143Nd/144Nd) \text{ meas.} - (147Sm/144Nd \text{ meas.} (e^{\lambda T} - 1)}{(143Nd/144Nd) \text{ CHUR} - (147Sm/144Nd) \text{ CHUR } (e^{\lambda T} - 1)} \, . \, 10^4$$

where T-is
the age of the rock. The following CHUR characteristics were used in calculations: (143Nd/144Nd) CHUR = 0.511847; (147Sm/144Nd) CHUR = 0.1967; (87Sr/86Sr) Ur = 0.7045; (87Rb/86Sr) Ur = 0.0827. $\lambda_{147Sm} = 6.54 \, . \, 10^{-12}$ year^{-1}, $\lambda_{87Rb} = 1.42 \, . \, 10^{-11}$ year^{-1}.

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