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New Evidence for the Composition and Structure of Volcanic Complexes on Cape Nalycheva and the Shipunskii Peninsula, Kamchatka

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Abstract—Studies carried out on Cape Nalycheva provided new data on the composition of the volcanic complexes that compose it. The volcanic rocks are of island arc origin and belong to the moderate-potassium calc-alkali series. Comparing the character of volcanism on Cape Nalycheva and on the Shipunskii Peninsula with the well-known complexes on the Kamchatskii Mys and Kronotskii peninsulas (which are northern fragments of the Kronotskii paleoarc), we find considerable differences, which probably reflect the heterogeneity of the base on which the Kronotskii arc originated.

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INTRODUCTION

The tectono-stratigraphic terrains of the eastern peninsulas of Kamchatka are commonly regarded as fragments of the Kronotskii paleoarc accreted to the Kamchatka margin during Cenozoic time [4, 7, 8, 12]. The volcanogenic and tuffaceous sedimentary formations in the Shipunskii Peninsula and on Cape Nalycheva are considered to constitute the southernmost fragment of the Late Cretaceous/Eocene Kronotskii volcanic arc [4]. At the same time, the volcanic and tuffaceous sedimentary complexes of Cape Nalycheva are considered by various workers either as an independent rock sequence (the Nalycheva sequence) [4, 13] or are compared with formations of the Khapitskii series found in the eastern ranges of eastern Kamchatka [3, 6]. These tentative identifications of the Cape Nalycheva rocks with formations found in different tectonic zones are due to the poorly defined position of these formations in the stratigraphic column and to an absence of stratigraphic contacts with adjacent complexes. In our opinion, the character of the column, the specific rock composition, and the available datings enable one to identify the volcanogenic and tuffaceous sedimentary formations on Cape Nalycheva as an independent stratigraphic unit—the Nalycheva sequence (we are using a loose term—sequence—since the formations that compose Cape Nalycheva are poorly characterized faunistically and have no stratigraphic contacts). As to the Shipunskii Peninsula, its volcanogenic and tuffaceous sedimentary complexes are comparable with those of the Kozlovskii and Kubovskii suites of the Kronotskii Peninsula as inferred from the character of the column [3, 6].

The present study gives an analysis of new evidence for the composition of volcanic rocks on Cape Nalycheva obtained during the 2006 field work and compares this evidence with known data on the composition of volcanic rocks in the Shipunskii, Kamchatskii Mys, and Kronotskii peninsulas.

A BRIEF GEOLOGICAL REVIEW

The Upper Cretaceous–Paleogene complexes of Cape Nalycheva, the Shipunskii Peninsula, and mounts Lekhova and Bazyleva in the interfluve of the Nalycheva and Vakhil' rivers compose a feature marked as the Vakhil' Uplift in the tectonic map of eastern Kamchatka [4, 12]. The Vakhil' Uplift has a nappe structure (Fig. 1). The relative autochthons are the tuffaceous sedimentary and volcanogenic formations of the Nalycheva sequence (Late Cretaceous?–Paleogene), the tuffaceous and volcanogenic formations of the Kozlovskii and Kubovskii suites (Eocene), and the tuffaceous terrigenous deposits of the Tyushevskii series (Oligocene–Miocene) in the Shipunskii Peninsula. The allochthon is formed by a rider of tectonic sheets displaced along a thrust plane dipping 30°–40° westward and northwestward. The sheets consist of formations of the Vetlovskii complex (tholeiite basalts and diabase, cherty rocks, Upper Paleogene–Eocene limestone and tuffaceous sedimentary rocks containing horizons of mixtites with amphibole andesites) [13]. This nappe struc-

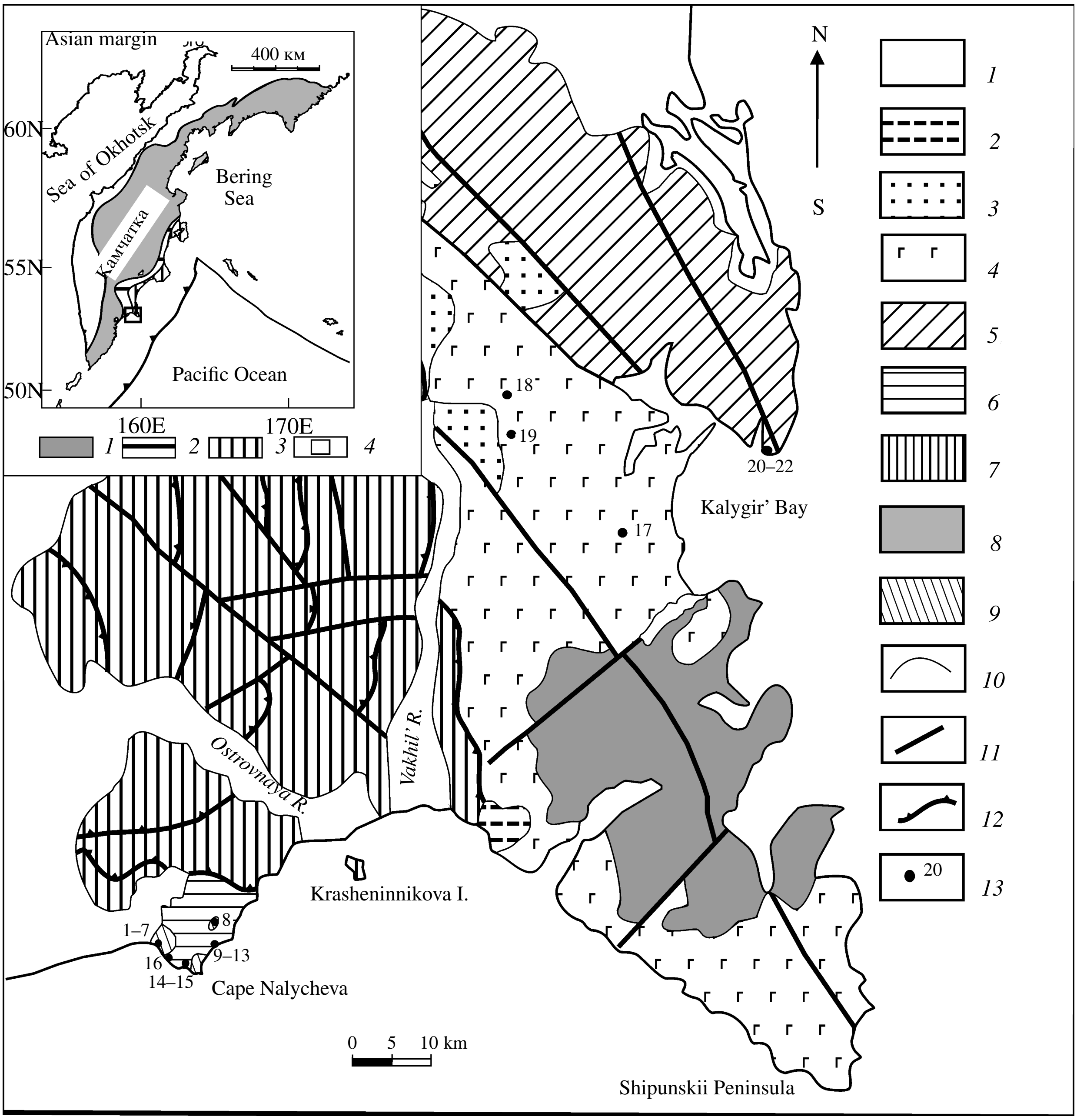

Fig. 1. A geological map of the Vakhil' Uplift after [6, 13] with these authors' modifications: (*1*) unstratified recent and Pliocene–Quaternary deposits, (*2*) Kornilovskii series (Miocene), (*3*) Tyushevskii series (Oligocene–Miocene), (*4*) Kubovskii suite (Eocene), (*5*) Kozlovskii suite (Eocene), (*6*) Nalycheva sequence (Maastrichtian?–Paleocene), (*7*) Vetlovskii complex, (*8*) Shipunskii gabbro–granodiorite intrusive complex (Oligocene), (*9*) subvolcanic andesite bodies in the Nalycheva sequence, (*10*) geological boundaries, (*11*) undifferentiated tectonic faults, (*12*) overthrusts, (*13*) sampling localities (numerals denote sample numbers corresponding to Table 1). The inset: (*1–3*) tectono-stratigraphic terrains after [4]: (*1*) Achaivayam–Valaginskii, (*2*) Vetlovskii, (*3*) of the eastern peninsulas, (*4*) area of study.

ture is sealed by deposits of the Miocene Kornilovskii series [3, 6].

The Nalycheva sequence divides into two subsequences judging by the character of the column: a lower dominated by fine- to medium-grained tuffaceous sedimentary rocks and an upper, much coarser one, with prevailing tuff and lava breccias. The lower subsequence at the bottom of the visible section is composed of alternating tuff breccias, psammite and psephite tuffs, and tuff sandstone with tuff aleurolite interbeds. In the upper part of the lower subsequence a set of thin-layered (a few centimeters to 20–30 cm), occasionally rhythmically alternating tuffites, tuff pelites, and tuff aleurolites with carbonate interbeds and pressures, and thin (below 10 cm) interbeds of acid tuffs is found. The rocks are found to involve gradational layering and traces of local rewashing.

The lower part of the upper subsequence contains clumpy tuff conglomerates and tuff breccias, agglomerate tuffs and lava breccias with fragments of basalt and andesite, and thin (5–7 m) basalt flows involving spheroidal jointing. The upper part of the column contains stocklike bodies of hornblende andesite as long as 2 km.

The fine-grained rocks of the lower subsequence were found to contain poorly preserved fragments of radiolarian skeletons and foraminiferal shells; this dates the host rocks as belonging to a broad age range, Maastrichtian?–Paleocene [13].

In the Shipunskii Peninsula the Kubovskii suite is found on the left bank of the Vakhil' River, while the Kozlovskii suite occurs in the northern part of the peninsula, north of the Kalygir' Bay. The lower part of the Kubovskii suite (P_2) is composed [3, 6] of tuffs alternating with lava breccias and flows of basalt, trachybasalt, andesite, and dacite with interbeds of tuffaceous sedimentary rocks. The upper part of the suite is mostly composed of tuff sandstone, tuff aleurolite, tuff conglomerate with occasional dacite interbeds. Associating with the Kubovskii suite is a dolerite–diorite–porphyry–rhyolite subvolcanic complex. The suite is thicker than 2000 m. The Kozlovskii suite (P_2) is composed [3, 6] of alternating basic tuffs, flows of lava breccia and basaltic and trachybasaltic lavas interspersed with sets of tuff aleurolite and tuff sandstone, and cherty rocks. The suite is thicker than 900 m. Associating with the Kozlovskii suite is a dolerite subvolcanic complex consisting of stocks, dikes, and sills of dolerite, basalt, and trachydolerite.

The deposits of the Tyushevskii series (P_3-N_1) are found on the left bank of the Vakhil' River and in the Krest'yanskie Mountains. They consist of tuff sandstone, tuff aleurolite, and tuff conglomerate, which overlie (with some scour) the Kubovskii suite [3, 6].

The deposits of the Kornilovskii suite (N_1) [3, 6] consist of alternating sandstone, gravelite, conglomerate, and aleurolite with lenses of coal and carbonized wood remains.

THE DATA SET AND THE METHODS OF STUDY

We have sampled and investigated the andesites that compose a stocklike body in the upper column of the Nalycheva sequence along the southwestern shore of Cape Nalycheva (samples 0601/1, 0601/3, 0601/4, 0602/1, 0602/2, 0602/5, 89/1, and 80/7 (Fig. 1, Table 1)), basalts from lava flows (samples 0607/1, 81/13), and lava breccia (80/6, 0606/12, 0606/13, 0606/14, 0606/15, and 0606/7) from the upper subsequence along the southeastern shore of Cape Nalycheva. For comparison with the Cape Nalycheva rocks we used several petrochemical analyses of samples from the Kozlovskii (79/88, 79-2/88, 1173) and the Kubovskii suites (95/1, 1052/8, 1048/10), Table 1. The Kozlovskii samples were taken on the northeastern shore of the Kalygir' Bay and the Kubovskii ones in the upper reaches (95/1) of Donesenskii Brook and in the middle reaches of Soldatskii Brook (Fig. 1).

The rock chemical composition was studied by the XRF method (Analyst A.V. Yakushev, IGEM RAN, Moscow), the trace element composition was studied using an ICP-MS spectrometer with inductively coupled plasma (Analyst D.Z. Zhuravlev, IMGRE, Moscow) (Table 2).

RESULTS

The Petrochemical Characteristics of the Cape Nalycheva Rocks. The andesites and andesite–dacites of the stocklike body are mostly represented by plagioclase–porphyry and amphibole–porphyry varieties with a hyalopilitic texture of the matrix. Plagioclase phenocrysts 1–4 mm across make up about 8% and are represented by tabular-shaped zonal crystals. They are partially or completely replaced with saussurite and calcite. Amphibole phenocrysts as large as 0.5–1 mm in size make up 2–3% and are partially replaced with chlorite. The groundmass contains plagioclase, quartz is less frequent, and dark minerals are replaced with epidote and chlorite. The ore mineral makes up as much as 5–8% and is represented by a fine-grained aggregate.

The flow basalts are represented by rare-porphyric porous varieties with a hyalopilitic groundmass. Phenocrysts as large as 1–2 mm in size make up 1–2% to 5% and are represented by clinopyroxene, and more rarely by orthopyroxene. There are numerous (about 40%) plagioclase microphenocrysts of elongate tabular shape as large as 0.2 mm. One can see individual plagioclase and clinopyroxene microlites in the poorly crystallized groundmass. The ore mineral, as large as 0.1–0.2 mm in size, makes as up much as 5%. The pores (5–7% in volume)are filled with chlorite and epidote. The plagioclase microphenocrysts are saussuritized.

The lava breccia basalts are represented by pyroxene–porphyry and aphyric rocks with a hyalopilitic and intersertal texture of the groundmass. Phenocrysts 3–5 mm in size make up 8% of the total rock volume and are represented by clinopyroxene and orthopyroxene. The matrix is crystallized nonuniformly and is formed by saussuritized plagioclase (up to 30%) and clinopyroxene microlites. The microlite size does not exceed 0.1–0.5 mm. The secondary minerals are quartz and chlorite segregations. The groundmass in aphyric, strongly porous varieties is composed of plagioclase microlites, which are found in a matrix that is more finely crystallized. The average size of plagioclase microlites is 0.25 mm. The pores have oval shapes, are up to 3–5 mm in size, and are filled with quartz and calcite. There is abundant chlorite and epidote in the groundmass. Segregations of fine-grained ore mineral

Table 1. Bulk composition of Cape Nalycheva and Shipunskii Peninsula magmatic rocks, wt %

Column no.	1	2	3	4	5	6	7	8	9	10	11
Sample no.	0601/1	0601/3	0601/4	0602/1	0602/2	0602/5	80/7	89/1	0606/14	0606/12	0606/13
SiO_2	55.57	60.52	56.60	57.02	57.85	56.04	58.56	63.18	52.58	50.73	50.95
TiO_2	0.81	0.73	0.98	0.55	0.54	0.56	0.66	0.70	1.01	0.98	0.96
Al_2O_3	15.50	16.11	15.92	15.20	15.66	15.49	16.90	15.46	13.67	13.06	12.91
FeO*	6.20	5.15	7.10	4.12	4.33	4.60	4.37	5.34	8.80	9.04	8.87
MnO	0.14	0.13	0.20	0.11	0.10	0.11	0.12	0.13	0.18	0.18	0.28
MgO	4.91	3.68	5.61	2.37	3.00	3.60	2.54	2.68	7.30	8.17	8.99
CaO	6.67	4.31	3.83	7.12	5.04	5.60	4.15	6.02	9.61	9.86	9.25
Na_2O	3.79	4.48	4.08	2.69	2.97	2.62	4.65	3.49	2.00	3.25	2.49
K_2O	0.76	1.53	0.85	1.51	1.51	1.59	2.29	0.88	0.98	0.64	1.23
P_2O_5	0.21	0.24	0.30	0.18	0.19	0.18	0.26	0.18	0.28	0.31	0.31
L.O.I.	4.75	2.54	3.75	8.68	8.33	9.10	4.67	1.45	2.60	2.77	2.77
Total	100.00	100.00	100.00	100.00	100.00	100.00	99.52	99.70	100.00	100.00	100.00
FeO*/MgO	1.26	1.40	1.27	1.74	1.44	1.28	1.99	1.72	1.21	1.11	0.99

Column no.	12	13	14	15	16	17	18	19	20	21	22
Sample no.	0606/15	0606/7	80/6	81/13	0607/1	95/1–89	1048/10	1052/8	79/88	79–2/88	1173
SiO_2	50.84	63.80	46.40	51.72	49.14	65.64	54.85	45.93	48.05	46.77	48.50
TiO_2	0.99	0.87	1.00	0.96	1.03	0.68	0.76	0.70	0.56	0.70	0.70
Al_2O_3	13.27	14.87	15.93	16.95	13.71	15.52	16.63	15.20	19.00	17.89	16.32
FeO*	8.89	4.31	10.58	8.66	8.85	6.20	6.76	9.68	9.34	10.38	10.41
MnO	0.18	0.13	0.22	0.17	0.18	0.14	0.14	0.17	0.15	0.18	0.22
MgO	8.06	1.20	7.58	5.78	8.62	2.15	6.69	10.87	4.86	5.15	5.36
CaO	8.26	6.04	6.92	7.10	9.12	2.99	6.67	9.51	11.02	9.59	9.85
Na_2O	1.69	5.85	2.22	3.36	1.95	5.67	4.52	1.66	2.63	3.45	2.36
K_2O	3.77	0.14	1.66	1.57	1.03	0.73	0.78	0.20	0.54	0.24	0.70
P_2O_5	0.31	0.40	0.41	0.39	0.27	0.13	0.16	0.10	0.11	0.13	0.14
L.O.I.	2.74	1.91	6.22	2.55	5.13	Ì.Ó.	2.32	5.56	3.34	5.24	3.94
Total	100.00	100.00	99.63	99.59	100.00	100.00	100.67	99.79	100.19	100.33	99.28
FeO*/MgO	1.10	3.59	1.40	1.50	1.03	2.88	1.01	0.89	1.92	2.02	1.94

Note: 1–16 Cape Nalycheva (1–8 andesites and dacite (8) from the stocklike body, 9–14 lava breccias from the lower subsequence of the Nalycheva sequence, 15–16 basalts from the upper subsuite of the Nalycheva sequence); 17–22 Shipunskii Peninsula (17–20 volcanic rocks of the Kubovskii suite, 21–22 basalts of the Kozlovskii suite). FeO* = FeO + 0.9 Fe_2O_3. Samples 17–22 were lent by A.F. Litvinov.

up to 0.05 mm in size make up to 5% of the groundmass volume. All the rocks contain abundant calcite, which fills in cracks and cavities.

All the magmatic rocks of Cape Nalycheva studied here have low concentrations of TiO_2 (0.54–1.03 wt %) with sufficiently wide variations of the FeO*/MgO ratio = 0.89–3.59, for the most part in the range 1.1–2.04. The rocks form a continuous differentiated series from basalts to dacites, which can be clearly seen in the SiO_2–element variational diagrams (Fig. 2). Most volcanites of this common series are situated in the field of moderately potassium calc-alkaline series in the discrimination diagrams FeO*/MgO–SiO_2, FeO*, and SiO_2–K_2O. Sample 80/6, as seen in the SiO_2–K_2O diagram, falls in the field of high potassium calc-alkaline series, while in the other two discrimination diagrams it is in the composition field of the tholeiite series. Considering that this sample has high losses on ignition (L.O.I.), it can be concluded that this scattering of parameters is obviously due to secondary alterations. Some samples, viz., 0606/7, 0606/1, and 81/13, as seen in the FeO*/MgO–SiO_2 diagram, fall in the composition field of the tholeiite series, while sample 0606/7, which is characterized by very low potassium, falls in the field of that series in the SiO_2–K_2O diagram as well. The discrepant characteristics of samples 0606/1 and 81/1 are

Table 2. Concentrations of admixture elements in Cape Nalycheva magmatic rocks

Sample no.	1	2	3	4	5	6	7	8	9
column no.	0601/1	0601/3	0601/4	0602/1	0606/12	0606/13	0606/15	0606/7	0607/1
Ba	228	220	160	214	89	390	389	39	245
Rb	9	18	10	26	12	14	13	1.60	12
Cs	0.19	0.31	0.27	0.75	0.14	0.16	0.18	0.06	0.24
Th	1.07	1.45	1.77	1.32	0.46	0.47	0.46	1.29	0.51
U	0.49	0.65	0.77	0.59	0.29	0.30	0.31	0.75	0.35
Ta	0.07	0.08	0.18	0.04	0.07	<0.02	<0.02	0.09	<0.02
Nb	1.64	1.95	3.40	3.96	1.49	1.71	1.55	3.89	2.52
La	8.56	11.11	13.64	8.83	6.05	5.96	5.91	11.41	6.42
Ce	21.76	27.25	35.46	21.04	15.90	15.23	15.22	32.39	15.74
Sr	588	667	401	289	269	480	468	143	666
Pr	3.16	3.80	4.82	3.01	2.53	2.53	2.50	5.29	2.72
Nd	14.23	16.16	21.02	12.75	12.89	12.73	12.72	25.19	13.89
Zr	104	124	88	122	66	92	91	175	65
Hf	2.68	3.12	2.84	3.12	1.90	2.38	2.50	4.82	1.83
Sm	3.61	3.78	4.77	2.90	3.79	3.60	3.64	6.54	3.84
Eu	1.12	1.10	1.29	0.85	1.19	1.19	1.15	1.64	1.24
Gd	3.40	3.33	4.48	2.79	4.02	3.98	3.91	6.92	4.08
Tb	0.52	0.47	0.63	0.43	0.60	0.59	0.61	1.11	0.66
Dy	3.15	2.84	3.74	2.54	3.82	3.61	3.85	6.79	4.09
Y	15	14	17	15	20	19	19	37	21
Ho	0.65	0.57	0.75	0.56	0.82	0.83	0.81	1.49	0.90
Er	1.69	1.63	2.01	1.50	2.20	2.15	2.18	4.12	2.39
Tm	0.26	0.25	0.30	0.23	0.31	0.32	0.31	0.61	0.34
Yb	1.57	1.49	1.84	1.52	2.00	1.91	2.00	3.97	2.28
Lu	0.24	0.24	0.26	0.24	0.31	0.30	0.31	0.61	0.33
V	195	158	228	153	299	335	332	118	281
Zn	81	84	137	58	73	72	75	91	92
Cu	25	10	51	<1	25	248	256	<1	122
Ni	61	37	13	5	84	84	42	<1	593
Cr	81	35	77	68	214	223	228	3.18	295
Be	1.65	2.01	1.85	1.37	0.91	1.11	1.06	1.44	1.01
Co	19	15	25	13	35	35	35	6	32
Ga	17	19	18	18	15	14	15	14	15
Mo	0.54	0.72	0.67	0.09	0.15	0.38	0.07	0.36	1.13

Note: 1–4 andesites from the stocklike body, 5–8 lava breccias from the lower subsequence of the Nalycheva sequence, 9 basalt from the upper subsuite of the Nalycheva sequence

also due to their secondary transformations. However, the origin of sample 0606/7 remains an open question.

Most of the samples studied here have rare-earth element (REE) spectra close to those for volcanites of the calc-alkaline series (Fig. 3). These spectra typically involve a continuous increase in the normalized concentrations from heavy REEs to light ones, except for the heaviest REEs, which are at the same level. Sample 0606/1, having discrepant petrochemical characteristics, coincides in the behavior of REEs with the bulk of studied samples, and can thus be unequivocally classified as belonging to the calc-alkaline series. Sample

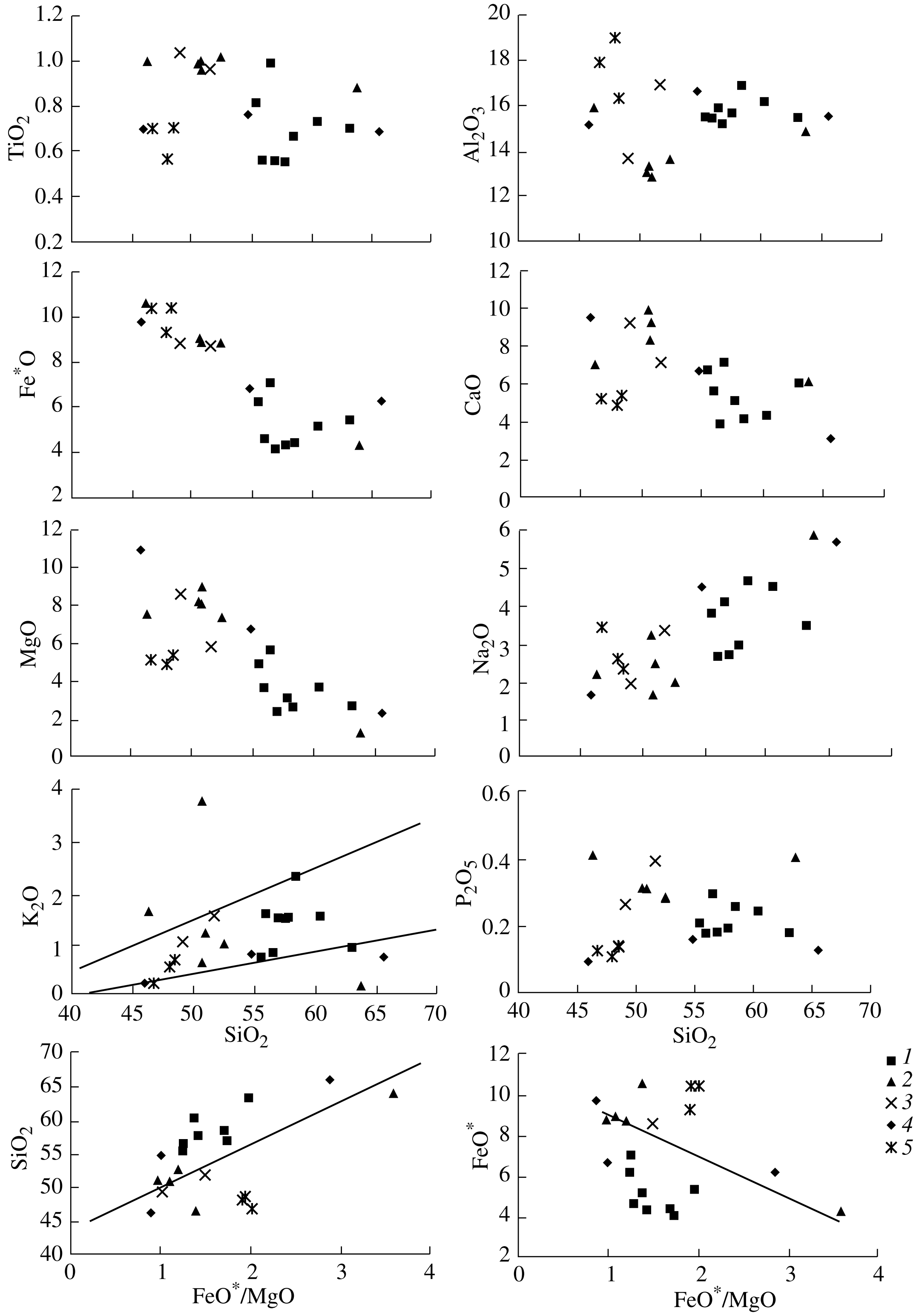

Fig. 2. Variational diagrams of petrogenic elements in the magmatic rocks of Cape Nalycheva and the Shipunskii Peninsula: (*1–3*) Nalycheva sequence: (*1*) andesites and andesitic dacites of the stocklike body, (*2*) volcanic rocks in the lava breccias of the upper subsequence, (*3*) flow basalts in the upper subsequence, (*4*) volcanic rocks of the Kubovskii suite, (*5*) volcanic rocks of the Kozlovskii suite. The diagrams FeO*/MgO–SiO_2 and FeO*/MgO–FeO*: CA and Th denote the composition fields of the calc-alkaline and tholeiite series, respectively [16, 17], the SiO_2–K_2O diagram shows composition fields of the tholeiite (*I*), normal (*II*), and high potassium (*III*) calc-alkaline series [19].

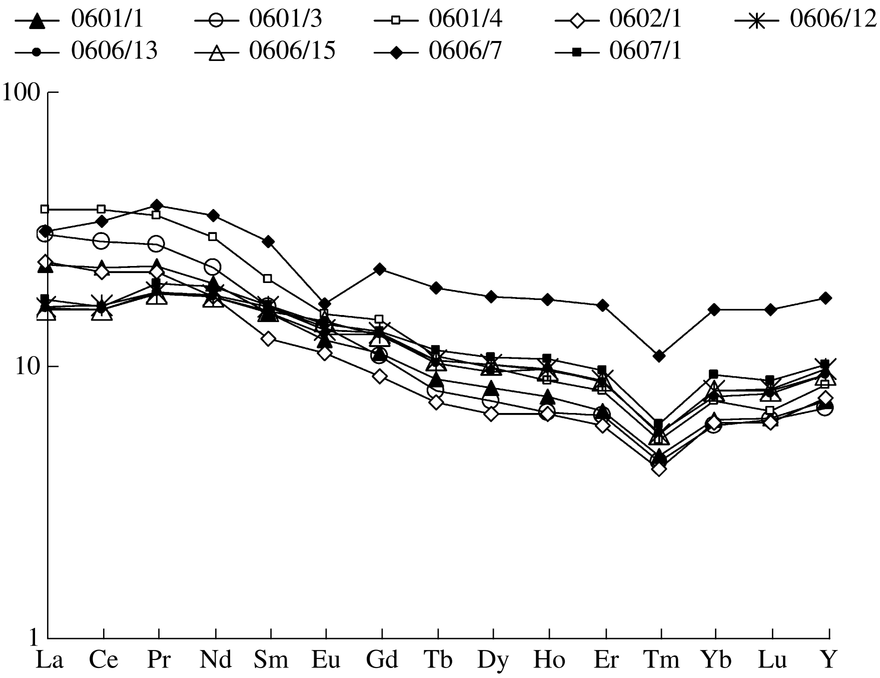

Fig. 3. Distribution of rare earth elements in the magmatic rocks of the Nalycheva sequence normalized by the chondrite composition [15].

0606/7 is different from the other samples by the character of the REE spectrum as well. Its spectrum shows about the same level of heavy and intermediate REEs and increased relative concentrations of light REEs (Fig. 3), which is similar to the spectra of samples of the tholeiite series. In the absolute concentrations of heavy and light REEs it is substantially higher than the other volcanites, since it is the most differentiated variety, judging from its bulk composition. This is also indicated by a clear negative anomaly of europium and a clear negative anomaly of strontium in the spider diagram for this sample, which provide evidence showing that the fractionation of plagioclase has also played a significant part in the differentiation.

The spider diagrams of all samples studied (Fig. 4) exhibit the typomorphic features of island arc volcanic rocks: deep negative anomalies in niobium and tantalum, less sharp negative anomalies in yttrium, titanium, and occasionally zirconium. A sharp positive anomaly in strontium is characteristic for all calc-alkaline varieties. Members of the calc-alkaline series show increased concentrations of large-ion lithofile elements. In contrast to these, sample 0606/7 has low concentrations of caesium, rubidium, and barium.

Thus, those volcanic rocks of Cape Nalycheva studied here which are definitely of island-arc origin are mostly represented by rocks of the calc-alkaline, moderately potassium series. Sample 0606/7, which is close to the tholeiite series in several of its parameters, seems also to be drawn from the calc-alkaline series. It should be borne in mind that, first, this sample contains a very large amount of secondary quartz and, secondly, the sample was taken from lava breccia adjacent to calc-alkaline volcanic rocks in a common column.

The Shipunskii Peninsula. The samples of the Kozlovskii suite (79/88, 79-2/88, 1173) and that of the Kubovskii suite (1052/8) when viewed in the discrimination diagrams SiO_2–K_2O, FeO*/MgO–FeO*, and FeO*/MgO–SiO_2 fall in the composition field of volcanic rocks of the tholeiite series, while samples 1048/10 and 95/1 from the Kubovskii suite are in the composition field of volcanic rocks of the calc-alkaline series (Fig. 2). The SiO_2–element variational diagrams (Fig. 2) show that the volcanic rocks studied form a field from basalts to dacites, with the tholeiites in these diagrams being distinguished by lower concentrations of titanium, magnesium, and phosphorus at the same levels of SiO_2 concentration.

DISCUSSION OF RESULTS AND CONCLUSIONS

As shown earlier [4], the Vakhil' Uplift structure (Fig. 1) has different structural–material complexes combined tectonically. The formations of the Nalycheva sequence on Cape Nalycheva, the Kozlovskii and the Kubovskii suites in the Shipunskii Peninsula developed during Maastrichtian?–Eocene time within an active volcanic zone exhibiting a volcanism of the island arc type. This temporal phase is in good correlation with the active phase of volcanism in the Kronotskii and Kamchatskii Mys peninsulas. In the present-day structure of Kamchatka (inset in Fig. 1),

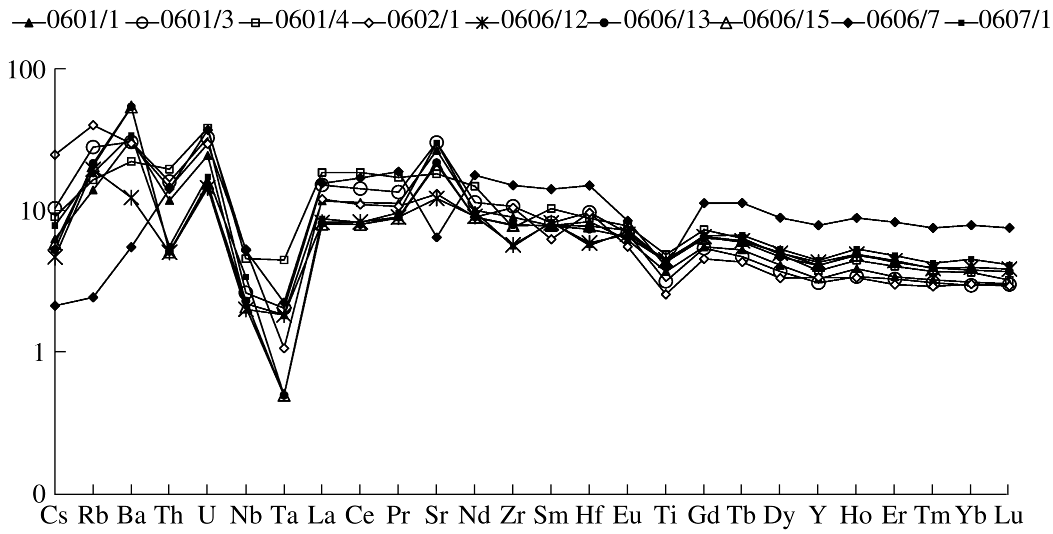

Fig. 4. Diagram showing the distribution of admixture elements for the magmatic rocks of the Nalycheva sequence normalized by the primitive mantle composition [18].

the eastern peninsulas are separated from the eastern range composed of island-arc complexes of the Ozernovskii–Valaginskii segment of the Achaivayam–Valaginskii arc by the Vetlovskii complex-structured accretionary complex of backarc origin, which marks an Oligocene–Early Miocene collision suture in the present-day structure [5, 14].

The data we have obtained show that Cape Nalycheva is dominated by volcanic rocks of the moderately potassium calc-alkaline series. Comparison of the Cape Nalycheva magmatic rocks with those of the Shipunskii Peninsula shows certain differences. The Kozlovskii suite in the Shipunskii Peninsula mostly contains effusive rocks of the tholeiite island arc series, while the Kubovskii suite also contains representatives of the calc-alkaline series. In the character of their column and rock composition the formations of the Nalycheva sequence are similar to rocks of the Kubovskii suite found in the southern and eastern parts of the Shipunskii Peninsula. The structural setting of Cape Nalycheva (Fig. 1), which along with the Shipunskii Peninsula is a relative autochthon overthrust by the Vetlovskii allochthon, allows us to consider the volcanogenic complexes of these structures as a fragment of the southern segment of the Kronotskii paleoarc.

Earlier it was found that there are differences between the composition of Late Cretaceous volcanic rocks of the Kronotskii paleoarc found in the northern (Kamchatskii Mys and Kronotskii) segments and that the compositions of the Eocene island arc effusives within these segments are identical [9]. The Upper Cretaceous island arc complexes in the Kamchatskii Mys peninsula are represented by island arc tholeiites. In the Kronotskii Peninsula, fragments of the arc are represented by plagiotholeiites of the Kamenistskii suite of Coniacian–Campanian–Maastrichtian age. The Eocene volcanic rocks found on Kamchatskii Mys and in the Kronotskii Peninsula are analogues and are represented by high alumina plagiotholeiites [10].

The magmatic rocks in the Shipunskii Peninsula and on Cape Nalycheva, which were generated simultaneously with the volcanic rocks found in the northern segment of the Kronotskii arc, differ from these considerably. Rocks of the calc-alkaline series are widely abundant there, especially on Cape Nalycheva, and no plagiotholeiites have been detected.

A change in the character of volcanism during the evolution of volcanic arcs and in different segments of the arcs is identified for many of these and is related to a change in the geodynamic regime in the subduction zone, and to the thickness and composition of the crust where the island arc originated [1, 2, 11, etc.]. The Kronotskii paleoarc is ensimatic and was developing in an oceanic crust [4, 8]. This conclusion is corroborated by the tholeiitic character of island arc volcanism typical of the northern segments of the arc: the Kamchatskii Mys and the Kronotskii, where the volcanism is specific to that locality. These specific features can be explained by the differences in geodynamic setting for different segments of the arc. In particular, the hypothesis was made that subduction for the Kula–Pacific spreading ridge occurred and the influence of the Hawaiian plume was hypothesized in the area of the Kamchatskii Mys segment [9]. However, if the hypothesis that the island arc formations on Cape Nalycheva and in the southeastern part of the Shipunskii Peninsula are a common formational complex is correct, it follows that the differences between the southern and the northern segments of the Kronotskii paleoarc are greater. The calc-alkaline type of volcanism, mostly characteristic for the southern segment of the paleoarc, is evolving under different geodynamic conditions compared with the ensimatic arcs. Calc-alkaline volcanism is an indicator of maturity for this arc and of its originating in a thicker crust. More studies are required to elucidate the causes of calc-alkaline volcanism found in the southern Kronotskii paleoarc. One possible explanation may be the hypothesis that the Shipunskii segment of the Kronotskii paleoarc was superimposed on an older island arc system.

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