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GEOCHEMISTRY

Pantellerite–Comendite–Alkali Granite Association of the Paleogene Bimodal Series of the Okhotsk–Chukotka Volcanoplutonic Belt

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Alkaline rocks have unique composition and have long attracted attention from geologists, petrologists, and geochemists as indicators of deep processes, magma generation conditions, and geodynamic settings.

In eastern Chukotka, acid alkaline rocks of supposedly Tertiary age have been found within the Amguema–Kanchalan volcanic field (AKVF) of the Okhotsk–Chukotka volcanoplutonic belt (OCVB) during systematic prospecting as early as in the 1950s–1960s. Two main varieties mapped as comendites and alkali granites–granite porphyry have been distinguished among the rocks. During later thematic works, we found one more variety, subvolcanic comendite–pantellerites, termed as pantellerites for convenience. Based on petrological and geological investigations [7, 8, and others], the subvolcanic and hypabyssal acid alkaline rocks were combined with subalkali mesites and basic rocks into a bimodal trachydacite–comendite–trachybasalt series of marginal–continental–riftogenic type (Nunligran, Tanyurer, and Tnekveem volcanogenic formations with subvolcanic and subplutonic counterparts).

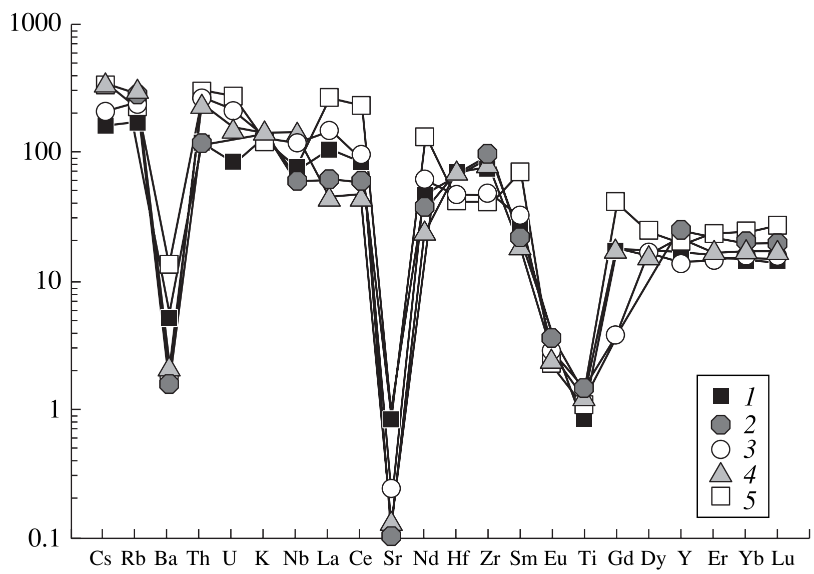

Fig. 1. Primitive mantle-normalized distribution pattern of rare and incompatible elements. Composition of the primitive mantle, according to [14]. (*1–5*) Alkali rocks: (*1*) PN-29-263 (pantellerite), (*2*) PN-201-1515 (comendite), (*3*) PN-203-1530 (comendite), (*4*) PN-201-1515A (comendite), (*5*) O-1408-3 (alkali granite).

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Table 1. Chemical compositions of minerals in acid alkaline rocks from the Paleogene bimodal series of the AKVF (wt %)

Mineral	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total	*f*	*l*
Sample PN-29-263 (subvolcanic pantellerite)													
Anorthoclase	–	–	–	–	–	–	–	3.67	8.24	1.31	–	–	–
Sanidine	68.31	0.01	19.90	0.07	0.04	0.01	0.00	0.00	5.48	5.89	99.70	–	14.63
Hedenbergite	47.87	0.36	0.47	0.09	29.57	0.81	0.03	20.13	0.65	0.01	99.97	99.83	0.41
Arfvedsonite	56.72	0.81	4.27	0.00	26.16	0.38	0.00	1.04	9.58	0.44	99.41	99.98	30.75
Enigmatite	40.76	7.63	0.76	0.23	43.25	0.81	0.00	0.39	5.73	0.03	99.58	99.99	0.57
Sample O-1408-3 (alkali granite)													
Sanidine	67.85	0.03	17.25	0.04	0.41	0.01	0.00	0.00	5.79	8.20	99.59	–	13.02
Aegirine	54.12	0.62	0.58	0.00	31.78	0.09	0.00	0.41	11.77	0.02	99.41	99.99	0.44
Arfvedsonite	48.85	1.56	1.08	0.02	34.80	1.27	0.26	2.17	6.60	1.27	97.87	98.60	0.81
Iron	–	0.59	1.74	0.98	112.0	0.69	0.00	–	–	–	116.01	100.0	–
Sample PN-201-1515 (subvolcanic comendite)													
Sanidine	68.66	0.01	18.4	0.00	0.62	0.02	0.00	0.00	4.71	8.12	100.55	–	13.52
Arfvedsonite	50.95	0.93	0.39	0.02	35.44	1.06	0.03	1.51	6.56	2.05	98.94	99.85	0.29
	53.00	1.17	0.25	0.01	30.76	0.47	0.47	0.00	4.54	8.12	0.01	98.32	0.15
Ferrorichterite	50.96	0.02	0.32	0.00	30.82	0.02	0.00	9.92	5.68	0.04	97.79	99.99	0.23
Sample PN-203-1530 (subvolcanic comendite)													
Sanidine	65.34	0.01	17.53	0.06	0.08	0.00	0.00	0.00	0.13	17.19	100.34	–	13.65
Albite	71.08	0.01	19.64	0.00	0.00	0.00	0.00	0.00	8.58	0.05	99.38	–	13.95
Arfvedsonite	49.14	1.98	0.38	0.14	34.2	0.48	0.00	1.00	6.63	1.82	95.78	99.99	0.30
Richterite	52.86	1.20	0.30	0.08	31.2	0.21	0.00	4.00	9.12	0.02	99.00	99.98	0.22
Ferrorichterite	52.76	0.72	0.40	0.11	35.49	0.55	0.03	1.11	9.28	0.01	100.48	99.83	0.29
Ilmenite	–	37.93	0.65	0.00	60.06	1.48	0.00	–	–	–	100.13	99.99	–

Note: Analyses were performed on an JXA-5A microprobe at the Analytical Center of the Far East Geological Institute (N.I. Ekimova, analyst). All Fe is given as FeO. (–)Not determined. $f = Fe/(Fe + Mg) \cdot 100$, $l = Al/(Al + Fe + Mg + Mn + Ti + Si) \cdot 100$, mole fractions. Incomplete analysis of anorthoclase was conducted by traditional microchemistry at the Far East Geological Institute (Zh.A. Shcheka, analyst).

The bimodal series was initiated on the thick granite–metamorphic crust (Eskimos or East Chukotka Massif), whereas the monomodal basalt–trachybasalt series was formed on the transitional crust.

The bimodal volcanic and plutonic rocks have Paleocene–Eocene age [4, 6, 9], whereas rocks of the monomodal series have Late Cretaceous–Paleogene age [1, 3, 10].

The acid members of the bimodal series are divided into subalkaline and alkaline rock associations. The subalkaline association comprises trachydacite and trachyrhyolite ignimbrites, as well as subvolcanic rhyolites and trachyrhyolites. The alkaline association includes pantellerites, comendites, alkali granites, and granite porphyries.

Subvolcanoes and dikes of pantellerites and comendites in AKVF are confined to the fault-related troughs and volcanic grabens (Korotkaya and Nygchekvaam [5]), while the subintrusions of alkali granites and granite porphyries occur in extended volcanic grabens (Varenai and Belye Uvali [5]).

The pantellerites have clinopyroxene–two-feldspar phenocryst assemblage, while comendites and alkali granites contain arfvedsonite–quartz–sanidine and arfvedsonite–richterite–quartz–two-feldspar phenocryst assemblages. The predominant minerals are quartz and K-feldspar, or feldspars (sanidine and albite, occasionally anorthoclase). The clinopyroxene in pantellerites is zonal, with a Na hedenbergite ($Aeg_{7.4}Di_{0.2}Hed_{92.4}$) core and aegirine–augite and aegirine rim. In addition to quartz, the groundmass contains abundant Na-alkaline minerals, such as aegirine, riebeckite, richterite, arfvedsonite, K-feldspar, and albite (Table 1), which reflect the Na specifics of the rocks (Fig. 2). Accessory minerals are enigmatite and ilmenite, while granites contain native iron (Table 1).

The alkaline rock association shows high Na content (at elevated K contents) and low contents of Mg, Ca, P, Ti, and bound water. The microelement composition is characterized by high concentrations of almost all REE, Y, Th, U, and HFSE (Ti, Zr, Nb, Hf, Ta) and negligible contents of Ba and Sr (Fig. 1, Table 3). It is interesting

Table 2. Chemical composition (wt %) and petrochemical modules of the representative samples of the alkaline rocks from the Paleogene bimodal series of the AKVF

Components	Sample no.							
	PN-29-263	72	6	317-3	994	PN-203-1530	PN-201-1515	O-1408-3
	1	2	3	4	5	6	7	8
SiO_2	71.30	71.41	71.29	75.22	75.42	76.18	74.96	74.82
TiO_2	0.16	0.16	0.22	0.21	0.13	0.23	0.28	0.21
Al_2O_3	14.49	14.18	15.36	11.49	11.34	10.57	10.60	13.52
Fe_2O_3	1.40	1.62	1.75	2.10	2.33	2.78	2.75	0.74
FeO	1.48	1.47	0.91	1.69	1.04	0.61	1.35	1.67
MnO	0.07	0.11	0.05	0.07	0.06	0.04	0.08	0.05
MgO	0.10	0.05	0.36	0.21	0.18	0.04	0.04	0.16
CaO	0.49	0.42	0.08	0.10	0.08	0.37	0.48	0.04
Na_2O	5.41	5.50	5.05	4.50	4.49	4.16	4.16	4.09
K_2O	4.20	4.33	4.21	4.03	4.31	4.21	4.51	3.99
P_2O_5	0.08	0.09	0.02	0.05	0.01	0.03	0.02	0.10
H_2O	0.05	0.05	0.20	0.03	0.18	0.16	0.14	0.01
LOI	0.28	0.45	0.31	0.01	0.20	0.57	0.22	0.19
Total	99.51	99.79	99.85	99.71	99.77	99.91	99.54	99.55
f	0.93	0.96	0.79	0.91	0.90	0.97	0.98	0.89
a	0.93	0.96	0.84	1.02	1.05	1.08	1.06	0.82
n	0.66	0.66	0.65	0.63	0.61	0.60	0.58	0.61
c	0.03	0.03	0.01	0.01	0.01	0.03	0.04	0.01
l	1.04	1.01	1.19	0.97	0.94	0.90	0.87	1.21

Note: Petrochemical modules (in atomic weight percents): a = (Na + K)/Al, n = Na/(Na + K), c = Ca/(Ca + Na + K), f = Fe/(Fe + Mg) and l = Al/(Ca + Na + K). The chemical analyses were carried out at the Far East Geological Institute (L.I. Alekseeva, analyst). Samples taken from collections: (Sample 72) V.G. Silkin, 1966; (Sample 6) M.V. Filimonov, 1972; (Sample 317-3) E.E. Petrenko, 1979; (Sample 994) G.I. Bogomolov, 1986. (1–3) Subvolcanic and subintrusive pantellerites from the Korotkaya River, Kytepnaivaam River, Chumveem River basins; (4–6) subvolcanic comendites, Ostrokamennyi Massif, Mt. Vetrennaya, Terkenmemveem River basin; (7) subvolcanic comendite, Mt. Greben, (8) alkali granite, Lake Alyamgytgyn.

that rocks of the studied association are the only rocks with distinct Eu anomaly in the OCVB [7 and others]. Alkali granites exhibit the maximal Eu anomaly and the highest REE (especially, LREE) abundance and some other features that differ from those of other members of the association (Table 3, Figs. 1–3).

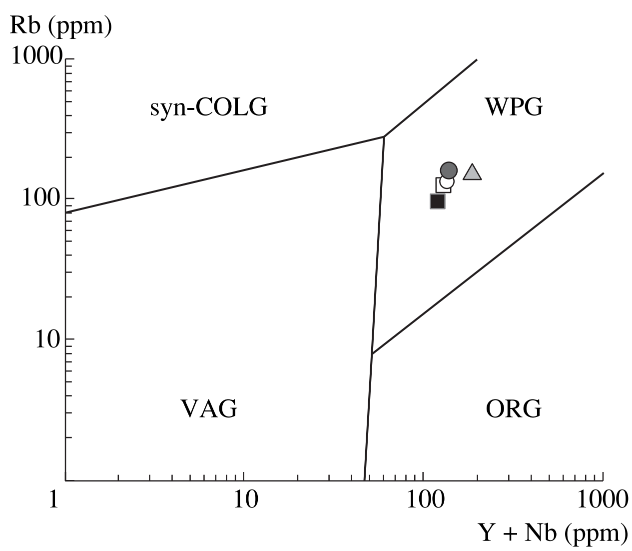

Fig. 2. Discriminant diagram [13] for acid alkali rocks of the AKVF. Symbols are as in Fig. 1.

In terms of Th, Ta, and La contents (Table 3, Fig. 3) and Ta/Th values, the studied rocks are plotted in the within-plate rock field [7, 11].

The affiliation of pantellerite–comendite–alkali granite association to the typical within-plate rocks is also observed in the Pearce [13] and La–Ta diagrams (Figs. 2, 3).

Comparison with the rocks of typical geodynamic settings indicates that the Paleogene pantellerites, comendites, and alkali granites of the Chukotka branch of the OCVB are identical to the acid members of the within-plate and marginal–continental–riftogenic bimodal complexes, and in some features, to anorogenic granites [11–13].

Of special interest is the age of the Paleogene alkaline association. We obtained new K–Ar dates on acid alkaline rocks of the Amguema–Kanchalan volcanic field (Table 4).

The K–Ar dating of K-feldspar from the acid alkali rocks of different segments of the AKVF indicates their

Table 3. Microelement compositions (ppm) and some other parameters in the representative samples of the acid alkaline rocks of the Paleogene bimodal series of the AKVF

Components	PN-29-263*** pantellerite	PN-201-1515** comendite	PN-203-1530* comendite	C-1408-3* alkali granite	PN-201-1515A* comendite
Cr	1.3	8.0	19.35	12.68	21.22
Ni	6.70	1.0	0.83	10.10	0.94
Co	0.07	1.0	0.18	1.96	0.09
Sc	1.0	–	1.19	6.91	2.16
V	8.3	6.0	1.01	8.03	2.04
Cu	–	9.0	4.54	22.20	2.44
Zn	151	–	278.07	200.13	370.96
Rb	95	160	138.65	125.11	156.52
Cs	1.12	–	1.43	2.35	2.36
Ba	32	10	10.78	82.67	13.58
Sr	17	1.8	4.65	14.80	2.46
Ga	–	–	22.45	32.14	27.07
Ge	–	–	1.90	2.67	2.49
Ta	3.45	–	5.74	3.02	4.48
Nb	49	39	76.75	49.39	92.7
Hf	19.6	–	12.83	11.93	20.17
Zr	754	960	467.32	407.52	769.67
Y	68	97	54.63	78.40	87.26
Th	10.4	–	24.08	26.15	21.99
U	1.8	–	4.63	6.15	3.39
La	65.80	38	91.93	171.04	28.71
Ce	136.0	–	140.83	374.81	75.44
Pr	–	–	20.83	43.28	7.58
Nd	55.50	48	75.05	160.27	30.50
Sm	10.40	8.40	12.84	27.74	7.58
Eu	0.52	0.54	0.45	0.35	0.42
Gd	9.17	–	13.80	21.62	9.88
Tb	–	2.20	1.96	3.2	1.66
Dy	–	–	10.78	16.25	10.74
Ho	–	–	2.21	3.21	2.41
Er	–	–	6.33	10.20	7.13
Tm	–	–	1.0	1.50	1.11
Yb	6.41	8.60	6.91	10.75	7.55
Lu	–	1.30	0.99	1.80	1.16
B	6.4	8.00	9.0	5.5	20.17
ΣTR + Y	>403.28	>204.04	440.54	924.42	279.13
Eu/Eu*	0.16	–	0.27	0.04	0.15
Rb/Sr	5.94	88.88	29.82	8.45	63.63
La/Ta	19.07	10.86	16.02	56.64	6.41
Th/Ta	3.01	2.86	4.20	8.66	4.91
Ba/Nb	0.66	0.26	0.14	1.67	0.15
Ba/Zr	32.71	10.11	10.90	83.23	13.73
$^{87}Sr/^{86}Sr \pm 2s$	–	–	–	0.70765 ± 8	–

Note: Chemical compositions of the rocks are presented in Table 2. Sample PN-201-1515A is a replication of sample PN-201-1515. The Sr isotopic composition and contents of REE and other rare elements were analyzed at the following analytical centers: (*) Vinogradov Institute of Geochemistry and Analytical Chemistry, Irkutsk, (**) Geological Institute, Moscow, (***) US Geological Survey, Denver (E.V. Smirnova, G.P. Sandimirova, V.I. Lozhkin, and S.M. Lyapunov, analysts). (–) Not analyzed.

Table 4. Results of the K–Ar age determinations in the acid alkaline rocks of the trachydacite–comendite–trachybasalt rock association of the AKVF

Sample	Geological body	Mineral/Rock	Potassium, % ±σ	$^{40}Ar_{rad}$, (ng/g) ±σ	Age, Ma ±2σ
PN-201-1515	Stock, Mt. Greben	Sanidine/comendite	5.57 ± 0.06	23.19 ± 0.08	59.0 ± 1.4
PN-29-263	Extrusion, Korotkaya River, peak 496.1	Sanidine/pantellerite	4.79 ± 0.05	20.57 ± 0.07	60.9 ± 1.4
O-1408-3	Stock, Lake Alyamgytgyn	Sanidine/alkali granite	6.09 ± 0.06	25.6 ± 0.05	60.9 ± 2.0
6*	Extrusion, Chumeveem River	Pantellerite	–	–	60.0 ± 1.6
502-6**	Stock, Mt. Greben	Comendite	3.85 ± 0.04	15.7 ± 0.03	58.0 ± 1.0

Note: K–Ar dating was performed by isotope dilution with ^{38}Ar tracer on an MI-1201 IG mass spectrometer at the Laboratory of Isotope Geochemistry and Geochronology of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry; K was determined by flame spectrophotometry (M.M. Arakelyants and V.A. Lebedev, analysts). Absolute K–Ar ages estimated at the Northeastern Complex Research Institute, Magadan: (*) data of M.V. Filimonov (1972) (I.A. Zagruzina, analyst); (**) data of N.I. Romanov et al. (1999), (A.D. Lyuskin, analyst).

almost simultaneous formation in Paleocene within a narrow range of 59–61 Ma, which coincides with dates obtained by M.V. Filimonov and N.I. Romanov et al. (Table 4). Since the K–Ar feldspar dates were not supported by the K–Ar datings on other minerals or other isotope methods, the obtained values can be considered as an upper age limit of the corresponding rock.

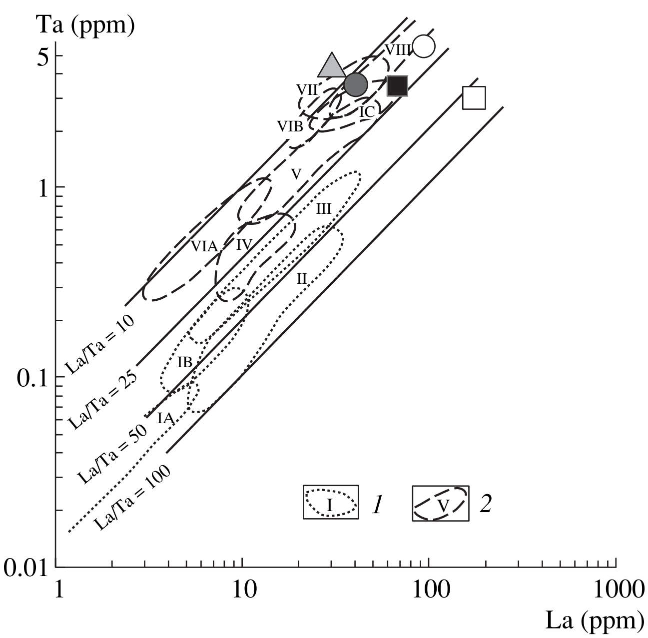

Fig. 3. La vs. Ta contents in the acid alkaline rocks of the bimodal series of the AKVF. (*1, 2*) Rock fields (according to [2]: (*1*) island arcs and active continental margins, (*2*) intraplate associations. Other legends as in Fig. 1.

The intraformational position of the acid alkali rocks inferred from absolute ages is well consistent with the facts that acid alkali rocks intrude the Paleogene olivine basalts on the left bank of the Korotkaya River and the Late Senonian acid pyroclastic sequence on Mt. Greben. In turn, the acid alkali rocks are cut by the dikes of the Paleogene olivine trachybasalts.

Geological data and age values indicate that the Na-alkaline volcanoplutonic manifestations in eastern Chukotka were controlled by sublatitudinal and sublongitudinal extensional structures. These processes were simultaneous with the opening of pull-apart basins and large-volume basaltic volcanism.

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