Doklady Earth Sciences, Vol. 389, No. 2, 2003, pp. 195–198. Translated from Doklady Akademii Nauk, Vol. 388, No. 5, 2003, pp. 664–668.

GEOCHEMISTRY

New Data on Geochemistry of the Oldest (2.95–3.05 Ga) Andesite Association in Eastern Fennoscandia

S. A. Svetov

Presented by Academician V.A. Koroteev July 5, 2002

Received July 29, 2002

The paper presents results of geochemical study of the oldest (2.95–3.05 Ga) andesite association of the Chalka volcanic structure, which is a member of the Archean Vedlozero–Segozero greenstone belt located in the southeastern part of the Fennoscandian Shield. The Vedlozero–Segozero greenstone belt extends longitudinally over about 300 km (width 50–60 km) and includes several local greenstone structures (Hautavaara, Koikary, Palasel'ga, Semch, Sovdozero, Oster, and others) [1].

The greenstone belt consists of komatiite–basalt associations (2.95–3.05 Ga) and volcanic andesitic–dacitic rocks of two age ranges (2.95–3.05 and 2.85–2.90 Ga) [2].

Based on facies-formational analysis, ancient andesite associations of the Hautavaara make up a series of central-type paleovolcanoes (Nyal'mozero, Ignoila, Hautavaara, and Chalka) formed in a shallow marine environment [3]. The U–Pb zircon dating yielded an age of 2995 ± 20 Ma for subvolcanic andesidacite from the Ignoila neck [4], 3000 ± 40 Ma for subvolcanic andesites from the Palasel'ga structure, and 3020 ± 10 Ma for subvolcanic stock from the Oster structure [5].

The most complete section of the oldest basaltic andesite–andesite–dacite association crops out in the Chalka paleovolcanic zone in the northern part of the Hautavaara structure [6, 7]. Volcanic structures are preserved in the studied rocks owing to metamorphism of the epidote–amphibolite facies (andalusite–sillimanite type).

The vent zone of the Chalka paleovolcano consists of two necks, which are rimmed by boulder and agglomerate tuffs of the facies of explosive eruptions and agglomerate flows, and lenticular intercalations of flows of coarse pillow lava, clastolava, and massive lava. The latter is characterized by lumpy and amygdaloidal structures, as well as the presence of pillow breccia and various (boulder, agglomerate, and lapilli) tuffs. The lenticular beds are from 15 to 50–70 m thick and 500–700 m long.

The northern neck consists of microporphyritic andesites in the central part, coarse-porphyritic and glomeroporphyritic andesites in the marginal parts, and agglomeratic andesites at the southern margin. The coarse-porphyritic andesidacites grade into clastolavas and pillow lavas.

The southern neck of massive fine-grained andesites is confined to tuffs. The vent zone includes numerous dikes of andesites, dacites, and less common rhyolites and diorites.

With increasing distance from the vent zone, lavas become more homogeneous and acid. Massive and amygdaloidal varieties, which prevail in the distal zone, intercalate with lapilli and psammitic tuffs. The lava flows are from a few meters to 40–60 m thick, where the tuff interbeds are 0.5–1.5 m thick.

The total thickness of the reconstructed section of the Chalka paleovolcano is 2.5 km. The facies composition of eruption products suggests that this structure is a polygenic stratovolcano with nearly equal proportions of lavas and tuffs.

In order to carry out precision geochemical study, we took the least altered samples of different facies from the entire section of the paleovolcano. The major elements were analyzed by the XRF method on a VRA-33 analyzer at the Geological Institute, Karelian Research Center. The measurement error was <3% for elements with a concentration of >0.5 wt % and 5% for elements with a concentration of <0.5 wt %. Trace and rare earth elements were analyzed by the ICP-MS method in the Analytical Laboratory of the Institute of Geology and Geochemistry, Ural Division, Russian Academy of Sciences. The measurement error was less than 2%. Classification diagrams presented in this work include previously published data on Chalka paleovolcano (80 analyses) and Ignoila paleovolcano (140 analyses) [3, 7].

Institute of Geology, Karelian Research Center, Russian Academy of Sciences, Pushkinskaya ul. 11, Petrozavodsk, 185610 Karelia, Russia

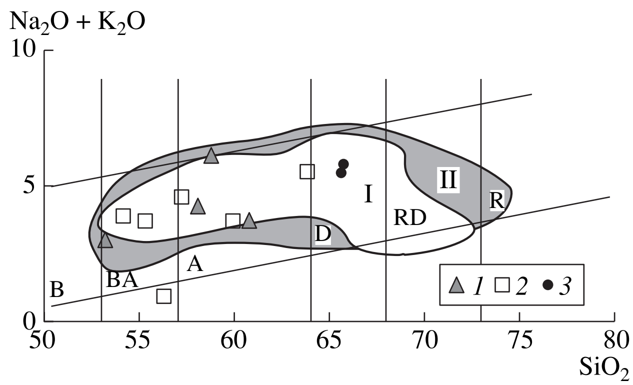

Fig. 1. ($Na_2O + K_2O$) vs. SiO_2 plot for rocks of the oldest andesite association of the Vedlozero–Segozero greenstone belt. (*1*) Massive lava, (*2*) tuff, (*3*) subvolcanic adakite. Fields: (I) volcanic and subvolcanic rocks of the Chalka paleovolcano [3, 7], (II) volcanic and subvolcanic rocks of the Ignoila paleovolcano [3, 7]. (B) Basalt, (BA) basaltic andesite, (A) andesite, (D) dacite, (RD) rhyodacite, (R) rhyolite.

In terms of SiO_2 and ($Na_2O + K_2O$) contents, lavas and tuffs of the Chalka paleovolcano can be classified as basaltic andesites, andesites, and less common rhyodacites of moderate alkalinity (table, Fig. 1). The rocks are most differentiated (from basalts to rhyolites) in the Ignoila structure. Volcanic rocks are characterized by the predominance of Na over K, which is typical of the island-arc andesite series [8]. They exhibit high Cr and Ni contents in primary melts and high Co, Zr, and Y contents in late differentiates.

The Sr/Y (<12), Ce/Nb (<4.5), and Th/Nb (<0.72) ratios in Chalka volcanic rocks are close to those of island arc-series. The lavas show LREE-rich patterns ($(La/Sm)_n = 1.67 \pm 0.98$) with nearly flat HREE patterns ($(Gd/Yb)_n = 1.26 \pm 0.14$, $(Ce/Yb)_n = 2.75 \pm 1.69$). The tuffs are also characterized by a similar REE distribution, but the background REE content is higher (Fig. 2). The Eu anomaly is insignificant.

The PM-normalized [9] spidergrams for volcanic rocks and tuffs of the Chalka paleovolcano are similar to those for the basalt–andesite–dacite–rhyolite series of the Archean Kamennoe Ozero structure in eastern Fennoscandia [10] and the Kuril–Kamchatka island arc [11].

Subvolcanic rocks of the Chalka paleovolcano belong to the adakite series and differ from calc-alkaline dacites by very high contents of the following elements (ppm): Ba (470), Sr (480), Zr (218), and Cs (7.28). Contents of HREE and other elements are low (ppm, unless otherwise stated): MgO (1.7–1.9 wt %), Ni (200), Co (10), V (63–66), Nb (4.8–5.2), Y (9–11), Sc (5–6), and Ta (0.25–0.35) (table). The studied subvolcanic rocks correlate with adakites from the Circum-Pacific ocean–continent transitional zones of Kamchatka, Japan, Ecuador, and Costa Rica [12]. These adakites are characterized by the following geochemical features: $SiO_2 > 56$ wt %; $3.5 < Na_2O < 7.5\%$; high Ba and Sr contents; and low Ni, Y, Nb, Ta, and HREE contents. In the Sr/Y–Y and $(La/Yb)_n$–Yb_n diagrams (Fig. 3), data points of subvolcanic rocks are plotted in the field of typical adakite series (near adakites of the Southeast Japanese volcanic arc). Data points of dikes in Ignoila and Hautavaara taken from the previous works also belong to the adakite series. As compared to

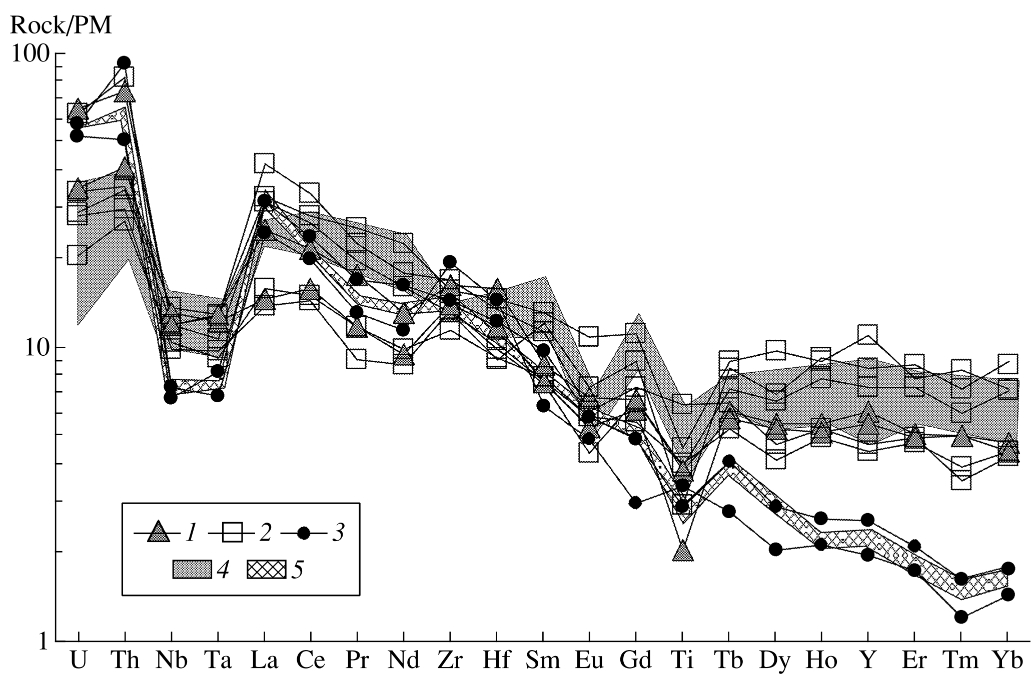

Fig. 2. PM-normalized [9] spidergram for andesite association of the Chalka paleovolcano. (*1*) Massive lava; (*2*) tuff; (*3*) adakite; (*4*) average composition of the basalt–andesite–dacite association of the Kamennoe Ozero structure [10]; (*5*) average adakite from Cook Island [12].

Chemical composition of rocks of the andesite association in the Chalka paleovolcanic zone (oxides are given in wt %; others, in ppm)

Component	103-5	101-1	C556-1	111-3	104-1	104-5	101-2	110-8	102-2	105-1	103-2	105-7
	Island-arc basaltic andesite and andesite										Adakite	
	M	M	M	MP	PT	ATF	ATF	ATF	PT	PT	D	D
SiO_2	58.78	58.04	60.76	53.16	59.94	54.14	57.40	63.80	55.32	56.32	65.66	65.78
TiO_2	0.45	0.76	0.87	0.83	0.64	1.82	0.86	1.40	0.99	0.88	0.74	0.63
Al_2O_3	14.83	15.00	16.02	18.31	15.26	15.10	16.64	15.72	15.22	13.87	14.26	16.37
Fe_2O_3	3.44	1.73	0.81	2.33	1.56	3.52	1.41	1.76	1.36	2.08	2.07	2.52
FeO	4.46	7.62	6.55	7.71	4.88	4.74	6.11	2.72	9.30	7.84	3.88	1.87
MnO	0.140	0.200	0.130	0.170	0.14	0.320	0.130	0.180	0.300	0.366	0.070	0.053
MgO	4.96	3.88	3.27	4.00	4.94	3.61	4.77	1.17	6.55	5.23	1.76	1.90
CaO	5.32	6.17	3.58	7.29	7.86	11.20	6.17	5.88	4.06	9.55	4.76	4.14
Na_2O	4.66	3.27	2.23	1.55	3.02	2.56	2.56	3.71	1.28	0.51	3.86	4.48
K_2O	1.48	0.98	1.50	1.48	0.65	1.30	2.00	1.80	2.41	0.39	1.72	1.30
H_2O	0.11	0.09	0.26	0.13	0.09	0.10	0.08	n.d.	0.06	0.08	0.11	0.11
P.p.p.	1.23	1.96	3.83	2.86	1.15	1.24	1.62	1.28	2.85	2.30	0.72	0.66
Total	99.86	99.70	99.81	99.82	100.13	99.93	99.75	99.42	99.70	99.70	99.62	99.81
Cr	392	272	380	496	236	180	541	165	619	614	202	201
Ni	157	150	113	139	368	86	184	36	549	363	35	24
Co	25.4	22.3	18.5	29.1	58.2	23.7	39.5	15.2	81.9	45.2	9.9	9.6
V	140	131	118	263	188	129	232	144	252	205	66	63
Pb	7.05	7.38	6.55	11.63	7.76	7.88	3.59	9.85	3.02	9.05	8.55	24.60
Rb	11.62	9.92	15.11	55.04	20.61	45.52	40.57	52.26	8.02	10.04	61.57	43.37
Ba	179.63	107.62	345.81	312.05	196.01	280.64	248.80	343.42	68.37	79.12	476.91	447.77
Sr	275.46	299.87	236.46	218.99	258.32	463.83	148.83	385.57	36.51	276.66	472.21	486.92
Nb	9.302	8.149	5.260	8.524	8.467	6.375	6.990	8.463	9.747	7.398	5.207	4.770
Zr	157.34	155.31	135.73	183.55	146.17	180.51	151.75	188.99	175.76	129.08	218.35	161.96
Y	27.66	24.82	19.02	24.98	38.89	16.68	33.54	21.36	49.69	20.11	8.96	11.69
Th	3.533	2.993	3.756	6.280	2.896	6.092	2.537	6.987	3.003	2.275	7.840	4.258
La	10.037	5.590	2.331	17.260	21.413	26.221	9.485	28.716	22.215	10.933	16.894	21.329
Ce	28.320	12.799	7.115	38.479	47.175	59.220	25.466	59.354	49.402	26.469	35.648	42.373
Pr	3.234	1.610	0.861	4.849	5.435	6.107	2.498	6.227	6.995	3.240	3.600	4.702
Nd	12.834	8.391	5.771	17.819	21.862	29.686	11.877	24.201	30.571	13.350	15.442	21.942
Sm	3.367	2.726	2.675	3.873	5.375	5.399	3.349	5.019	5.863	3.530	2.807	4.326
Eu	0.903	0.835	0.722	1.135	1.235	1.358	0.740	1.025	1.817	0.976	0.821	0.975
Gd	3.641	3.006	2.601	3.959	5.330	3.577	3.990	4.389	6.602	3.352	1.768	2.922
Tb	0.651	0.595	0.465	0.619	0.916	0.548	0.777	0.701	0.968	0.570	0.302	0.438
Dy	4.066	4.128	3.128	3.901	5.100	2.884	4.844	3.444	7.177	3.047	1.521	2.117
Ho	0.902	0.931	0.706	0.850	1.504	0.650	1.277	0.866	1.468	0.812	0.349	0.433
Er	2.445	2.109	1.732	2.385	4.208	1.406	3.498	2.362	3.772	2.275	0.841	1.013
Tm	0.374	0.313	0.259	0.374	0.533	0.186	0.439	0.264	0.624	0.290	0.095	0.122
Yb	2.355	2.104	1.769	2.202	4.440	1.381	3.528	2.099	3.541	2.201	0.713	0.868
Lu	0.341	0.261	0.235	0.332	0.663	0.170	0.515	0.321	0.539	0.320	0.090	0.112
U	0.732	0.654	0.898	1.371	0.605	1.465	0.586	1.313	0.707	0.431	1.207	1.093
Ga	15.55	17.54	15.20	27.25	17.57	19.57	14.03	17.36	15.97	15.70	18.06	19.59
Sc	21.04	19.14	17.11	24.22	31.07	14.42	37.56	13.42	32.57	24.77	6.58	5.19
Hf	3.655	3.417	3.291	4.880	2.797	3.991	3.051	4.162	4.491	2.864	4.476	3.809
Ta	0.503	0.536	0.414	0.528	0.440	0.395	0.395	0.520	0.527	0.381	0.283	0.340
Cs	1.54	0.81	0.87	2.79	1.66	3.26	4.27	2.53	0.76	0.57	7.28	2.90
Be	1.01	0.87	0.85	1.48	1.16	1.84	0.64	1.21	1.17	0.89	1.76	1.44

Notes: Structural varieties: (M) massive lava, (PC) pillow core, (MP) massive porphyric, (ATF) agglomerate tuff fragment, (PT) psammitic tuff, (D) subvolcanic rock. (n.d.) Not detected.

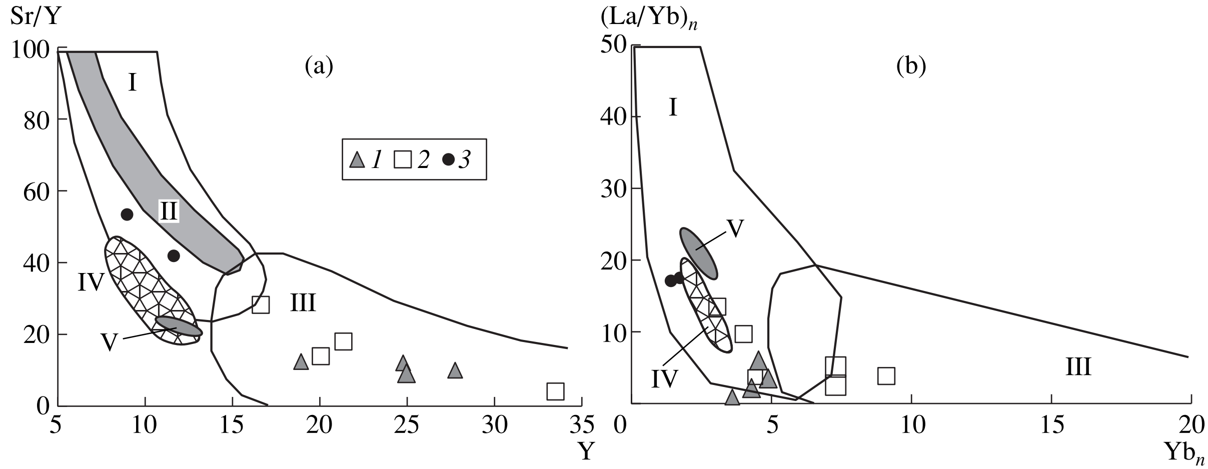

Fig. 3. (a) Sr/Y vs. Y and (b) $(La/Yb)_n$ vs. Yb_n plots for andesite association of the Chalka paleovolcano. (*1*) Massive lava; (*2*) tuff, (*3*) adakite. Fields: (I) typical adakites [13], (II) adakites of southeastern Japan [13], (III) island-arc andesite–dacite–rhyolite association, (IV) subvolcanic rocks of the Hautavaara paleovolcano [3, 7], (V) subvolcanic rocks of the Ignoila paleovolcano [3, 7].

present-day adakites, adakites of the Chalka paleovolcano are enriched in Cr (up to 200 ppm).

At present, adakites are known in many areas of Archean greenstone belts, such as Lumbi Lake and Red Lake (2.9–3.0 Ga) [13] and Birch Uchi (2739 ± 2 Ma) [14] in the northern Superior Craton (Canada), upper BADR association (2875 ± 2 Ma) in the Kamennoe Ozero structure (eastern Fennoscandia), and some others [10].

Based on the lithology, cross section, and geochemical characteristics, differentiated basaltic andesite–andesite–dacite–rhyodacite series and subvolcanic adakitic rocks of the Chalka structure are relicts of the oldest volcanic arc in eastern Fennoscandia. The development of this arc (3.05–2.85 Ga ago) resulted in the formation of the Vedlozero–Segozero greenstone belt.

ACKNOWLEDGMENTS

We are grateful to I.V. Semenov (Institute of Geology and Geochemistry, Ural Division, Russian Academy of Sciences) for support of investigations, Yu.A. Ronkin for analytical works, and A.I. Svetova (Institute of Geology, Karelian Scientific Center, Russian Academy of Sciences) for help in field study of objects and discussion of data.

This study was supported by the Program "Archean Magmatic Systems of Ocean–Continent Transitional Zones in Fennoscandia" (Institute of Geology, Karelian Scientific Center) and the Russian Foundation for Basic Research, project nos. 01-05-64228 and 02-05-97507.

REFERENCES

1. Svetov, S.A., *Komatiit-toleitovye assotsiatsii Vedlozersko-Segozerskogo zelenokamennogo poyasa Tsentral'noi Karelii* (Komatiite–Tholeiite Associations of the Vedlozero–Segozero Greenstone Belt), Petrozavodsk: Karel. Nauch. Tsentr Ross. Akad. Nauk, 1997.
2. Svetov, S.A., Svetova, A.I., and Huhma, H., *Geochem. Int.*, 2001, vol. 39, Suppl. 1, pp. s24–s38.
3. Svetova, A.I., *Arkheiskii vulkanizm Vedlozersko-Segozerskogo zelenokamennogo poyasa Karelii* (Archean Volcanism of the Vedlozero–Segozero Greenstone Belt), Petrozavodsk: Karel. Nauchn. Tsentr Ross. Akad. Nauk, 1988.
4. Sergeev, S.A., Geology and Isotope Geochronology of Archean Granite–Greenstone Complexes in Central and Southeastern Karelia, *Extended Abstract of PhD. (Geol.–Miner.) Dissertation*, Leningrad, 1989.
5. Lobikov, A.F., in *Problemy izotopnogo datirovaniya protsessov vulkanizma i osadkoobrazovaniya* (Problems of the Isotope Dating of Volcanism and Sedimentation), Kiev, 1982, pp. 90–91.
6. *Vulkanizm arkheiskikh zelenokamennykh poyasov Karelii* (Volcanism in Archean Greenstone Belts of Karelia), Sokolov, V.A., Ed., Leningrad: Nauka, 1981.
7. *Stratigrafiya dokembriya Karelii: Opornye razrezy verkhnearkheiskikh otlozhenii* (The Precambrian Stratigraphy in Karelia), Rybakov, S.I., Ed., Petrozavodsk: Karel. Nauchn. Tsentr Ross. Akad. Nauk, 1992.
8. Bogatikov, O.A. and Tsvetkov, A.A., *Magmaticheskaya evolyutsiya ostrovnykh dug* (Magmatic Evolution of Island Arcs), Moscow: Nauka, 1988.
9. Sun, S.S. and McDonough, W.F., *Geol. Soc. Spec. Publ.*, 1989, vol. 42, pp. 313–345.
10. Puchtel, I.S., Hofmann, A.W., Amelin, Yu.V., *et al.*, *Geochim. Cosmochim. Acta*, 1999, vol. 63, pp. 3579–3595.
11. Kepezhinskas, P., McDermott, F., Defant, M.J., *et al.*, *Geochim. Cosmochim. Acta*, 1997, vol. 3, pp. 577–600.
12. Matrin, H., *Lithos*, 1999, vol. 46, pp. 411–429.
13. Hollings, P., Wyman, D., and Kerrich, R., *Lithos*, 1999, vol. 46, pp. 137–161.
14. Hollings, P. and Kerrich, R., *Contrib. Mineral. Petrol.*, 2000, vol. 139, pp. 208–226.