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GEOCHEMISTRY

Mesoarchean Island-Arc Association in the Central Karelian Terrane, Fennoscandian Shield: New Geochronological Data

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Most Archean granite–greenstone terranes contain subduction–accretionary complexes composed of tectonic fragments of island arcs, back-arc basins, obducted oceanic plateaus, microcontinents, and associated sedimentary assemblages [1, 2].

This work presents new geochronological data on the oldest (Mesoarchean) island-arc association of the Central Karelian terrane (Fennoscandian Shield), which is located in the southeastern part of the Karelian Craton in the western framing of the Vodlozero block.

This terrane is characterized by a high degree of preservation of stratotectonic associations (STA) of the island-arc BADR-adakite (3.05–2.95 Ga), oceanic komatiite–basalt (3.05–2.95 Ga), and continental-margin dacite–rhyolite–adakite (2.90–2.85 Ga) types.

Fragment of the oldest island-arc complex in this terrane consists of the relicts of paleovolcanic edifices made up of differentiated basaltic andesite–andesite–dacite–rhyolite associations of the calc-alkaline series. The rocks are represented by boulder, agglomerate, and fine tuffs intercalated with coarse-pillow, massive, and amygdaloidal lavas, lavabreccias, and clastolavas up to 2.5 km thick (Fig. 1).

The best-preserved island-arc sequences occur in the southwestern part of the terrane within the Hautavaara megastructure, which includes the Hautavaara, Ignoila, Chalka, and Njalmozero paleovolcanoes. The U–Pb age data on the Ignoila structure are as follows: 2945 ± 19 Ma [3] for andesite lavas and 2995 ± 20 Ma for the andesidacite neck [4].

Based on subsequent investigations, island-arc (calc-alkaline BADR-series) rocks were divided into the subvolcanic–volcanic phase with adakitic characteristics and the volcanic phase with tholeiitic characteristics [5, 6].

The island-arc complex is overlain by mafic allochthon composed of komatiite–basaltic association with a Sm–Nd age of 3179 ± 45 Ma (ε_{Nd} = + 1.9, MSWD = 0.61, $n = 6$) for the lower and 2962 ± 51 Ma (ε_{Nd} = + 1.9, MSWD = 1.3, $n = 8$) for the upper part of the sequence. Mafic allochthon is locally replaced by the mafic graywacke sequence (e.g., Ignoila domain).

The aim of our study was to refine the timing of initiation and closure of the island-arc system. Therefore, we investigated adakites that are generated through the melting of hot oceanic crust at the initial stages of low-angle subduction [7, 8].

Adakites found in the Hautavaara, Ignoila, Chalka, and other structures of the Central Karelian terrane belong to andesite–dacites in terms of SiO_2 content (56–69 wt %) and differ from calk-alkaline rocks by their higher contents of Na_2O, K_2O, Al_2O_3, and Mg# (>0.4), as well as by their depleted HREE distribution.

The Sm–Nd systematics of adakites was studied at the Zavaritskii Institute of Geology and Geochemistry by isotope dilution with MS-termination on a high-pre-

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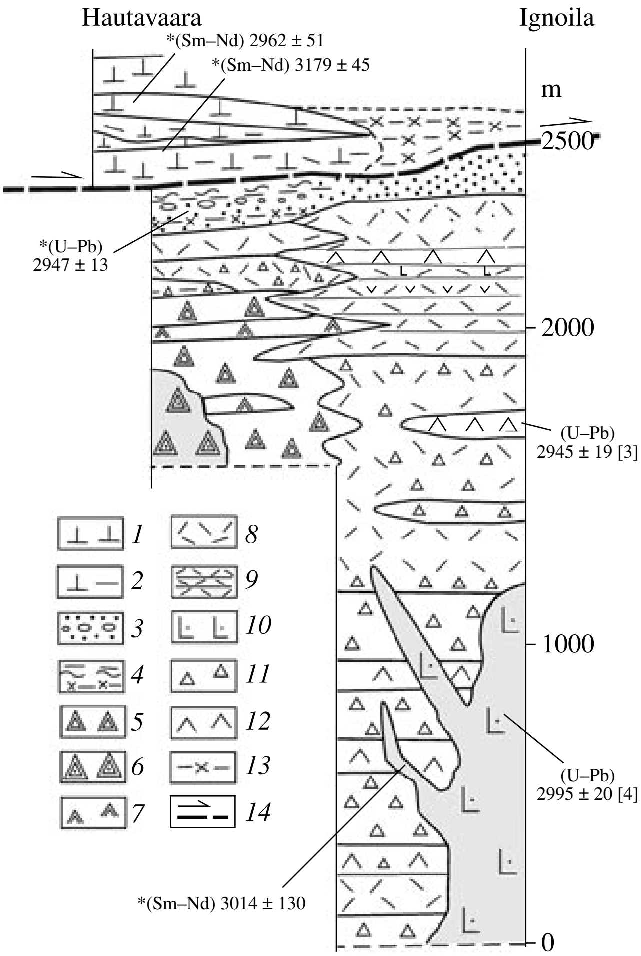

Fig. 1. Schematic structure of the island-arc stratotectonic association within the Hautavaara megastructure. Cross-section from the Hautavaara to Ignoila paleovolcanoes, NW–SE orientation, distance along the profile is 15 km. Asterisks denote new geochronological data described in the text. (*1*) Komatiite lavas; (*2*) komatiite tuffs; (*3*) terrigenous graywackes, arkoses, and monoconglomerates; (*4*) volcanosedimentary sequence (redeposited tuffs, tuffites, tuffstones, silicites, graphitic siltstones, and mafic graywackes); (*5*) agglomerate and lapilli dacite tuffs; (*6*) explosive dacite breccia; (*7*) dacite lavas and lavabreccia; (*8*) andesidacite psammitic tuffs; (*9*) banded andesidacite tuffs; (*10*) subvolcanic dacites; (*11*) basaltic andesite and andesite agglomerate tuffs; (*12*) lavas and lavabreccias of basaltic andesites and andesites; (*13*) mafic graywackes; (*14*) plane and displacement direction of mafic allochthon.

cision Finnigan MAT-262 mass spectrometer. The measurement accuracy was less than 0.5 for $^{147}Sm/^{144}Nd$ and less than 0.002% for $^{143}Nd/^{144}Nd$. Previous data obtained on a VG Sector 54 mass spectrometer at the Isotope Laboratory of the Geological Survey of Finland (Espoo) were also used. The measurement accuracy of $^{147}Sm/^{144}Nd$ was 0.4%; $^{143}Nd/^{144}Nd$ was normalized to $^{146}Nd/^{144}Nd = 0.7219$; and the Nd La Jolla standard yielded an average ratio of $^{143}Nd/^{144}Nd = 0.511851 \pm 6$ ($n = 10$).

It was found that initial ε_{Nd} ratios for adakite series of the Ignoila paleovolcano vary from +0.7 to +2.3 (Table 1). Model ages according to the De Paolo model [9] vary from 2956 to 3092 Ma. Adakites from the adjacent Chalka paleovolcano have ε_{Nd} from +0.8 to +2.0 at model ages from 2979 to 3071 Ma. Taking into consideration previous isotope data, the Sm–Nd isochron age is estimated at 3014 ± 130 Ma (ε_{Nd} = +1.1, MSWD = 27, n = 15) for Ignoila adakites and 2990 ± 140 Ma (ε_{Nd} = +1.4, MSWD = 2.1, n = 6) for Chalka adakites.

The calculated age of the adakite series of the Hautavaara megastructure (adakites of all paleovolcanic edifices) is 2976 ± 130 Ma (ε_{Nd} = +1.2, MSWD = 15, n = 8) (Fig. 2b). Taking into consideration previous data (Svetov, 2005), the isochron age is 3005 ± 96 Ma (ε_{Nd} = +1.1, MSWD = 16, n = 18), which is consistent with U–Pb data.

Thus, the island-arc complex including the BADR and adakite series began to form 3.05–3.01 Ga ago.

To decipher events terminating the island-arc stage of the terrane evolution, we studied zircon monofractions extracted from the most mature rocks (terrigenous graywackes) of the upper graywacke layer in the rear part of the basin.

Terrigenous graywackes rest on the volcanosedimentary sequence (intercalation of dacite tuffites, tuffstones, mafic graywackes, and graphitic siltstones). They are overlain by monoconglomerates with boulders and pebbles of coarsely porphyritic dacite and fine-grained sediments. This lithotype is the closest analogue of the consolidated material of the source area.

Terrigenous graywackes contain clasts of dacites (tuffs and lavas) and granites 0.5–2 cm in size in a dark-gray coarse-grained quartz–plagioclase–chlorite–biotite matrix. Heavy fraction consists of minerals typical of granitoids, such as rutile (60%), apatite (24.8%), and zircon (12.8%), as well as single grains of tourmaline, garnet, epidote, hornblende, biotite, pyroxene, pyrite, chalcopyrite, and magnetite.

Zircon separated from graywacke sample no. 9 consists of euhedral (bipyramidal-prismatic and rounded) transparent brown and dark brown crystals. Bipyramidal-prismatic crystals are dominated by {110} and {111} faces with smoothed edges and K_{el} = 2.0–3.0. Crystals show coarse zoning in an immersion liquid.

Four fractions of the best-preserved zircons were taken for U–Pb isotope dating. Three fractions were represented by bipyramidal-prismatic crystals (+125, –125+75, and +150 μm in size), and one fraction consisted of rounded crystals 100 μm in size.

U–Pb geochronological investigations were carried out on MI-1201T and Finnigan MAT-262 (RPQ) mass spectrometers at the Geological Institute of the Kola Scientific Center. The measurement error of the U/Pb ratio was 0.5% for the MAT-262 and 0.7% for the MI-1201T. Observed ratios were corrected to a mass fractionation factor of 0.12 ± 0.04 amu for the MAT-262 and 0.18 ± 0.06 amu for the MI-1201T. The procedure

Table 1. Whole-rock Sm–Nd data on island-arc adakite series of the Central Karelian terrane

Sample	Rock	Sm, ppm	Nd, ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(T)$	T_{DM}
Chalka structure							
S-103-25	D	4.15	28.32	0.0885	0.510599	2.0	2979
S-103-2b	D	2.47	13.90	0.1074	0.510909	0.8	3071
S-103-2	D	2.30	6.574	0.2115	0.512999	1.4	–
S-111-11	D	13.7	70.66	0.1169	0.511109	1.0	3058
104-5	LT	5.03	23.20	0.1311	0.511447	2.1	2959
105-7	D	3.96	18.59	0.1286	0.511358	1.3	3036
Ignoila structure							
U-20	SVS	6.36	35.70	0.1077	0.510919	0.8	3065
U-21	SVS	3.36	18.72	0.1083	0.511004	2.3	2956
U-3	LB	8.93	49.04	0.1101	0.511021	1.9	2984
U-2	CAT	3.46	16.81	0.1244	0.511241	0.7	3092

Note: $\varepsilon_{Nd}(T)$ was calculated for 2995 Ga; T_{DM} is model age after De Paolo [9]. Abbreviations: (D) andesite and dacite dike, (SVS) subvolcanic stock, (LB) andesite lavabreccia, (LT) lithoclast in agglomerate tuff, (CAT) cement of agglomerate tuff.

Table 2. U–Pb geochronological data on terrigenous graywackes from the upper sedimentary assemblage of the island-arc association of the Central Karelian terrane

Sample no./fraction no.	Fraction size (μm), weight (mg)	Content, μg/g		Isotope ratios		
		Pb	U	$^{206}Pb/^{204}Pb$*	$^{207}Pb/^{206}Pb$*	$^{208}Pb/^{206}Pb$*
9/1	+125, 2.5	120.4	183.1	670	0.2315 ± 1	0.2053 ± 1
9/2	–125 + 75, 1.4	143.5	226.8	468	0.2385 ± 2	0.2354 ± 2
9/3	–100, 2.3	138.3	201.0	309	0.2513 ± 2	0.2814 ± 2
9/4	+150, 0.6	169.5	239.4	248	0.2605 ± 8	0.2937 ± 9

Sample no./fraction no.	Fraction size (μm), weight (mg)	Isotope ratios		*Rho*	Age, Ma		
		$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
9/1	+125, 2.5	0.5206 ± 16	15.413 ± 46	0.92	2702 ± 8	2841 ± 9	2941 ± 2
9/2	–125 + 75, 1.4	0.4840 ± 15	14.294 ± 43	0.91	2545 ± 8	2769 ± 8	2938 ± 2
9/3	–100, 2.3	0.4983 ± 15	14.706 ± 58	0.91	2607 ± 8	2796 ± 11	2936 ± 3
9/4	+150, 0.6	0.5011 ± 31	14.792 ± 88	0.74	2619 ± 16	2802 ± 20	2937 ± 9

Note: Ages were calculated using the universally accepted values of uranium decay [10]. All errors are given at the 2σ level. Uncertainties correspond to the last significant digits. (*) Values are corrected for mass-fractionation, procedure blank, and common lead according to the model of Stacey–Kramers [11].

blank was no more than 0.1–0.2 ng for Pb and 0.05 ng for U (Table 2). Experimental data were processed with an Isoplot/Excel 3.22 program [12].

In the concordia diagram (Fig. 3), data points of all four fractions define a discordia with an upper intercept at 2947 ± 13 Ma (MSWD = 0.51), while the lower intercept marks the present-day Pb loss.

This age represents the averaged value and reflects the timing of the final phases of BADR associations and granitoid intrusions. The absence of detrital zircons older than 3 Ga (disintegration products of Paleoarchean TTG series of the Vodlozero block) in the terrigenous material of the back-arc basin indicates a significant opening of the back-arc basin.

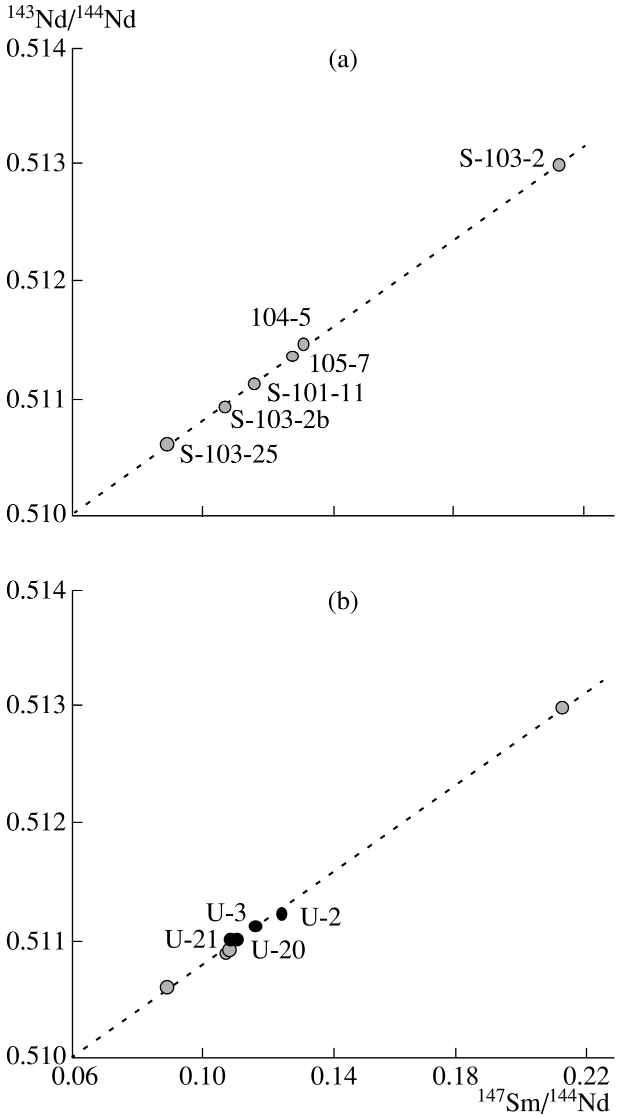

Fig. 2. Sm–Nd isochron diagram for adakite series of the Central Karelian terrane: (a) adakite series of the Chalka paleovolcanic edifice, (b) adakite series of the Hautavaara megastructure (data are used on adakites of the Chalka and Ignoila paleovolcanic edifices). Parameters in (a): $T = 2990 \pm 140$ Ma, $^{143}Nd/^{144}Nd = 0.50882 \pm 0.00012$, $\varepsilon_{Nd} = +1.4$, MSWD = 2.1 (six samples); parameters in (b): $T = 2976 \pm 130$ Ma, $^{143}Nd/^{144}Nd = 0.50883 \pm 0.00011$, $\varepsilon_{Nd} = +1.2$, MSWD = 15 (eight samples).

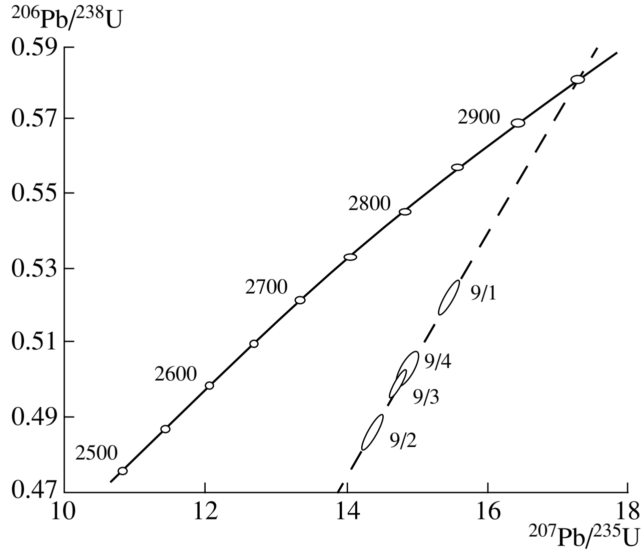

Fig. 3. U–Pb concordia diagram for zircon from terrigenous graywackes of the Hautavaara paleovolcanic edifice. Sample no. 9. (9/1–9/4) sample numbers of monofractions. $T = 151 \pm 210$ and 2947 ± 13 (± 15) Ma, MSWD = 0.51.

Thus, the data obtained allowed us to refine the timing of evolution of the oldest island-arc system in the Fennoscandian Shield. The island arcs began to form 3.05–3.01 Ga ago and terminated about 2.90 Ga ago at the western flank of the Vodlozero block.

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