Geologic setting and U-Pb age of the Shchuch'ia Bay Granitoids, Kola Peninsula

Article · January 2001

3 authors, including:

V. V. Chashchin
Russian Academy of Sciences

Geochemistry International, Vol. 39, Suppl. 1, 2001, pp. S18–S23.
Original Russian Text Copyright © 2001 by Chashchin, Bayanova, Apanasevich.
English Translation Copyright © 2001 by MAIK "Nauka/Interperiodica" (Russia).

Geologic Setting and U–Pb Age of the Shchuch'ia Bay Granitoids, Kola Peninsula

V. V. Chashchin*, T. B. Bayanova, and E. A. Apanasevich****

* *Central Kola Geological Expedition Stock Corporation,*
Komsomol'skaya ul. 23, Monchegorsk, Murmansk oblast, 184280 Russia
e-mail: cke@monch.mels.ru
** *Geological Institute, Kola Research Center, Russian Academy of Sciences,*
ul. Fersmana 14, Apatity, Murmansk oblast, 184200 Russia

Received November 17, 1999; in final form, May 25, 2000

Abstract—U–Pb age values were obtained on an intrusion of alkaline quartz diorite in the northwestern closing of the Paleoproterozoic Imandra–Varzuga sedimentary–volcanic structure in the Kola Peninsula. The diorite is hosted by volcanics of the Kukshinskaya Formation, which were produced early in the evolution of the structure, and the Late Archean Arvarechka Formation. According to our data, the rocks have an age of 2048 ± 8 Ma and mark the switch from an early to a late rifting environment in the evolution of the structure. This period is characterized by an increase in the magma generation depths and was associated with a significant heating of the upper crust and the development of secondary magmatic chambers.

INTRODUCTION

Acid and intermediate intrusive rocks occur not very widely in the Paleoproterozoic Pechenga–Varzuga sedimentary–volcanic belt in the central Kola Peninsula. In the western portion of the belt, among volcanics of the Imandra–Varzuga structure, such rocks were not recognized at all up until recently. The structure is known to host widespread alkaline magmatic rocks, which were produced during the initial and final stages of its evolution. The early evolutionary stages are characterized by large intrusions of alkaline granite in the structure flanks [1], and the final stages were associated with the intrusion of the Soustov alkaline syenite massif with a Rb–Sr age of 1.9 Ga [2].

The latest geological surveying conducted by the Central Kola Expedition in the central part of the Imandra–Varzuga structure led to the discovery of intrusions of the Pana River granite–monzodiorite complex. These intrusions are spatially restricted to the contact zone between the Pana River and Ilmozero formations, which correspond to the final stage in the evolution of the structure and carry evidence of their production under hypabyssal conditions. They are spatially and, possibly, genetically associated with gold mineralization. The age of intrusions of the Pana River Complex is defined by their active effect on the metabasalts of the Ilmozero Formation. The latter is correlated with the volcanic rocks of the Zapolyarninskaya Formation in the Pechenga structure, which is the western part of the Pechenga–Varzuga belt. The Rb–Sr age of the Zapolyarninskaya Formation volcanics is 2114 ± 52 Ma [3]. It should be mentioned that the Pechenga structure contains diorite and granite intrusions of the 1.94 Ga Kaskeljavr Complex [4, 5]. The intrusions are hosted by sedimentary–volcanic rocks of the southern subzone of this structure, and their genesis is related to the orogenic stage in its evolution [6].

In this context, it seems to be expedient to determine the U–Pb age of the diorite intrusion, which is hosted by the volcanics of the initial evolutionary stage of the Imandra–Varzuga structure, particularly taking into account the absence of geochronologic data on the volcanic rocks themselves. This research is a part of the study of reference regional geologic structures and successions and was conducted within the project Gosgeolkarta 200 in the Monchegorsk mining district.

GEOLOGIC SETTING OF THE INTRUSIONS

The intrusions are located north of Shchuch'ya Bay of Lake Bol'shaya Imandra, within the northwestern closing of the Imandra–Varzuga structure. These are relatively small massifs of subalkaline quartz diorites and veins of granite porphyry. One of the bodies, approximately 2.5 by 1.2 km in size, is hosted by the volcanics of the Kukshinskaya Formation (Fig. 1). These rocks characterize the early stage in the evolution of the Imandra–Varzuga structure and rest on the weathered surface of ancient (Late Archean) granitoids and the Early Proterozoic gabbronorites of the Monchegorsk pluton with Ni mineralization cementing eluvial fragments of these rocks [7], composing a discontinuous horizon of conglomeratic breccia (Fig. 1). The U–Pb zircon age (determined in different laboratories) of the Monchegorsk pluton is 2493 ± 7 [8] and 2504.4 ± 1.5 Ma [9], and the Sm–Nd age (on rock-forming minerals) is 2492 ± 31 Ma [10].

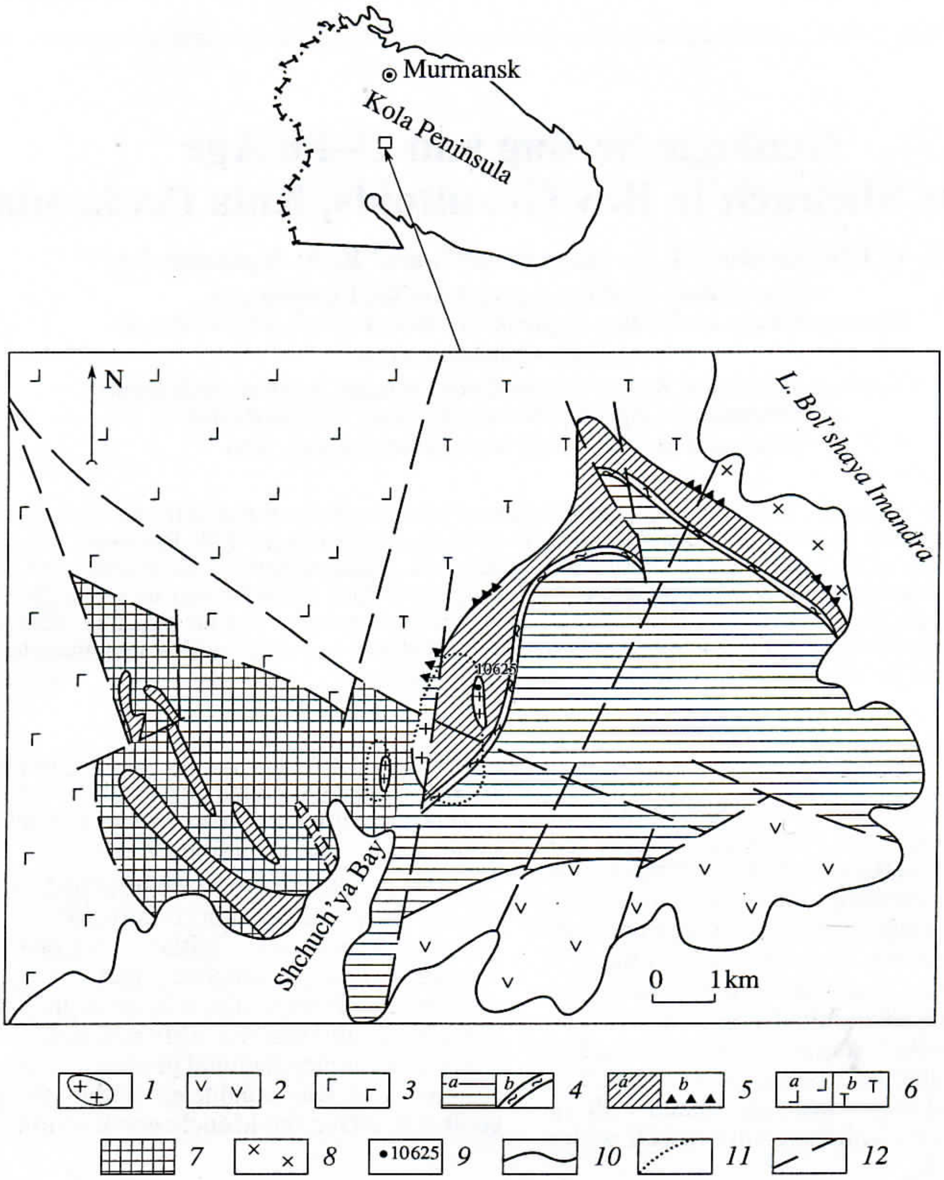

Fig. 1. Schematic geological map of the western closing of the Imandra–Varzuga structure.
(*1*) Shchuch'ya Bay sublakaline quartz diorite; (*2*) amphibolized gabbronorite of the Monche Cape Massif; (*3*) leucogabbro of the Monche Tundra Massif; (*4–5*) rocks of the Lower Proterozoic Imandra–Varzuga structure: (*4*) Seidorechka Formation (*a*—metamorphosed basalts and basaltic andesites of the Upper Subforamation, *b*—quartzites and sericite–chlorite–quartz schists of the Lower Subformation), (*5*) Kuksha Formation (*a*—metabasalts, *b*—elluvial conglomeratic breccia); (*6*) Monchegorsk Ni-bearing pluton (*a*—orthopyroxenite, *b*—gabbronorite); (*7*) metarhyodacite and metadacite of the Late Archean Arvarechka Formation; (*8*) Late Archean diorite–plagiogranite of the Central Kola block; (*9*) sampling sites for U–Pb dating and sample numbers; (*10*) geologic boundaries; (*11*) contours of intrusive bodies cencealed beneath overlying rocks; (*12*) faults.

Another diorite massif, whose composition is analogous to that of the first body, is situated west of it and has dimensions of 1.0 by 0.4 km. It is hosted by the acid volcanics of the Late Archean Arvarechka Formation (Fig. 1). Both intrusions are lens-shaped in map view, with their long axes oriented in roughly south–north directions. Although significant parts of their areas are concealed beneath volcanics, the shapes of the bodies and their sizes are reliably mapped on the basis of materials obtained during surface magnetometric surveying.

The bodies crop out in a single exposure and are penetrated by holes, which were drilled in the 1970s during prospecting works for Cu–Ni mineralization. Since no relationships between the intrusions and their host rocks can be observed, the relative age of the intrusions with respect to the volcanics of the Imandra–Varzuga structure was previously considered uncertain. It was hypothesized that the intrusions are basement uplifts, exposed by erosion, and, correspondingly, should be

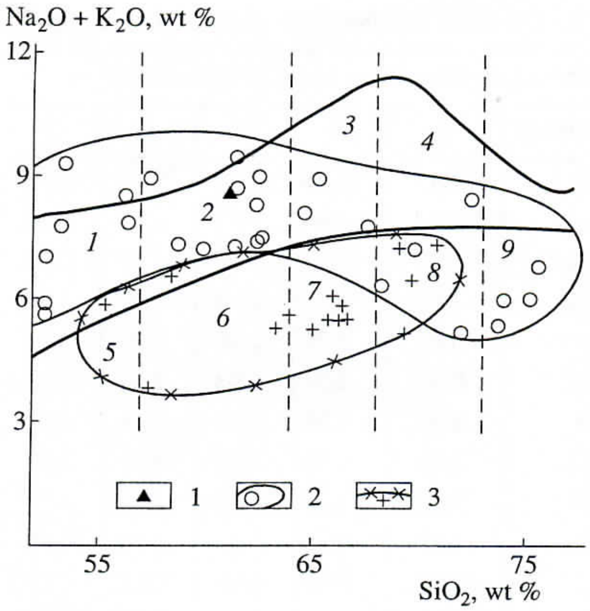

Fig. 2. SiO_2 vs. $Na_2O + K_2O$ plot for granitoids from Shchuch'ya Bay and the Pana River and Kaskeljavr complexes.

(1) Shchuch'ya Bay granitoids; (2) intrusions of the Pana River Complex; (3) intrusions of the Kaskeljavr Complex. Numbers denote the fields of typical reference rocks: (*1*) subalkaline diorite and monzodiorite, (*2*) subalkaline quartz diorite and quartz monzodiorite, (*3*) quartz syenite, (*4*) subalkaline granite, (*5*) diorite, (*6*) quartz diorite, (*7*) granodiorite and tonalite, (*8*) plagiogranite, (*9*) leucogranite.

older than the volcanic rocks, although a younger age was also not ruled out.

ROCK COMPOSITION

The diorites are medium-grained, massive rocks of light gray color, with a hypidiomorphic-granular microtexture, and consisting of saussuritized plagioclase (80–90%), quartz (5%), and biotite (2–3%). The rocks sometimes contain single grains of bluish green subalkaline amphibole. The secondary minerals are chlorite (2–3%), carbonate (2–3%), and sericite (1–2%). The accessories are titanomagnetite, apatite, sphene, and pyrite. Drilling materials indicate that the diorite includes 4–5-m-thick intervals with elevated concentrations of titanomagnetite (up to 20–30%) and thin veinlets of quartz–epidote, quartz–pyrite, or pyrite-dominated composition.

Chemically, the Shchuch'ya Bay rocks correspond to subalkaline quartz diorite (Fig. 2) and affiliate with aluminous rocks of the sodic calc–alkaline series. They differ from the typical rocks of this series by elevated Na concentrations and lower contents of Ca, K, Rb, and Nb (Table 1).

The biotite granite porphyry is supposedly the vein facies of the complex. These rocks crop out 8–10 km northwest of the diorite massifs and are hosted by both pyroxenites of the Monchegorsk pluton and Late Archean granitoids. The veins vary from 200 to 600–700 m in length at thicknesses of 3–10 m and are oriented roughly north to south or in northwestern directions. These are gray rocks composed of quartz or, more rarely, plagioclase phenocrysts submerged in a matrix of quartz–plagioclase composition. The minor minerals are microcline (5%), biotite (2–3%), muscovite (2–3%), and epidote (1–2%); the rocks sometimes contain rare pyrite pockets. The microtexture of the rocks is porphyritic with patches of spherulitic and felsitic groundmass. The granite porphyry is chemically approximated by normal aluminous leucogranite of the K–Na calc–alkaline series (Table 1). The rocks differ from the typical granitoids of this group by somewhat lower Al concentrations.

In general, the Shchuch'ya Bay diorites and granites are chemically fairly similar to the corresponding rocks of the Pana River Complex (Table 1, Fig. 2) but differ

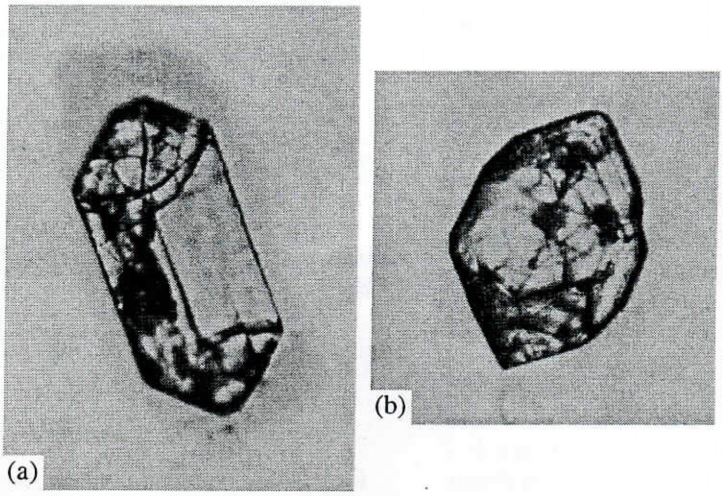

Fig. 3. Morphological types of zircon from the Shchuch'ya Bay subalkaline quartz diorite. (a) Dipyramidal crystals no more than 100 μm in size, (b) tubular, weakly zoned equant crystals approximately 80–100 μm in size.

from them by lower concentrations of Ti and Ca, higher concentrations of Mg and Al, and a strong predominance of Na over K (Table 1). In contrast to the aforementioned Kaskeljavr Complex, these rocks are relatively rich in alkalis (Table 1, Fig. 2) but are lower in Fe.

U–Pb AGE

Zircon Descriptions

In order to determine the age of the diorite, a ~30 kg sample (Sample 10 625) was taken from an exposure, whose location is indicated in the map of Fig. 1. With the use of the conventional separation routine with an electromagnet and a heavy liquid, this rock sample was separated into a zircon separate, 45 mg in weight, and a non-electromagnetic fraction. Most of the zircon grains are poorly preserved and occur as grain fragments. Of them, we hand-picked 2.35 mg of apparently magmatic grains with good faceting (~5% of the total mass of the zircon fraction) for U–Pb dating. Based on their morphology, the selected zircon grains were subdivided into four types. Zircon populations I and II comprise elongated crystals of the zircon type, dipyramidal habit, up to 100 μm in size, transparent, with a glassy luster, and fractured. In accordance with the intensity of their color, the grains were grouped into two types: colorless and pale pink. In immersion liquids, zircons of this populations display thin zoning, which is partly obscured by gas–liquid inclusions and heavy fracturing (Figs. 3a, 4, points *2* and *4*).

Populations III and IV consist of tabular, flattened, weakly zoned equant crystals, 80–100 μm in size, which can be subdivided into colorless transparent and pale yellow varieties (Figs. 3b, 4, points *1* and *3*).

Table 1. Chemical composition (major oxides are given in wt %, trace elements are in ppm) of granitoids from Shchuch'ya Bay, Pana River, and Kaskeljavr complexes

Components	1	2	3	4	5
SiO_2	61.15	75.18	62.20	72.34	63.36
TiO_2	0.35	0.44	0.71	0.33	0.67
Al_2O_3	17.27	11.91	15.50	12.87	15.02
Fe_2O_3	1.04	0.49	2.63	1.11	1.88
FeO	3.60	1.76	2.07	1.78	3.96
MnO	0.10	0.04	0.08	0.04	0.10
CaO	1.93	1.26	2.55	1.11	4.69
MgO	3.46	0.42	2.09	1.11	3.33
Na_2O	7.40	3.20	3.96	4.70	4.36
K_2O	1.38	4.17	4.30	1.96	1.35
SO_3	<0.50	0.55	0.16	0.01	0.07
P_2O_5	0.14		0.19	0.17	0.16
NiO	0.028				0.006
CuO	0.005				0.012
Cr_2O_3	0.066		0.017	0.009	0.015
LOI	2.37	0.48	2.30	1.22	0.70
H_2O^-	0.31	0.05	0.27	0.22	0.09
CO_2	0.81		1.33	0.57	
Total	100.29	99.73	99.81	99.31	99.42
Rb	<30				
Sr	140				
Zr	100				
Nb	15				

Note: (1–2) Shchuch'ya Bay granitoids: (1) subalkaline quartz diorite, (2) granite porphyry; (3–4) granodiorite of the Pana River Complex: (3) subalkaline quartz diorite (average of 9 analyses), (4) granite (average of 7 analyses); (5) quartz diorite of the Kaskeljavr Complex (average of 11 analyses). Rb, Sr, Zr, and Nb were determined by X-ray radiometric techniques at the Kola Geological Information Center Corporation, Apatity, analyst L.K. Raevskaya.

Analytical Techniques

In compliance with the conventional analytical routine [11], the samples were hydrothermally decomposed in concentrated (48%) HF at temperatures of 205–210°C for 7 days, and 3.1 N HCl was added to the dried sample to dissolve fluorides at a temperature of 130°C for 8–10 h. The sample was then divided into two aliquots in 3.1 N HCl to measure the Pb isotopic composition and the Pb and U concentrations by the isotopic dilution technique with the use of a mixed ^{208}Pb + ^{235}U tracer. Pb and U for the isotopic analysis were extracted on AG 1 × 8 (200–400 mesh) anion exchanger packed in Teflon columns. The total laboratory blanks were <0.2 ng for Pb and 0.04 ng for U. The U and Pb concentrations were determined by isotopic dilution on a MI-1201T mass spectrometer, with an error of ±0.15% for Pb. Silica gel was utilized as an ion emitter. The errors in the U and Pb analyses were ±0.5%. All isotopic ratios were corrected for mass discrimination, which was estimated by replicate analyses of the SRM-981 and SRM-982 standards. The errors of the U–Pb ratios were assayed by the statistical treatment of replicate analyses of the IGFM-87 standards and were assumed equal to ±0.7%. The coordinates of points and isochron parameters were calculated with the computer programs by Ludwig [12, 13]. The age values were calculated based on the currently adopted U decay constants [14], all errors are cited for the 2σ level. The correction for common Pb was made in compliance with the model of Stacey and Kramers [15].

U–Pb Dating Results

Our U–Pb isotopic data on the four zircon fractions are listed in Table 2 and graphically presented in Fig. 4. The U–Pb zircon age determined by the upper intercept of the concordia and discordia is equal to 2048 ± 8 Ma

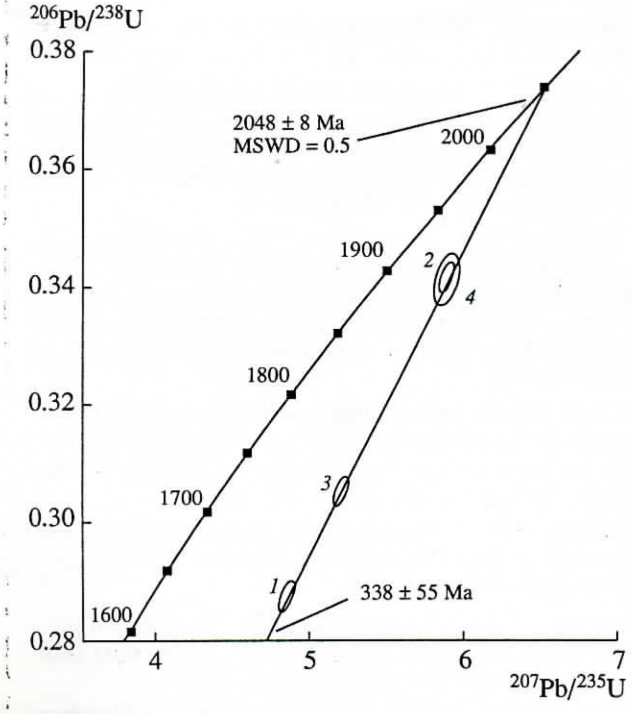

Fig. 4. U–Pb concordia plot for zircon from the Shchuch'ya Bay subalkaline quartz diorite.

(Fig. 4), MSWD = 0.5. We interpret this value as the age of the diorite intrusion. It is pertinent to mention that points *2* and *4* of the prismatic zircon are less discordant than points *1* and *3* of tabular zircon. Moreover, all of the zircons are characterized by high U and Pb concentrations (Table 2), which are characteristic of alkaline rocks. The lower intercept between the discordia and concordia defines an age of 338 ± 55 Ma and, perhaps, reflects Pb loss during the tectono-magmatic reactivation of the eastern Baltic Shield in Paleozoic time [16].

We were the first to discover intrusive rocks of this age in the Imandra–Varzuga structure and whole region. The granitoids serve as age markers for stratigraphic units because they make it possible to constrain the age interval of magmatism and sedimentation in the Imandra–Varzuga structure.

The rocks were produced at the Jatulian–Ludicovian boundary in connection with the transition between an early to late rifting regime in the evolution of the structure [6]. This period preceded the eruption of large volumes of tholeiitic and ferropicritic volcanic rocks in the Pilgujarvi (in the Pechenga structure) and Tominga (in the Imandra–Varzuga structure) groups and the intrusion of mafic–ultramafic bodies of the gabbro–wehrlite association with Ni mineralization. This process seems to have caused a significant heating of the upper crust and the development of secondary magmatic chambers.

CONCLUSION

The diorites and granites exposed around Shchuch'ya Bay are chemically and petrochemically similar to intrusions of the Pana River granite–monzonite complex. These similarities imply the possibility of the discovery of gold mineralization that could be associated with the Shchuch'ya Bay granitoids, particularly with the apical portions of their massifs underlying volcanic rocks. Isotopic U–Pb age data and geological observations indicate that the rocks were intruded in relation to a change in the tectonic regimes in the evolution of the Imandra–Varzuga structure. They seem to mark the termination of the early rifting stage, which was followed by extension and the formation of a volcanic pile (Tominga group). An increase in the alkalinity of the acid magmas reflects, first of all, a dramatic deepening of the magma generation zones. This was probably caused by an increase in the depths of the faults, which mainly coincided with the axial zones of the riftogenic depression.

Table 2. U–Pb isotopic data on zircon in subalkaline quartz diorite from Shchucn'ya Bay

Sample no.	Weight, mg	Concentration, ppm		Pb isotopic composition*			Isotopic ratios and age, Ma**		
		Pb total	U	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{206}Pb/^{208}Pb$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
1	0.40	143.8	367.1	1830	7.707	2.282	4.868	0.2877	1996
2	0.35	125.1	256.6	800	6.540	2.215	5.891	0.3418	2029
3	0.50	239.4	543.5	1010	7.300	1.968	5.230	0.3058	2015
4	1.10	214.0	444.9	900	6.874	2.199	5.900	0.3417	2037

* All ratios are corrected for blanks (0.2 ng for Pb and 0.04 ng for U) and mass discrimination (0.17± 0.05%).

** The correction for common Pb was determined for an age in compliance with the model of Stacey and Kramers [15].

REFERENCES

1. *Magmatizm i metallogeniya riftogennykh sistem vostochnoi chasti Baltiiskogo shchita* (Magmatism and Metallogeny of Rifting Systems in the Eastern Part of the Baltic Shiels), Shcheglov, A.D., Ed., St. Petersburg: Nedra, 1993.
2. Batieva, I.D., Bel'kov, I.V., Kravchenko, M.P., *et al.*, The Age of Alkaline Magmatism of the Soustov Massif, Kola Peninsula, *Dokl. Akad. Nauk SSSR*, 1983, vol. 270, pp. 931–933.
3. Balashov, Yu.A., Geochronology of Early Proterozoic Rocks in the Pechenga–Varzuga Structure, Kola Peninsula, *Petrologiya*, 1996, vol. 4, no. 1, pp. 3–25.
4. Vetrin, V.P., Pushkarev, Yu.D., Ryungenen, G.I., *et al.*, Geologic Setting and Age of Granitoids in the Southern Framing of Pechenga, in *Stroenie i metamorficheskaya evolyutsiya glavnykh strukturnykh zon Baltiiskogo shchita* (Inner Structure and Metamorphic Evolution of the Main Tectonic Zones of the Baltic Shield), Apatity: Kol. Fil. Akad. Nauk SSSR, 1987, pp. 83–92.
5. Bayanova, T.B., Skuf'in, P.K., and Smol'kin, V.F., U–Pb Age of Plagiogranites in the Southern Framing of the Pechenga Structure, Kola Peninsula, *Mezhdunar. Konf. Riftogenez, magmatizm, metallogeniya dokembriya. Korellyatsii geologicheskikh kompleksov Fennoskandii* (Int. Conf. Rifting, Magmatism, and Metallogeny of the Precambrian: Correlation of Geologic Complexes in Fennoscandia), Petrozavodsk, 1999, pp. 17–18.
6. Smol'kin, V.F., Magmatism in the Early Proterozoic (2.5–1.7 Ga) Fossil Rift System in the Northwestern Baltic Shield, *Petrologiya*, 1997, vol. 5, no. 4, pp. 394–411.
7. Luneva, O.I., *Dokembriiskie konglomeraty Kol'skogo poluostrova* (Precambrian Conglomerates of the Kola Peninsula), Moscow: Nauka, 1977.
8. Bayanova, T.B., Genetic Succession of Layered Peridotite–Pyroxenite–Gabbronorite Intrusions of the Kola Area: Isotopic Evidence, *Cand. Sci. (Geol.–Mineral.) Dissertation*, Moscow: Institute of the Lithosphere, Russ. Acad. Sci., 1992.
9. Amelin, Yu.V., Heaman, L.M., and Semenov, V.S., U–Pb Geochronology of Layered Mafic Intrusions in the Eastern Baltic Shield: Implications for the Timing and Duration of Paleoproterozoic Continental Rifting, *Precambrian Res.*, 1995, vol. 75, pp. 31–46.
10. Tolstikhin, I.N., Dokuchaeva, V.S., Kamensky, L.L., *et al.*, Juvenile Helium in Ancient Rocks: II. U–He, K–Ar, Sm–Nd and Rb–Sr Systematics in the Monche Pluton. ^{3}He/^{4}He Ratios Frozen in Uranium-Free Ultramafic Rocks, *Geochim. Cosmochim. Acta*, 1992, vol. 56, pp. 987–999.
11. Krogh, T.E., A Low-Contamination Method for Hydrothermal Dissolution of Zircon and Extraction of U and Pb for Isotopic Age Determination, *Geochim. Cosmochim. Acta*, 1973, vol. 37, pp. 485–494.
12. Ludwig, K.R., Pb Dat—A Computer Program for Processing Pb–U–Th Isotope Data, Version 1.22, *US Geol. Surv. Open File Rep.*, 1991.
13. Ludwig, K.R., Isoplot/Excel—A Geochronological Toolkit for Microsoft Excel, Version 2.05, *Berkley Geochronol. Center Spec. Publ. No.1a*, 1999.
14. Steiger, R.H. and Jäger, E., Subcommission on Geochronology: Convention on the Use of Decay Constants in Geo- and Cosmochronology, *Earth Planet. Sci. Lett.*, 1977, vol. 36, no. 3, pp. 359–362.
15. Stacey, J.S. and Kramers, J.D., Approximation of Terrestrial Lead Isotope Evolution by a Two-Stage Model, *Earth Planet. Sci. Lett.*, 1975, vol. 26, no. 2, pp. 207–221.
16. Kramm, U., Kogarko, L.N., Kononova, V.A., and Vartiainen, H., The Kola Alkaline Province of the CIS and Finland: Precise Rb–Sr Ages Define the 380–360 Ma Age Range for All Magmatism, *Lithos*, 1993, vol. 30, pp. 33–44.