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GEOLOGY

Geological Structure, Composition, and Age of the Pyalochnoozero Ultramafic–Mafic Massif, Northeastern Baltic Shield

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The finding of low-sulfide PGE mineralization in the Sumian layered peridotite–pyroxenite–gabbronorite massifs located in the Pechenga–Varzuga and North Karelian riftogenic system of the Baltic Shield [1] sparked increased interest in other, less studied similar objects. One of them is the Pyalochnoozero Massif 90 km^2 in area located in the eastern Belomorian Block. The massif was traditionally combined with Ondomozero and Peschanoozero massifs into the Sumian pyroxenite–peridotite–gabbronorite [2] or gabbroanorthosite [3] complexes. Though geochemical PGE anomalies were found in the rocks of the Pyalochnoozero Massif during large-scale geological survey, the internal structure, rock associations, composition, age, and metallogenic potential of the intrusion remained poorly studied. Detailed study of the massif helped us to significantly refine its geological structure and composition and determine its formation age.

Geological structure. The Pyalochnoozero Massif is located in the southeastern part of the Kola Peninsula in the upper reaches of the Pyalitsa and Ust'-Pyalka massifs. It is located in the eastern termination of the Imandra–Varzuga lithostructural zone, at the contact of Saamian complexes with Late Archean greenstone belts. The massif intrudes fine-grained biotite, garnet–biotite, amphibole–biotite gneisses, and their granitized varieties of the Archean Belomorian Complex (more rarely, Upper Lopian rocks) and is crosscut by dikes and veins of plagiomicrocline granites, pegmatites, and aplites of the Late Karelian Strel'na Group. Geological–geophysical data show that the massif gently dips northwest and has a NE-trending droplet shape with a long axis equal to 6 km and a width varying from 1–2 km in the southwest to 6 km in the northeast. They are separated from the host rocks by mainly NE-trending faults and less abundant submeridional and sublongitudinal faults traced as blastomylonite zones, which split the massif into lenslike blocks of different sizes.

Structural–geological data showed that the massif has a complex zoned and differentiated internal structure (Fig. 1). Unaltered rocks are dominated by gabbronorites with subordinate norites, pyroxenites, peridotites, and olivinites, which are spatially associated and characterized by gradual transitions. They mainly occur in the southeastern, central, and northern parts of the massif as large lenslike domains up to 700–1200 m wide, which are conformable with a general trend of the massif and alternated with zones of tectonites developed after the lenslike domains. The Pyalochnoozero Massif underwent intense cataclasis, foliation, and mylonitization. Therefore, the present-day section is mainly composed of recrystallized gabbroids with secondary eutaxitic structures and apogabbroid blastotectonites, which were sometimes taken as Archean crystalline schists and granulites. The most intense transformations are observed in the western part of the massif, where blastomylonite bodies (up to a few hundred meters thick) composed of amphibole, garnet–amphibole–plagioclase, scapolite–epidote–biotite–garnet–amphibole–plagioclase, and amphibole schists retain relicts of gabbronorites in some places. Foliation and mylonitization are accompanied by the formation of garnet, clinopyroxene, plagioclase, amphibole, quartz, and occasional sillimanite and kyanite, which are observed both as individual minerals and as veins, veinlets, lenses, and irregular spots.

The vein phase of the intrusion includes pegmatoid gabbronorite, micronorite porphyries, and hornblende microgabbros, which form rare veins up to 1.5 m thick.

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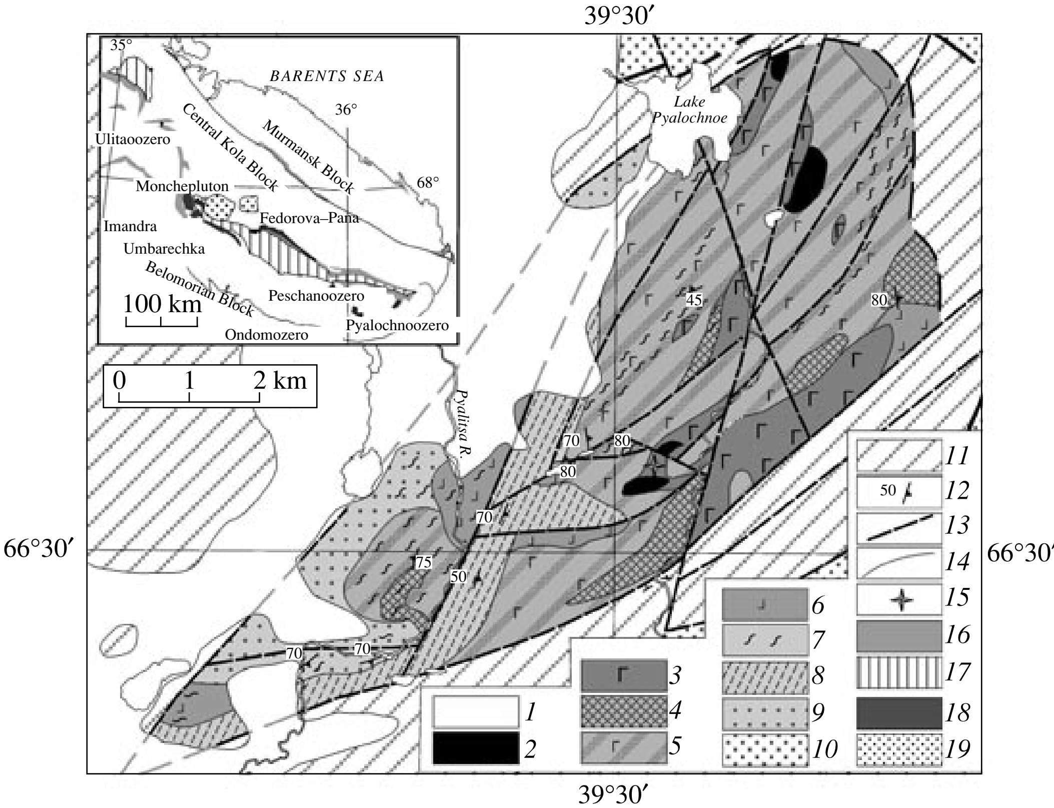

Fig. 1. Geological scheme of the Pyalochnoozero Massif (modified after E.E. Selivanovskaya et al., 1964 and V.V. Semenov et al., 1988). (*1*) Quaternary deposits; (*2–9*) Pyalochnoozero Complex: (*2*) ultramafic rocks, (*3*) medium- to coarse-grained gabbronorites and norites, (*4*) microgabbronorites and micronorites with lenses of medium-grained gabbronorites, locally amphibolized and silicified, (*5*) thin-banded gabbronorites with eutaxitic structure, lenses of microgabbronorites and numerous zones of (garnet)–quartz–plagioclase–amphibole blastotectonites, (*6*) amphibolites and amphibole schists (apogabbroids), (*7*) zones of intense garnetization of gabbronorites, (*8*) garnet–amphibole schists (apogabbroids), (*9*) scapolite–epidote–biotite–amphibole schists (apogabbroids); (*10, 11*) host rocks: (*10*) schistose amphibolites and biotite–garnet gneisses of the Pyalochnoe sequence, (*11*) gneisses of the Belomorian Complex; (*12*) dip and strike; (*13*) faults; (*14*) boundaries of domains of different rocks of the Pyalochnoozero Complex; (*15*) geochronological sampling locality. Inset shows the location of the Pyalochnoozero Massif within the northeastern Baltic Shield: (*16*) fragments of the Lopian greenstone belts, (*17*) Polmak–Pasvik–Pechenga–Imandra–Varzuga riftogenic structure, (*18*) large layered mafic–ultramafic intrusions, (*19*) Paleozoic alkaline intrusions.

Petrography and geochemistry of the gabbronorites. The gabronorites are gray massive medium- to coarse-grained, occasionally trachytoid, rocks with distinct cumulus (Pl–Opx–Cpx cumulates), or more rarely a hypidimorphic texture. They consist of variable proportions of labradorite An_{58-70} (30–65%), hypersthene En_{70-76} (5–50%), diopside-augite $En_{42-52}Wo_{32-48}$ (5–55%), magnetite and ilmenite (2–5%), and apatite (up to 1%). Magnesian cumulus gabbronorites are closely associated with ultramafic rocks. Gabbronorites with gabbroic texture are developed mainly in the southern part of the massif. These two varieties differ in the K_f value of the rocks (K_f = 20–33 and 38–49%, respectively) and the type of constituent pyroxenes. However, the major part of the Pyalochnoozero Massif is composed of recrystallized gabbronorite with oriented structures and blastotectonite lenses. These rocks are represented by alternation of lenses and variable thicknesses of bands of medium- to fine-grained eutaxitic gabbronorites, microgabbronorites, hornblende microgabbro, quartz–plagioclase–amphibole blastotectonites, lit-par-lit quartz–plagioclase veins with garnet, and so on. Relicts of massive gabbronorites with gabbroic texture are related to the aforementioned rocks through gradual transitions. Gabbroids of the Pyalochnoozero Massif are characterized by the intense development of secondary garnet, which is most widespread in linear zones conformable with the general trend of the massif. Sillimanite and occasional kyanite are confined to garnetization zones in gabbronorites.

In terms of the petrochemical composition, the Pyalochnoozero Massif is ascribed to the SiO_2-saturated alkali earth rocks. Its rocks are characterized by elevated contents of Si, Ti, Fe, Na, and especially P (the average P_2O_5 content is 0.28%, which is 3–4 times higher than in other mafic–ultramafic massifs of the area); lower contents of Mg and Ca; and, consequently, moderate *f* values (50%, on average) (Table 1).

Age of the Pyalochonoozero Massif. In the regional correlation schemes, the Pyalochnoozero Massif is cor-

Table 1. Composition of gabbronorites from the Pyalochnoozero Massif

Component	1	2	Component	1	2	Component	1	2
SiO_2	51.6	51.1	Ba	141	252	La	2.37	11.15
TiO_2	0.23	0.60	V	25	108	Ce	5.97	27.60
Al_2O_3	18.40	18.06	Cr	167	138	Pr	0.85	4.07
Fe_2O_3	4.09	3.45	Co	29.2	44	Nd	3.65	17.83
FeO	1.60	4.42	Cu	72.6	82	Sm	0.86	3.79
MnO	0.10	0.13	Ni	199	142	Eu	0.49	1.39
MgO	11.90	7.70	Zn		106	Gd	0.67	3.25
CaO	9.87	10.76	Rb	1	1.03	Tb	0.12	0.47
Na_2O	2.00	2.70	Sr	1330	999	Dy	0.73	2.60
K_2O	0.24	0.28	Zr	1.81	24	Ho	0.15	0.50
P_2O_5	0.025	0.14	Y	3.78	9.7	Er	0.41	1.32
L.O.I.	0.12	0.15	Pb	0.98	3.1	Tm	0.06	0.19
Total	100.2	99.51	Nb	0.25	1.7	Yb	0.30	1.12
						Lu	0.05	0.16

Note: (1) Chemical composition of gabbronorites, sample 486-1; (2) average composition of gabbronorites of the Pyalochnoozero Massif (n = 19). The major element contents are given in wt %; trace elements, in ppm.

related with the Sumian (2464–2492 Ma) intrusions of pyroxenite–peridotite–gabbronorite or gabbroanorthosite complexes. To determine the age of the massif, the gabbronorites were dated by the U–Pb zircon method on a SHRIMP II ion microprobe at the Center of Isotope Research, Karpinskii All-Russia Research Institute of Geology. The representative 20-kg sample (no. 486-1) was taken from the least altered high-Mg gabbronorites in the central part of the massif (Fig. 1).

Detailed study of the zircons from this sample showed the presence of two morphological types (Fig. 2): predominant large fragments of pink-brown prismatic crystals and rare light pink grains. The fragments are 200–300 μm long, while the light pink crystals are up to 150–200 μm in size (coefficient of elongation varies from 2 to 4). In cathode rays, the zircons are marked by obscure planar zoning and low luminescence along their margins (occasionally, whole grains). The light pink crystals manifest more distinct zoning. The U content is 115–865 mg/g in the light zones of zircons and 670–865 mg/g in the dark zones. The Th/U ratio is no more than 0.21–0.53 (Table 2). The U–Pb study was conducted for prismatic grains and fragments of both the central and the peripheral parts of the crystal. In the $^{206}Pb/^{238}U$–$^{207}Pb/^{235}U$ diagram (Fig. 3), data points of zircons of different shapes and from different parts of the crystals occupy a near-concordant position with an age of 1875 ± 12 Ma (MSWD = 0.99). The morphology and geochemistry of the zircons attest to their magmatic origin. Hence, the obtained age can be interpreted as the crystallization age.

One of the zircon grains (no. 5) represents an elongated crystal (Fig. 2), which differs from other crystals in the internal structure in the cathodoluminescence image and geochemistry. The U content is low (87 mg/g) in the thinly zoned core of the crystal and as much as 375 mg/g in the dark homogenous rim. The Th/U ratio is 0.29 in the core and 0.10 in the rim. The isotope ratios in the central and peripheral parts of crystal no. 5 defined a concordant age of 2657 ± 30 Ma (Fig. 3). These data indicate that this crystal was entrapped by the parent melt from the Late Archean granite gneiss complex, with subsequent dissolution and assimilation. The magmatic melt could have been contaminated with crustal material during its ascent and emplacement in the magma chamber or the collapse of roof rocks.

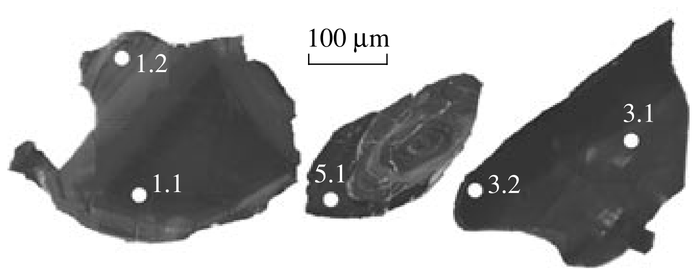

Fig. 2. Cathodoluminescence images of zircons from gabbronoites. Numbers in images correspond to dating points (Table 2).

Table 2. U–Pb zircon data on gabbronorites (sample 486-1)

Sample no.	$^{206}Pb_c$, %	Content, ppm			$\frac{^{232}Th}{^{238}U}$	Age, Ma		D, %	(1) $\frac{^{207}Pb^*}{^{235}U}$	(1) $\frac{^{206}Pb^*}{^{238}U}$	*Rho*, rel. u.
		$^{206}Pb^*$	U	Th		(1) $\frac{^{208}Pb}{^{238}U}$	(1) $\frac{^{207}Pb}{^{206}Pb}$				
1.1	0.04	172	670	213	0.33	1688 ± 50	1890 ± 14	11	4.78 ± 3.4	0.299 ± 3.4	.975
1.2	0.07	37	115	23	0.21	2051 ± 64	1904 ± 33	–8	6.02 ± 4.0	0.375 ± 3.6	.894
2.1	0.21	111	387	122	0.33	1851 ± 55	1841 ± 21	–1	5.16 ± 3.6	0.333 ± 3.4	.947
3.1	0.28	69	226	57	0.26	1956 ± 58	1867 ± 25	–5	5.58 ± 3.7	0.354 ± 3.5	.927
3.2	0.15	219	865	442	0.53	1664 ± 49	1875 ± 14	11	4.66 ± 3.4	0.2945 ± 3.3	.975
4.1	0.20	121	436	184	0.44	1803 ± 53	1896 ± 19	5	5.16 ± 3.6	0.323 ± 3.4	.955
5.1	0.24	160	375	35	0.10	2595 ± 72	2649 ± 12	2	12.27 ± 3.5	0.496 ± 3.4	.978
6.1	0.08	206	812	311	0.40	1665 ± 49	1871 ± 12	11	4.65 ± 3.4	0.2947 ± 3.3	.980
7.1	0.35	100	353	127	0.37	1833 ± 56	1849 ± 27	1	5.13 ± 3.8	0.329 ± 3.5	.917

Note: Errors are given at 1σ level (Ma for ages, % for ratios); (Pb_c, Pb*) common and radiogenic lead, respectively; (D) discordance; (*Rho*) correlation coefficient. Errors in standard calibration are 1.08%. (1) Correction for common lead was ascribed to the measured ^{204}Pb. Accessory zircon grains were extracted using the conventional magnetic heavy-liquid technique. Hand-picked zircons were implanted in an epoxy resin together with standards TEMORA and 91500, sectioned approximately in half, and polished. Areas (points) for dating were selected using optical (in transmitted and reflected light) and cathodoluminescence images, which demonstrate the internal structure and zoning. U–Pb zircon dating was conducted on a SHRIMP-II ion microprobe at the Center of Isotope Research, Karpinskii All-Russia Research Institute of Geology. Measurements of U–Pb ratios were performed using the technique described by Williams [4]. The intensity of the primary beam of negatively charged oxygen atoms was 5 nA (crater diameter 25 μm). The obtained data were processed with the program SQUID [5]. The U–Pb ratios were normalized to 0.0668 in the TEMORA standard, which corresponds to the zircon age of 416.57 Ma [6]. The errors in single analyses (ratios and ages) are quoted at the 1σ level, while errors in the calculated concordant ages and intersections with concordia are given at 2σ. The diagrams were plotted with the ISOPLOT/Ex program [7].

Thus, the Pyalochnoozero Massif differs in age from the Sumian peridotite–pyroxenite–gabbronorite massifs and the Ondomozero Massif dated at 1966 ± 5.6 Ma [8]. Hence, the considered massif must be distinguished as an independent Pyalochnoozero norite–gabbronorite complex of Late Karelian (Vepsian) age.

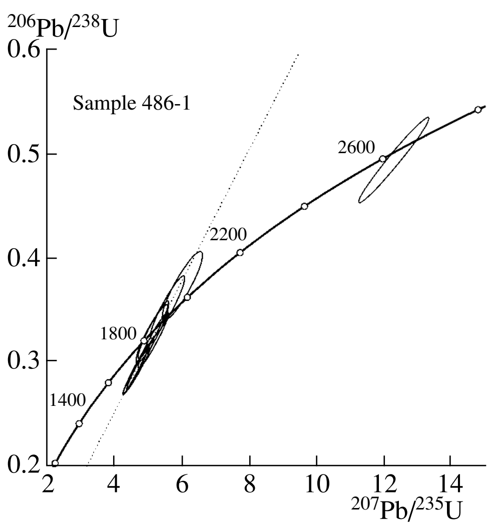

Fig. 3. Concordia diagram for zircons from gabbronorites (error ellipses are given at the 1σ interval). The upper intercept is 1875 ± 12 Ma (error for the 2σ interval), and the lower intercept is recorded at 0 Ma (MSWD = 0.99).

CONCLUSIONS

The Pyalochnoozero Massif consists of a single rock series ranging from olivinites to leucogabbronorites, which were mostly transformed into blastotectonites and metasomatites under the influence of intense mylonitization and metasomatism. The U–Pb zircon age of unaltered gabbronorites of the massif is 1875 ± 12 Ma. The new age data obtained for the Pyalochnoozero and Ondomozero massifs indicate several pulses of mafic–ultramafic magmatic activity in both the eastern and the western parts of the Pechenga–Varzuga riftogenic belt at the final stage of riftogenesis, which was known previously only in the Pechenga structure.

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