

GEOCHEMISTRY

First Th–U–Pb Single Zircon Dating of Metasomatites from the Belomorian Mobile Belt

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Metasomatites have long been known among the rocks of the Belomorian mobile belt (BMB) [1–4]. These rocks are distributed over the entire belt as relatively small lenslike or vein-shaped bodies restricted to the local shear zones. The metasomatites are most abundant in the Chupa sequence of the BMB and at its junction with the Karelian Craton [3]. Study of the formation conditions and localization of the metasomatites is of great significance for deciphering endogenous activity within the BMB, elucidating the fluid regime during metamorphism, detection of deep-seated and other conduits for fluid circulation, and discovery of ore objects among the metamorphic rocks of the belt. The BMB has a long-term intricate evolution related to repeated deformations, polymetamorphism, and multiple emplacements of the magmatic melts [5]. Therefore, it is necessary to determine the age of the metasomatic process in this belt. The aim of this paper was to carry out the Th–U–Pb single zircon dating of metasomatic rocks of the BMB.

We studied the corundum-bearing metasomatites that replace the Chupa gneisses of the BMB. Their metasomatic genesis was substantiated by Serebryakov [4, 6]. These rocks are exposed over the entire extension of the Chupa sequence within the Chupa segment of the BMB. The corundum-bearing metasomatites are subdivided into two groups: (I) metasomatites developed after migmatized kyanite–garnet–biotite plagiogneisses and (II) metasomatites developed after gab-

broid amphibolites. If the replaced rocks are adjacent, these two types are often spatially associated. Type I is also related to the formation of anchimonomineral oligoclases. Metasomatites of both types are considered to be either Archean [3] or Paleoproterozoic [7]. According to [4], geological relations with reference geological objects for the BMB suggest the Paleoproterozoic Svecofennian age of metasomatism. The corundum-bearing metasomatites developed after gneisses are controlled by the same shear zones as muscovite pegmatites (about 1.8 Ga). The oligoclases replace the rocks of the Svecofennian diaphthoresis zone in kyanite gneisses. The corundum-bearing metasomatites developed after metabasic rocks have cross-cutting relations with Iherzolite–gabbro-norite massifs (2.44 Ga [8]), and amphibolites developed after them.

We studied zircon from the corundum-bearing metasomatites developed after kyanite gneisses from the Khitoostrov occurrence [4, 6], which is located at the western extremity of Lake Verkhnyaya Pulonga, the Loukhi area of Karelia (Fig. 1). The metasomatites occur in the sublatitudinal shear zone and form a single en-echelon structure with pegmatite veins. The corundum-bearing rocks are up to 75 m thick and are separated from kyanite gneisses by a series of ~150-m-thick transitional rocks characterized by metasomatic zoning. All the metasomatites are coarse-grained and gneissic rocks. The replacement of kyanite gneisses is accompanied by the disappearance of quartz, formation of calcic amphibole (tschermakite–pargasite) and sodic low-Si gedrite, increase of Ca and Mg contents in garnet, and increase of Ca in plagioclase. At the contact of kyanite with calcic amphibole and garnet, staurolite–plagioclase symplectite is developed as rims up to complete pseudomorphous replacement of kyanite. Staurolite in the rims has no contact with calcic amphibole and garnet. Upon approaching the rear zone, kyanite relicts within the staurolite–plagioclase pseudomorphs are replaced by corundum–plagioclase symplectites. In the rear zone, euhedral staurolite and kyanite grains up to 3 cm in size are formed instead of pseudomorphs

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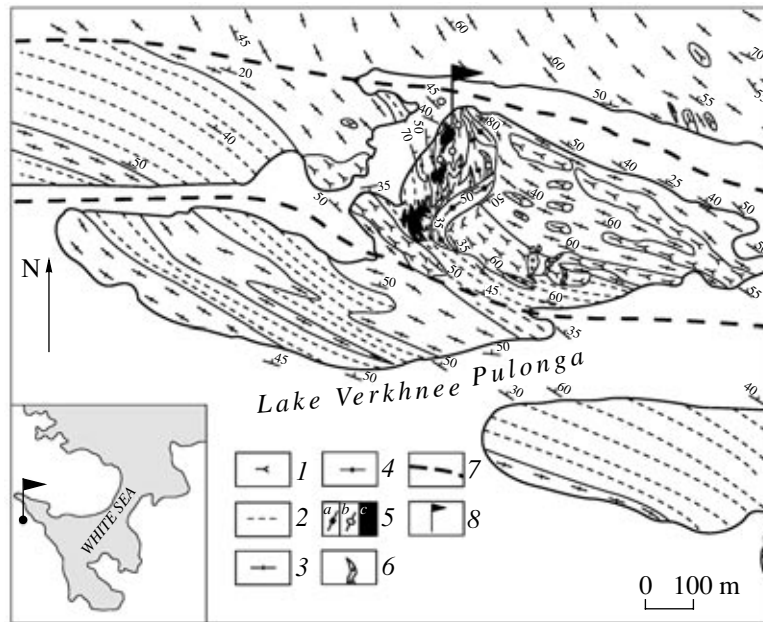


Fig. 1. Geological scheme of Khitoostrov (modified after survey materials of E.P. Chuikina (1971) and observations of one of the authors). (1) Metamorphosed gabbroids or “garnet” gabbro complex, according to (Stepanov, 1981); (2) Grt–Bt plagiogneisses; (3) Ky–Grt–Bt plagiogneisses; (4) two-mica plagiogneisses; (5) (a, b) corundum-bearing metasomatites: (a) outer zone with St–Pl pseudomorphs after kyanite, (b) rocks with Crn–St–Pl pseudomorphs (after kyanite) and large corundum crystals, (c) oligoclasites; (6) pegmatites; (7) faults; (8) sampling locality.

developed after kyanite. Staurolite is in contact with all minerals of the rock. The increasing replacement of kyanite and change in corundum and staurolite morphologies attest to the increase in the degree of crystallization (and fluid reworking) of the rocks toward the rear zone. The rock in this zone consists of plagioclase, pargasite, sodic low-Si gedrite, garnet, biotite, staurolite, and corundum. No reaction relations are observed between minerals. Accessories are zircon, rutile, and allanite. The metasomatites were formed at 60–700°C and 6–8 kbar [4, 6]. Secondary minerals are chlorite (developed after amphibole and biotite) and sericite (developed after plagioclase).

Zircon for local Th–U–Pb SHRIMP-II dating was separated from the rear metasomatites. The zircon forms subhedral prismatic crystals about 50–250 μm in size with the elongation coefficient of 1.2–2.8 and zoned structure (Fig. 2). The core (up to 80 \times 150 μm in size) typically has a lighter yellowish brown tint with thin rhythmic growth zoning and sectorial structure. It is overgrown by a 10- to 70- μm -thick rim of fissured turbid, often virtually opaque dark brown zircon. In the cathodoluminescence image, one can see that the dark gray or almost black rim often distinctly corrodes the primary zoning of the core (Fig. 2). In turn, the dark brown zircon is overgrown by the 5- to 80- μm -thick rim of lighter yellowish brown zircon. Occasionally, it shows a coarse growth zoning. Based on these data, we can distinguish three zircon generations: (1) core zir-

con, (2) dark brown zircon in the inner rim, and (3) pale zircon in the outer rim.

These generations are well distinguished by the U content and Th/U ratio. Zircon 1 has a moderate U content (150–300 ppm) at Th/U 0.5–1.2. Zircon 2 has the highest U content (500–1800 ppm) and extremely low Th/U ratio (<0.02). Zircon 3 has the same Th/U ratio (<0.02), but a significantly lower U content (200–350 ppm) close to that in zircon 1 (table).

The data points of zircon I (four determinations) are almost concordant and correspond to an age of 2857 ± 30 Ma. The data points of zircon 2 (five determinations) are somewhat discordant. Their age is determined by the upper intercept at 2692 ± 68 Ma. The data points of zircon 3 are concordant and define an age of 1894 ± 17 Ma (Fig. 3).

Discrimination of metasomatic zircon generations and later generations imposed on (or inherited) during the replacement of rocks is essential for the solution of the problems formulated in this paper. It should be noted that the existence of postmetasomatic zircon is hardly probable, because the corundum-bearing rocks were not subjected to significant epigenetic alterations, which could promote the growth of new rims around zircon. This fact reliably indicates the metamorphic origin of zircon 3 that forms the outer rim of zircon grains.

The nature of zircons 1 and 2 was deciphered using existing geochronological data [5, 13] on the migmatized kyanite–garnet–biotite plagiogneisses, which were replaced by corundum-bearing metasomatites.

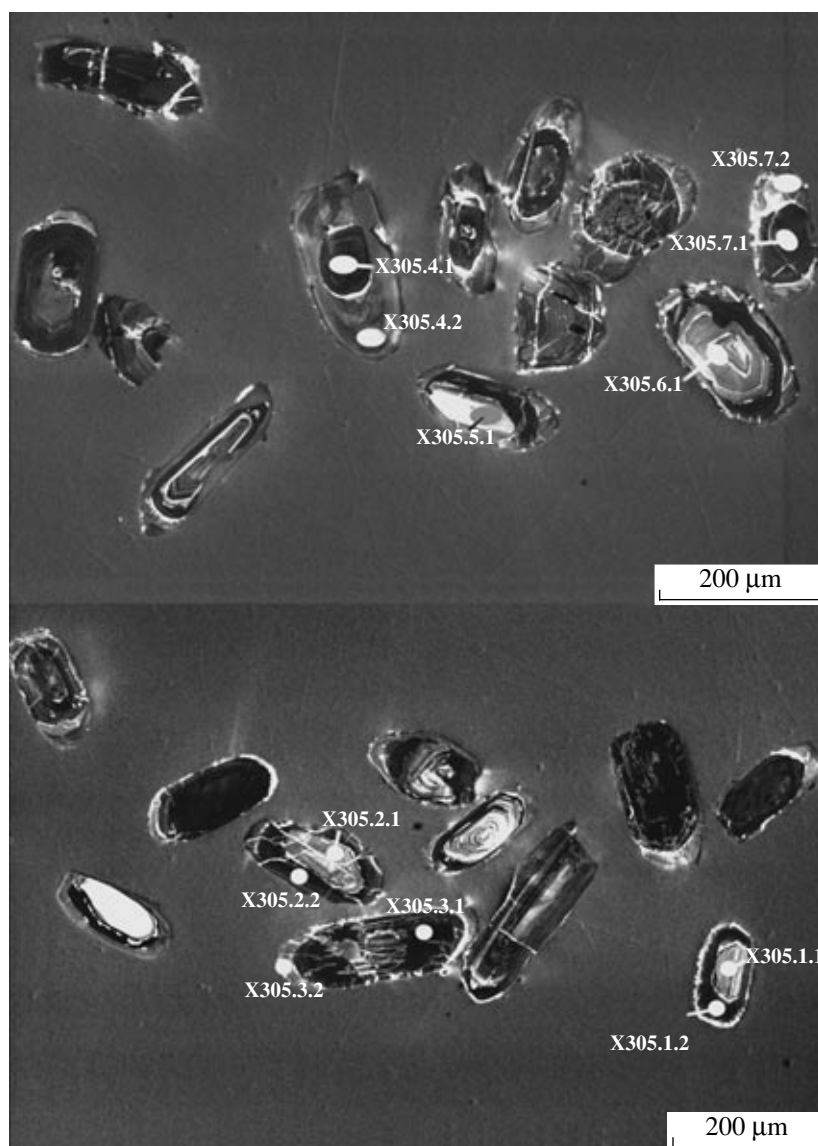


Fig. 2. Internal structure of zircons from corundum-bearing metasomatites of Khitoostrov based on cathodoluminescence data. Analyzed points and their numbers are shown (see Table 1).

These gneisses were formed after fine-grained garnet–biotite gneisses, which, in turn, were developed during metamorphism of graywackes (disintegration products of the magmatic rocks of different compositions) [14]. Thus, zircon in these gneisses may have both magmatic and metamorphic genesis.

Study of the migmatized kyanite–garnet–biotite plagiogneisses of the Chupa sequence [5, 13] showed the presence of zircon generation similar to zircons 1 and 2 from our sample. In particular, zircon with thin zoning and moderate U and Th contents (similar to those in the Khitoostrov zircon I) often appears as cores of heterogeneous grains in the Chupa gneisses. Its age is estimated at 2820 ± 15 [5] or 2883 ± 22 Ma [13], which is sufficiently close to the age of zircon I from our samples. Most geologists assume a magmatic genesis for

this zircon. However, a metamorphic origin also is not ruled out for zoned zircon [5]. The dark brown zircon with high U and a low Th/U ratio, which is similar to the Khitoostrov zircon 2, is typical of migmatized kyanite–garnet–biotite plagiogneisses [5, 13], whereas nonmigmatized gneisses do not contain this zircon. Hence, the formation of this zircon was presumably related to migmatization of gneisses. Its age is estimated at 2615 ± 15 [5] or 2691 ± 15 Ma [13]. These data are close to our datings of zircon 2.

One more zircon generation was reported by Bibikova et al. from aluminous gneisses in the muscovite pegmatite fields of BMB (Svecofennian diaphthoresis zone) [5]. This generation also has high U contents (700–800 ppm) and a very low Th/U ratio (0.005). However, it is younger (1875 ± 10 Ma) and considered

Th–U–Pb isotope data on zircons from the Khitoostrov corundum-bearing rocks

No. of grains and points (X305.)	Generation	$^{206}\text{Pb}_c$, %	Concentration, ppm			$\frac{^{232}\text{Th}}{^{238}\text{U}}$	$^{207}\text{Pb}/^{206}\text{Pb}$ -age, Ma	Discordance, %	$\frac{^{207}\text{Pb}^*}{^{235}\text{U}}$	$\frac{^{206}\text{Pb}^*}{^{238}\text{U}}$	Error correlation
			$^{206}\text{Pb}^*$	U	Th						
1.1	1	0.10	136	294	223	0.78	$2.836.7 \pm 7.9$	2	14.92 ± 2.3	0.537 ± 2.2	0.977
1.2	2	0.03	398	956	3	0.00	2.660 ± 26	4	12.08 ± 2.7	0.485 ± 2.2	0.807
2.1	1	0.52	103	253	110	0.45	2.764 ± 12	10	12.47 ± 2.3	0.469 ± 2.2	0.952
2.2	2	0.03	238	580	11	0.02	$2.611.1 \pm 6.2$	4	11.54 ± 2.2	0.477 ± 2.2	0.985
3.1	2	0.00	731	1775	11	0.01	$2.644.9 \pm 3.5$	5	11.84 ± 2.2	0.479 ± 2.2	0.995
3.2	3	0.63	77.4	253	5	0.02	1.895 ± 22	-3	5.66 ± 2.6	0.3541 ± 2.3	0.889
4.1	2	0.02	348	803	6	0.01	$2.653.0 \pm 8.4$	1	12.52 ± 2.2	0.504 ± 2.1	0.973
4.2	3	0.00	101	343	4	0.01	1.895 ± 12	0	5.48 ± 2.3	0.3430 ± 2.2	0.956
5.1	1	1.91	79.5	165	185	1.16	2.836 ± 29	1	15.23 ± 2.8	0.549 ± 2.2	0.780
6.1	1	0.32	79.8	172	77	0.47	$2.847.0 \pm 9.8$	2	15.07 ± 2.4	0.539 ± 2.3	0.968
7.1	2	0.02	266	689	63	0.09	2.574 ± 12	7	10.64 ± 2.3	0.4494 ± 2.2	0.945
7.2	3	0.33	69.5	239	3	0.01	1.882 ± 17	1	5.35 ± 2.4	0.3371 ± 2.2	0.915

Note: Zircon monofractions were extracted at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (Moscow). Geochronological measurements were conducted using Temora and 91 500 zircon standards at the Center of Isotopic Research, Karpinskii All-Russia Research Institute of Geology. The analyzed points were selected by optical and cathodoluminescent (LinkAn-2000 electron microscope) observations. The Th–U–Pb isotope composition of zircons was measured using technique [9] on a secondary SHRIMP-II ion microprobe. The intensity of the primary beam of negative molecular oxygen ions was 4 nA, and the diameter of the spot (crater) was 18–20 μm in size. Data were processed with a SQUID program [10]. The U–Pb ratios were normalized to 0.0668 in TEMORA standard zircon corresponding to the age of 416.75 Ma [11]. Uncertainty of individual analyses (ratios and ages) is given at 1σ level. Uncertainties of calculated concordant ages and concordia intercepts are given at 2σ . The concordia diagrams were plotted using ISOPLOT/EX programs [12]. Pb_c and Pb^* are common and radiogenic lead, respectively. The calibration error of the measured zircon standard for a given sample was 0.88%. Correction for common lead was based on measured ^{204}Pb .

to be related to the pegmatite formation [5]. This date is close to the age of the Khitoostrov zircon 3. Since the corundum-bearing metasomatites are also located within the pegmatite field, zircon 3 can apparently be inherited from gneisses and altered during pegmatite formation. However, the gneiss-hosted zircon from the pegmatite fields differs from zircon 3 of the corundum-bearing metasomatites in the high U content and morphology (large equant grains with thin growth zoning).

Since zircon 3 crystallized during the formation of corundum-bearing metasomatites, its age is Paleoproterozoic Svecofennian (1894 ± 17 Ma). This is consistent with age estimates based on geological relations with reliably dated objects. The assumption of the post-pegmatitic age of corundum metasomatites suggested by Serebryakov [4] is also based on geological data. However, isotope data attest to practically similar ages of metasomatism and pegmatite formation. The difference in the timing of metasomatites and pegmatites is likely within the error limit of the isotope method. The Archean zircons in metasomatites were inherited from replaced gneisses. Such zircons have detrital (zircon 1) or migmatite (zircon 2) origin.

The obtained data on the Svecofennian age of the corundum-bearing metasomatites serve as additional evidence for the wide development of Early Proterozoic processes, which were responsible for the significant

reworking of Archean rocks of the BMB. The development of metasomatites over the entire extension of the Chupa sequence within the Chupa segment testifies to

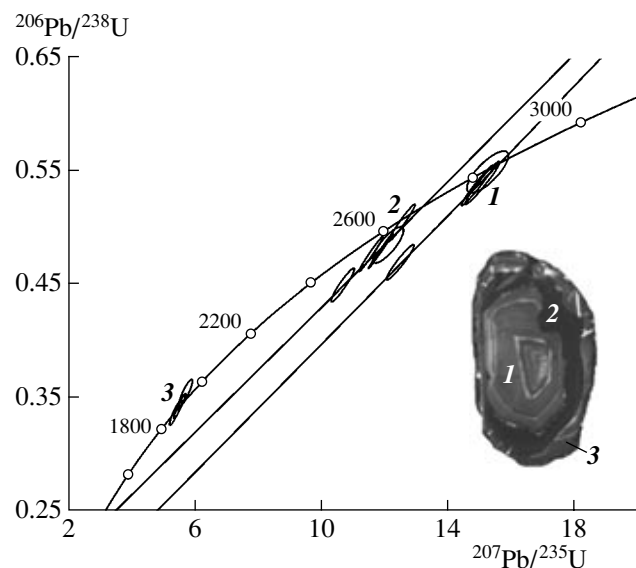


Fig. 3. Concordia diagram for zircons from the Khitoostrov corundum-bearing metasomatites. Extracted zircon generations have the following ages: (1) 2857 ± 30 Ma; (2) 2692 ± 68 Ma; (3) 1894 ± 17 Ma

the existence of a regional fluid-permeable zone in the Early Proterozoic.

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REFERENCES

1. *Metamorphic Facies of the Eastern Belomorian Shield* (Nauka, Leningrad, 1990) [in Russian].
2. O. I. Volodichev, *The Belomorian Complex of Karelia: Geology and Petrology* (Nauka, Leningrad, 1990) [in Russian].
3. B. Yu. Astaf'ev and O. A. Voinova, in *Rifting, Magmatism, and Metallogeny of Precambrian: Correlation of the Fennoscandian Geological Complexes* (Petrozavodsk, 1999), pp. 9–10 [in Russian].
4. N. S. Serebryakov and Vs. V. Aristov, *Izv. Vyssh. Uchebn. Zaved., Geol. Razv.*, No. 4, 36 (2004).
5. E. V. Bibikova, S. V. Bogdanova, V. A. Glebovitsky, et al., *Petrology* **12**, 195 (2004) [*Petrologiya* **12**, 227 (2004)].
6. N. S. Serebryakov and V. L. Rusinov, *Dokl. Earth Sci.* **395**, 389 (2004) [*Dokl. Akad. Nauk* **395**, 529 (2004)].
7. E. N. Terekhov and V. I. Levitskii, *Izv. Vyssh. Uchebn. Zaved., Geol. Razv.*, No. 6, 3 (1991).
8. A. I. Slabunov, A. N. Larionov, E. V. Bibikova, et al., in *Geology and Mineral Resources of Karelia* (Petrozavodsk, 2001), Issue 3, pp. 3–14 [in Russian].
9. I. S. Williams, *Rev. Econ. Geol.*, No. 7, 1 (1998).
10. K. R. Ludwig, *Berkley Geochronol. Center, Spec. Publ.*, No. 2 (2000).
11. L. P. Black and S. L. Kamo, *Chem. Geol.* **200**, 155 (2003).
12. K. R. Ludwig, *Berkley Geochronol. Center, Spec. Publ.*, No. 1a (1999).
13. O. A. Levchenkov, O. I. Volodichev, T. F. Zinger, et al., *Dokl. Earth Sci.* **377**, 168 (2001) [*Dokl. Akad. Nauk* **377**, 235 (2001)].
14. T. I. Myskova, R. I. Mil'kevich, A. B. L'vov, and Yu. V. Miller, *Lithol. Miner. Res.* **35**, 583 (2000) [*Litol. Polezn. Iskop.*, No. 6, 653 (2000)].