ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 411A, No. 9, pp. 1476–1479. © Pleiades Publishing, Inc., 2006.
Original Russian Text © V.R. Vetrin, N.G. Berezhnaya, N.V. Rodionov, 2006, published in Doklady Akademii Nauk, 2006, Vol. 411, No. 6, pp. 798–802.

GEOCHEMISTRY

Petrology of Postorogenic Granitoids of the Northern Baltic Shield

V. R. Vetrin[a], N. G. Berezhnaya[b], and N. V. Rodionov[b]

Presented by Academician F.P. Mitrofanov, February 26, 2006

Received March 15, 2006

DOI: 10.1134/S1028334X06090327

Granitoids are an important element of the continental crust. In geological bodies, these rocks often associate with diorites and gabbro, the role of which in the genesis of granitoids remains debatable. Basic and intermediate rocks in granite massifs are considered derivatives of mantle melts, end products of assimilation and mixing, or relicts of the lower crust substrate captured by ascending granite magmas.

In the northern Baltic Shield, diorites, monzodiorites, and quartz diorites are constituents of postorogenic granite massifs, the localization of which was controlled by NE- and NW-trending fault zones (Fig. 1). The NE-trending transform faults controlled the emplacement of the Litsa–Aragub and Yuovvoaiv complexes (1.77–1.76 and 1.79–1.77 Ga old, respectively [1, 2]); the Vainospäa Massif; and, probably, the "Nattanen-type" massifs (Nattanen, Tepasto, Pomovaara, Riestovaara) (1.8 to 1.77 Ga old [3]) located at the southern framing of the Lapland granulite belt. Localization of small postorogenic massifs and dikes of the Chalmozero Complex [4] was governed by the NW-trending Chalmozero–Kandalaksha tectonic zone.

The Litsa–Aragub Complex with massifs occupying an area of approximately 900 km^2 is best studied among the granitoids. All intrusions are multiphase bodies that consist of two discrete (diorite and granite) associations without transitional varieties. The diorite association is represented by rocks of phases 1 and 5 (monzodiorites, diorites, quartz diorites, and granosyenites). The granite association includes porphyric and equigranular granodiorites, quartz monzonites, granites, leucogranites, and alaskites of phases 2 (main) through 4 (Table 1). All rocks of the complex are characterized by high alkali contents; the prevalence of potassium over sodium in rocks of the granite association; and a concentration of Zr, Nb, Mo, Ba, Sr, REE, U, and Th. According to [1], rocks of the diorite association are products of the differentiation of the mantle

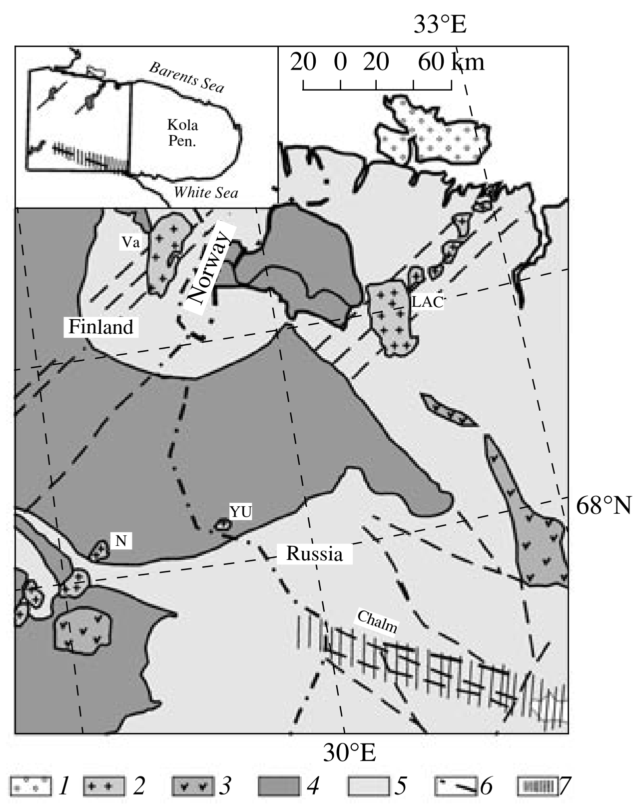

Fig. 1. Schematic location of postorogenic granite massifs in the northern Baltic Shield. (*1*) Vendian–Riphean sedimentary rocks; (*2*) massifs and complexes of postorogenic granitoids: (LAC) Litsa–Aragub Complex, (Va) Vainospäa Massif, (Chalm) Chalmozero Complex, (YU) Yuovvoaiv Massif, (N) "Nattanen-type" massifs; (*3*) mafic–ultramafic rocks; (*4*) Paleoproterozoic volcanosedimentary and intrusive complexes; (*5*) Late Archean supracrustal complexes; (*6*) fault projections; (*7*) Chalmozero–Kandalaksha fault zone. Inset shows geographic position of postorogenic granitoid massifs in the northern Baltic Shield.

[a] *Geological Institute, Kola Scientific Center, Russian Academy of Sciences, ul. Fersmana 14, Apatity, 184209 Russia; e-mail: vetrin@geoksc.apatity.ru*

[b] *All-Russia Geological Institute, Srednii pr. 74, St. Petersburg, 199026 Russia*

Average contents of major (wt %) and trace (ppm) elements in rocks of the Litsa–Aragub Complex

Component	Monzodiorites, quartz diorites, diorites of phase 1 (4)	Porphyric granites and subalkalic granites of the main phase 2 (41)	Porphyric granites and quartz monzonites of phase 3 (14)	Leucogranites and alaskites of phase 4 (20)	Granosyenites and monzonites of phase 5 (3)
SiO_2	55.35	68.67	72.31	73.88	64.78
TiO_2	0.90	0.57	0.29	0.21	0.87
Al_2O_3	16.62	14.48	14.02	13.38	15.22
FeO	3.98	1.80	0.99	0.96	2.31
Fe_2O_3	2.62	1.94	1.15	0.76	3.66
MgO	4.32	0.97	0.43	0.32	1.23
CaO	6.21	2.01	1.19	1.00	2.11
Na_2O	3.50	3.80	3.58	3.67	3.49
K_2O	2.43	4.57	5.01	5.01	5.19
Sr	1120	450	310	260	380
Y	18	31	18	9	30
Sr/Y	62	15	17	29	13

Note: Number of analyses is shown in parentheses.

asthenolith that provoked the formation of the secondary intracrustal chamber. This process was preceded by metasomatic transformation of the crust by juvenile solutions enriched in K, Zr, Nb, and REE.

Figure 2 demonstrates data on the Sm and Nd isotopic compositions of rocks of the Litsa–Aragub Complex. Isotopic analyses were carried out with a Finnigan-Mat mass spectrometer at the Geological Institute, Apatity (A.A. Delenitsyn, analyst). The $^{143}Nd/^{144}Nd$ values were corrected using standards La Jolla (0.511833, $n = 11$) and JiNd (0.512078, $n = 10$). Model ages and ε_{Nd} values were calculated in line with the model [5] with modern $^{143}Nd/^{144}Nd$ and $^{147}Nd/^{144}Nd$ values for the depleted mantle (DM) equal to 0.512359 and 0.2136, respectively.

The $\varepsilon_{Nd(1765)}$ values are rather similar (–6.6 to –8.5) for rocks of phases 1–3 and range from –7.1 to –11.8 for leucogranites of phase 4. The model age of these rocks is 2.37–2.62 and 2.58–3.23 Ga, respectively. The obtained isotopic characteristics introduce some constraints into the formation model of the complex. High negative ε_{Nd} values rule out the origin of primary melts for rocks of phase 1 from the upper mantle source depleted or enriched in subducted crustal material. This statement is consistent with the anatectic genesis of parental magmas. As is evident from experimental data [7], intermediate melts with elevated K, Al_2O_3, and Ca contents can most probably be generated by the dehydration melting of potassic metabasalts at high temperatures and moderate and high pressures. Garnet amphibolites, granulites, or eclogites may be in equilibrium with melts. The substantially clinopyroxene–garnet–rutile composition of restites during the formation of parental melts for monzodiorites and quartz diorites of phase 1 is confirmed by low Y and Ti concentrations; high Sr contents; and, correspondingly, high Sr/Y values in the rocks under consideration (Table 1). The difference between volumes of rocks of the diorite association (~180 km^3) and granite plutons (~3200 km^2) of the Litsa–Aragub Complex indicate that granitoids could hardly result from differentiation of the parental melt for monzodiorites and quartz diorites of phase 1. A similar inference also follows from different compositions of rocks of the diorite and granite associations that occupy separate fields in most of the petrochemical

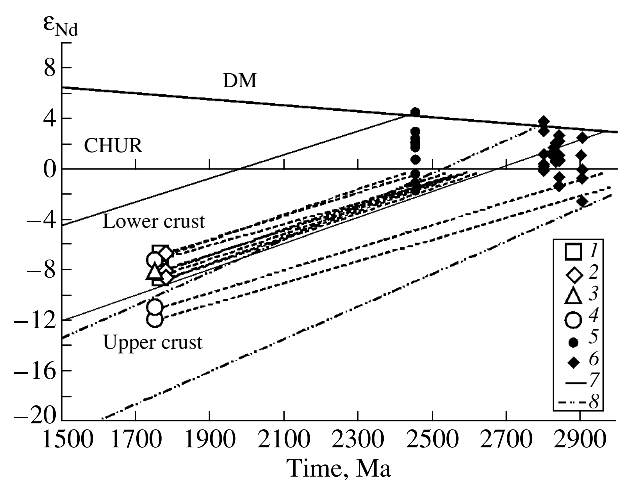

Fig. 2. Time (Ma)–ε_{Nd} diagram. (*1–4*) Granitoids of phases 1–4 from the Litsa–Aragub Complex; (*5, 6*) xenoliths of garnet granulites of the lower crust [10] and tonalite–trondhjemite rocks of the upper crust [6], respectively; (*7, 8*) boundary lines of areas of Nd isotopic composition in rocks of the lower and upper crust, respectively.

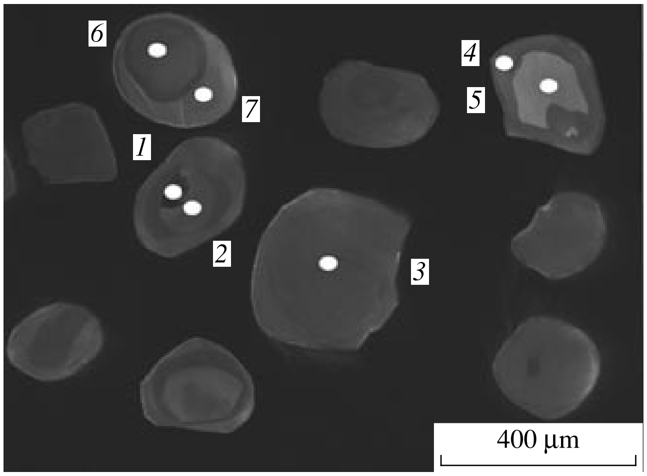

Fig. 3. Photomicrographs of zircons in cathode rays. The white ellipsis shows the crystal surface area subjected to isotopic analysis. Analysis point numbers are shown near the respective grains.

diagrams. These facts suggest that anatectic melting of the crust enriched in some elements (K, Zr, Nb, and REE) due to the preceding transformation of rocks by juvenile solutions is the most probable mechanism of the origin of parental melts for granitoids of phases 2–4 [1]. The substantially crustal genesis of melts of the granite association is also assumed for postorogenic granites of the Vainospäa and Nattanen massifs based on the study of Nd and Hf isotopes in these rocks [3, 8].

The model age of rocks of phases 1–3 from the Litsa–Aragub Complex (2.37–2.62 Ga) indicates that rocks of the lower crust could serve as a protolith for them. According to data on deep xenoliths [9], the lower crust of the region is largely composed of Neoarchean–Paleoproterozoic garnet granulites (Grt + Cpx + Pl ± Opx ± Qtz ± Rut) and subordinate pyroxenites (Cpx + Pl ± Grt ± Opx ± Hbl ± Qtz). Analogues of these rocks in the upper crust are Paleoproterozoic layered intrusions and comagmatic volcanics, drusites and gabbro–anorthosite intrusions, and volcanics of Neoarchean greenstone belts. The $\varepsilon_{Nd\ (1765)}$ values in granitoids of phases 1–4 (from –6.6 to –11.8) and lower crustal xenoliths (from –2.5 to –8.8) significantly overlap (Fig. 2). This fact and the similarity of model datings suggest that garnet granulites of the lower crust served as the parental substrate for melts of the Litsa–Aragub Complex. Thin dikes of leucogranites and alaskites of phase 4 among Archean tonalite gneisses recovered by the Kola superdeep borehole are characterized by low negative $\varepsilon_{Nd\ (1765)}$ values and elevated model ages as compared with rocks of phases 1–3. This may indicate either their Neoarchean sialic source or contamination of Paleoproterozoic melts by material from the Late Archean upper crust. This is also evident from the confinement of data points of granitoids to the Nd isotopic field of Neoarchean tonalite gneisses and supracrustal rocks of the upper crust (Fig. 2).

The duration of metasomatism and anatexis of the lower crust was determined based on the age of zircons from granitized garnet granulites. In these rocks, minerals of the pyroxene–garnet–plagioclase matrix are replaced by newly formed plagioclase, orthoclase, quartz, and scapolite. This process was accompanied by destruction of garnet grains and formation of rounded, complicatedly faceted zircon crystals up to 0.2–0.4 mm in size [9]. In cathode rays, the crystals are characterized by uniform (or zoned) structures and the presence of distinct rounded (or ellipsoid) cores that occupy up to half to 2/3 of the grain volume (Fig. 3). Sometimes, the core of isometric crystals contains inclusions of small brown prismatic zircon crystallites. The U–Pb age of zircons was determined with a SHRIMP-2 secondary ion microprobe in the Center of Isotopic Studies of the Karpinskii All-Russia Research Institute of Geology (St. Petersburg) in line with the technique described in [11]. The data were processed using the SQUID software [12]. As follows from Fig. 4, all the examined zircons are concordant. The oldest age (2003 ± 13 Ma) is recorded for the brown prismatic crystal (point *1*) enclosed in the core of the ellipsoid crystal. This zircon is characterized by the relatively high U content (405 ppm) and low Th/U value (0.07), suggesting its generation prior to granitization of garnet granulites. In other crystals, the U and Th concentrations are 56–82 and 44–354 ppm, respectively (Th/U = 0.79–6.14). The youngest age (1440 ± 200 Ma) is established for the crystal marked by a significant error in the $^{206}Pb/^{238}U$ value measurement due to the high share of common lead (Pb_c). The isotopic age of other zircon grains ranges from 1.83 to 1.66 Ga. It should be emphasized that the age of their cores is 20–40 Ma older relative to marginal parts. Figure 4 shows the average concordant ages calculated for crystals *3, 7* (1760 ± 20 Ma) and *4, 5* (1703 ± 8 Ma). These estimates indicate that the duration of the most intense stage of deep metasomatism is 50–60 Ma. The obtained values are close to the ages of zircons (1.82–1.71 Ga [13] and 1.77–1.61 Ga [14]), which presumably formed in the course of granitization and anatexis of garnet granulites of the lower crust.

Thus, granitization of the lower crust preceded the formation of postorogenic melts and continued after this event for approximately 100 Ma. The period of 1.8–1.6 Ga in the Baltic Shield history is marked by the emplacement of postorogenic potassic granites, carbonatites, lamprophyres, lamproites, and pegmatites. Some of these derivatives are characterized by mantle genesis and confinement to regional fault zones, which served as conduits for fluids ascending from deep magma chambers. Further cratonization of the Baltic Shield was accompanied by the formation of large anorogenic rapakivi granite massifs, including the oldest bodies with an age of 1.67–1.62 Ga.

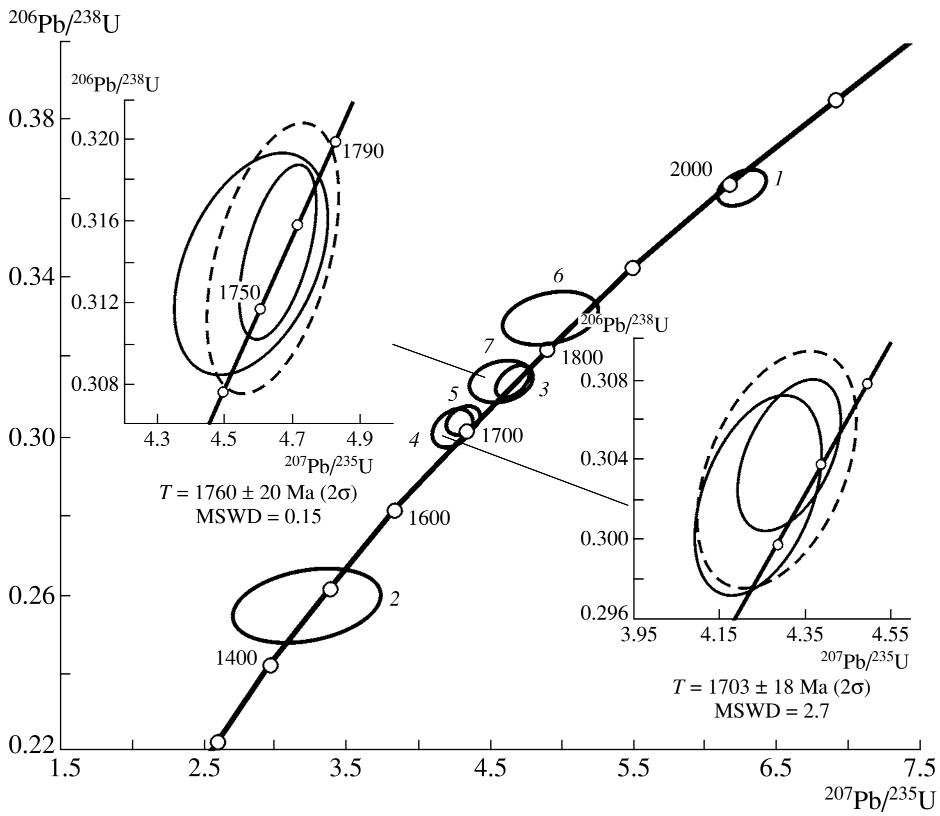

Fig. 4. Diagram with concordia for zircons from granitized garnet granulites. Error ellipses for individual analyses and concordant values are quoted at 1σ and 2σ levels, respectively. Analysis point numbers are shown near the respective grains.

ACKNOWLEDGMENTS

V. Vetrin thanks Prof. O. Eklupd (University of Turka, Finland) for participation in excursions in Laplandia in 2003 and for the possibility to study granitoids in Finland and Sweden.

This work was supported by the Russian Foundation for Basic Research (project no. 02-05-64394) and State Contract AL-02-06/32.

REFERENCES

1. V. R. Vetrin, T. B. Bayanova, I. L. Kamenskii, and S. V. Ikorskii, Dokl. Earth Sci. **387**, 943 (2002) [Dokl. Akad. Nauk **387**, 85 (2000)].
2. K. Front, M. Vaarma, E. Rantala, and A. Luukkonen, Geol. Surv. Finland. Rep. Investigation, No. 85, 1 (1989).
3. H. Huhma, Geol. Sur. Finland. Bull. **337**, 1 (1986).
4. A. V. Savitskii, V. I. Stepanenko, and E. B. Anderson, Dokl. Akad. Nauk SSSR **382**, 1186 (1988).
5. S. J. Goldstein, S. B. Jacobsen, O. M. Turkina, et al., Earth Planet. Sci. Lett. **87**, 249 (1988).
6. V. R. Vetrin, O. M. Turkina, J. Ladden, and A. A. Delenitzin, Petrology **11**, 177 (2003) (Petrologiya **11**, 196 (2003)].
7. L. I. Khodorevskaya and V. A. Zharikov, in *Experimental and Theoretical Modeling of Mineral Formation* (Nauka, Moscow, 1998), pp. 11–31 [in Russian].
8. P. J. Patchett, O. Kouvo, S. E. Hedge, and M. Tatsumoto, Contrib. Mineral. Petrol. **78**, 279 (1981).
9. V. R. Vetrin and M. M. Kalinkin, *Reconstruction of Intracrustal and Crustal–Mantle Magmatism and Metasomatism* (Kol'sk. Nauchn. Tsentr Ross. Akad. Nauk, Apatity, 1992) [in Russian].
10. P. D. Kempton, H. Downes, L. A. Neymark, et al., J. Petrology **42**, 731 (2001).
11. I. S. Williams, Rev. Econ. Geol. **7**, 1 (1998).
12. K. R. Ludwig, in *Berkley Geochronol. Center Spec. Publ.,* No. 1a, 1 (1999).
13. V. R. Vetrin and A. A. Nemchin, Dokl. Earth Sci. **359A**, 454 (1998) [Dokl. Akad. Nauk **359**, 808 (1998)].
14. H. Downes, P. Peltonen, I. Mänttäri, and E. V. Sharkov, J. Geol. Soc. London **159**, 485 (2002).
15. I. Haapala, O. T. Rämö, and S. Frindt, **80**, 1 (2005).