

The Archean Pulozero–Polnek–Tundra Enderbite–Granulite Complex of the Central Kola Block: Stages and Formation Conditions (Kola Peninsula)

L. S. Petrovskaya, Academician of the RAS F. P. Mitrofanov, T. B. Bayanova, and P. A. Serov

Received May 4, 2007

DOI: 10.1134/S1028334X07070252

The geological studies of granulite–gneiss complexes of the Central Kola Block have a long history [1–5]. Nevertheless, many problems of their evolution, including the age and nature of protoliths, as well as the stages of magmatic and metamorphic processes and their spatiotemporal relationships, remain a matter of debate.

The subject of this communication is the characteristic of the age, formation duration, and conditions of the heterogeneous Archean Pulozero–Polnek–Tundra enderbite–granulite complex located in the central part of the Central Kola Block (CKB). The study region incorporates compositionally and genetically different rocks that may be regarded as reference formations for the reconstruction of the geological history of this region (Fig. 1).

The metamorphic rocks are migmatized granulites and gneisses of the Kola Group that experienced regional granulite- and amphibolite-facies metamorphism. The intrusive rocks comprise enderbites, amphibole–biotite tonalites, and various veins. The enderbite pluton postdated granulite metamorphism of host rocks of the Kola Group as is indicated by cross-cutting relations between enderbites and granulite gneisses. Amphibole–biotite tonalites occupy local areas within the enderbite pluton. The boundaries between enderbites and tonalites are vague, and gradual transition is observed. Synmetamorphic veined garnet- and sillimanite-bearing microcline–plagioclase granites crosscut migmatitic banding of the Kola Group gneisses. Leucogranite and aplite veins, which crosscut all rock varieties mentioned above, are the youngest formations.

Two stages of mineral formation established in rocks of the Kola Group correspond to two stages of

regional metamorphism of the Pulozero–Polnek–Tundra Complex.

The first stage is recorded in the early subgranulitic mineral assemblage¹ Grt_{55–69} + Bt_{25–32} (reddish brown) ± Sil + Pl_{23–29} ± Kfsp + Qtz. This assemblage is characterized by $T = 700–800^{\circ}\text{C}$ and $P = 5.5–7.3$ kbar estimated using [6, 7]. The presence of biotite in this assemblage may be explained by the specific composition of this mineral (elevated Mg content and enrichment in Ti up to 5 wt %), which is stable in a wide range of high temperatures. The U–Pb zircon age of subgranulitic metamorphism (T_1) is 2724 ± 49 Ma (Fig. 2a).

The second (superimposed) stage of regional metamorphism in gneisses of the Kola Group is dated by the U–Pb zircon method (T_4) at 2568 ± 10 Ma (Fig. 2a) and characterized by retrograde transformation under conditions of amphibolite facies. Cordierite–quartz symplectites replacing garnet are associated with cordierite that appears between garnet and sillimanite + quartz. The Fe mole fraction in garnet increases while the Mg mole fraction decreases. The superimposed amphibolite-facies metamorphism is characterized by the formation of a late mineral assemblage: Grt_{75–80} + Bt_{38–42} (light green) ± Sil_(fibrolite) ± Crd_{13–17} + Pl_{22–24} + Qtz ± Kfsp. The formation conditions of the superimposed stage are estimated at $T = 580–640^{\circ}\text{C}$ and $P = 4.0–6.0$ kbar [6, 7].

The large enderbite pluton was emplaced between two stages of regional metamorphism. The U–Pb zircon age of enderbite (T_2) is 2656 ± 14 Ma (Fig. 2b). The U–Pb zircon age of amphibole–biotite tonalite (T_3) is $2640–2635$ Ma (Fig. 2b) and characterizes the time when enderbite was metamorphosed.

¹ Abbreviations of minerals used in the present paper: (Grt) garnet, (Crd) cordierite, Bt (biotite), (Sil) sillimanite, (Opx) orthopyroxene, (Cpx) clinopyroxene, (Cum) cummingtonite, (Hbl) hornblende, (Pl) plagioclase, Kfsp (potassium feldspar), and (Qtz) quartz. The subscripts denote the Fe mole fraction of Grt, Crd, Bt, Opx, Cpx, Cum, and Hbl and the content of the anorthite end member in plagioclase, mol %.

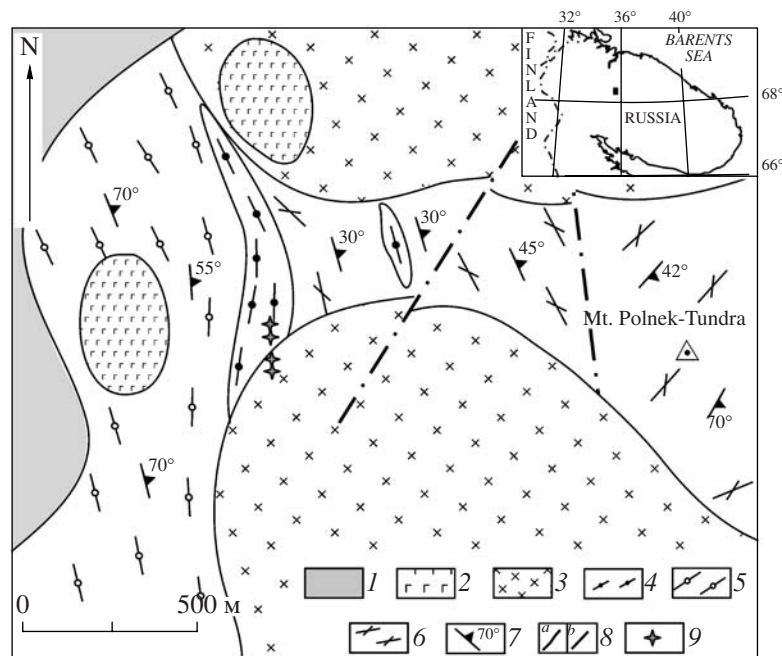


Fig. 1. Geological sketch map of the Pulozero–Polnek-Tundra district, compiled after S.A. Dyukov, V.V. Balagansky, and M.N. Bogdanova and using observations of L.S. Petrovskaya and M.N. Petrovsky. The study area is shown in the inset as a black rectangle. (1) Quaternary sediments; (2) gabbro; (3) enderbite; (4–6) gneisses of the Kola Group: (4) medium-calcic garnet-sillimanite-biotite, (5) medium-calcic garnet-biotite, (6) high-calcic garnet-biotite and biotite; (7) strike and dip of gneissic banding; (8a) geological boundaries and (8b) faults; (9) location of samples for isotopic dating.

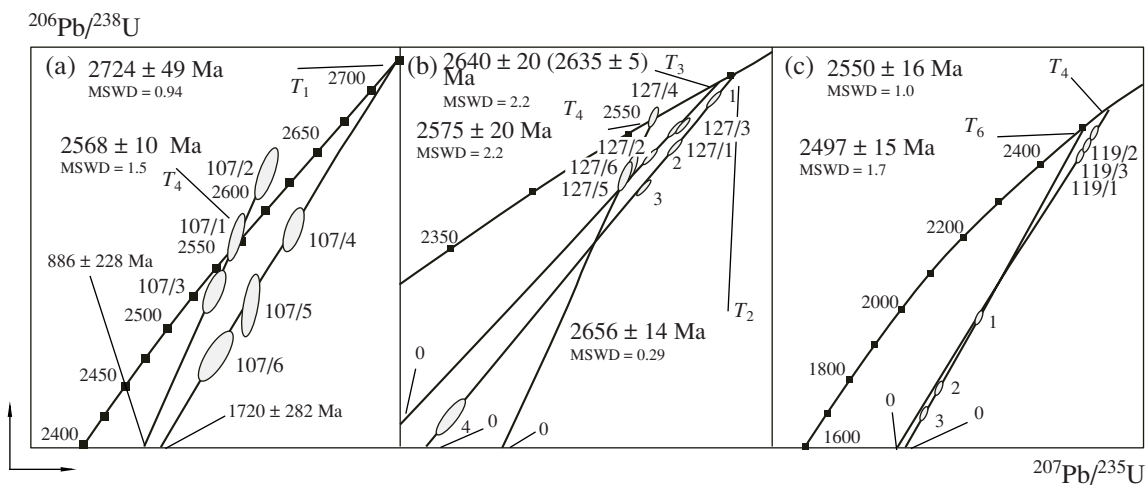


Fig. 2. U–Pb diagrams with concordia for zircons from (a) granulite and gneiss of the Kola Group (T_1 and T_4), (b) enderbite (T_2) and amphibole-biotite tonalite (T_3 and T_4), (c) veined garnet- and sillimanite-bearing microcline plagioclase granite (T_4) and veined leucogranite and aplite (T_6). Chemical separation of Pb and U was performed following the technique of [8]. All uncertainties are given at a level of 2σ . Coordinates of points and parameters of isochrons were calculated using [9, 10]. The common conventional decay constants [11] have been used.

The PT crystallization conditions of the igneous assemblage $\text{Opx}_{42-45} \pm \text{Cpx}_{30-35} + \text{Bt}_{41-44}$ (reddish brown) + $\text{Pl}_{27-33} + \text{Qtz}$ established in enderbite are estimated at $T = 700\text{--}800^\circ\text{C}$ and $P_{(\text{H}_2\text{O})} = 2.0\text{--}4.0$ kbar [12]. Metamorphism of enderbite resulted in the hydration of pyroxenes, which were replaced with biotite and

amphibole, and the formation of the mineral assemblage $\text{Cum}_{39-40} \pm \text{Hbl}_{40} + \text{Bt}_{40-41}$ (brownish green) + $\text{Pl}_{32-39} + \text{Qtz}$. The presence of cummingtonite testifies to the $P\text{--}T$ conditions of amphibolite facies of the andalusite-sillimanite type of metamorphism [13, 14].

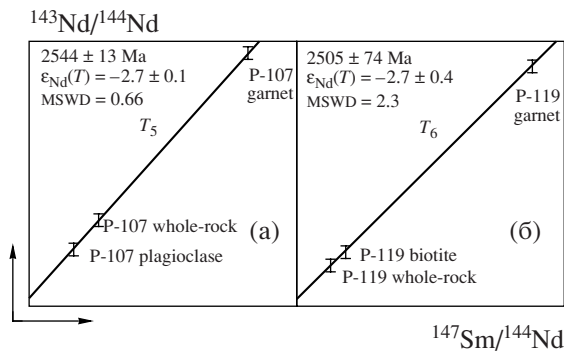


Fig. 3. Sm–Nd isochrons. (a) Gneiss of the Kola Group, sample 107; (b) veined garnet- and sillimanite-bearing microcline plagioclase granite veins crossing gneiss of the Kola Group, sample 119. The measurements were performed on a Finnigan-MAT-262 (RPG) seven-collector mass spectrometer in the static regime. Isochrons were calculated using [10]. The common conventional decay constants [11] have been used. Uncertainties are given at a level of 2σ .

The veined garnet- and sillimanite-bearing microcline plagioclase granites that cut aluminous gneisses of the Kola Group were formed at the ultrametamorphic stage of amphibolite-facies metamorphism and are characterized by the mineral assemblage Bt_{36} (brown) + Pl_{22-25} + $Kfsp$ + Qtz ± (Gr_{56-69} + Sil). The temperature of granite crystallization is estimated at 690°C [12] and $P_{(\text{H}_2\text{O})} = 2.6$ kbar. The U–Pb zircon age of this granite (T_4) is 2550 ± 16 Ma (Fig. 2c). This age is close to the timing of superimposed amphibolite-facies metamorphism recorded in gneisses of the Kola Group ($T_4 = 2568 \pm 10$ Ma) and the late stage of amphibolite-facies metamorphism in amphibole–biotite tonalite ($T_4 = 2575 \pm 20$ Ma).

The retrograde stage of low-temperature amphibolite-facies metamorphism of gneisses from the Kola Group, which is based on variations in the marginal parts of the late garnet, is characterized by $T = 500$ – 600°C and $P = 2.2$ – 5.3 kbar [6, 7]. The Sm–Nd garnet–

whole rock–plagioclase isochron age of this event (T_5) is 2544 ± 13 Ma (Fig. 3a).

The leucogranitic–aplitic veins with a U–Pb zircon age (T_6) of 2497 ± 15 Ma (Fig. 2c) that cut gneisses of the Kola Group, enderbites, and tonalites mark the upper age limit of folding and metamorphism in this district. The mineral assemblage is Bt_{36} (brownish green) + $Kfsp$ + Pl_{13} + Qtz . The crystallization temperature and water pressure are estimated at 690°C and 3.6 kbar, respectively [12].

The isotopic Sm–Nd study of mineral phases of garnet- and sillimanite-bearing microcline plagioclase granites shows that their Sm–Nd isotopic systems were closed (T_6) approximately $T_6 = 2.50$ Ga ago (Fig. 3b). The closure of Rb–Sr isotopic systems established from mineral isochrons for gneiss of the Kola Group and garnet- and sillimanite-bearing microcline–plagioclase granites is related to the Svecofennian event at $T_7 = 1827$ – 1811 Ma (Figs. 4a, 4b). In minerals from enderbites and associated granites, the Rb–Sr systems were closed in the Early Karelian epoch (Fig. 4c).

Thus, the results of geological and geochronological study allowed us to establish for the first time the succession of endogenic processes and formation conditions during the evolution of the Archean Pulozero–Polnek–Tundra enderbite–granulite complex 2.72–1.81 Ga ago. Three stages of metamorphism have been documented in gneisses of the Kola Group: (I) early subgranulitic (2.72 Ga), (II) superimposed amphibolite-facies (2.57 Ga), and (III) retrograde low-temperature amphibolite-facies (2.54 Ga). Stages I and II were separated by emplacement of enderbites (2.66 Ga) and formation of amphibole–biotite tonalites after enderbites (2.64 Ga). Ultrametamorphism in gneisses of the Kola Group was accompanied by injections of anatectic veins of microcline–plagioclase granites with garnet and sillimanite (2.55 Ga ago). The tectonic and magmatic activity was completed by injection of leucogranitic veins (~2.50 Ga ago) that crosscut gneisses of the Kola Group, enderbites, and amphibole–biotite tonalites. Based on Sm–Nd and Rb–Sr methods, the influence of Paleoproterozoic processes on the granulite–enderbite

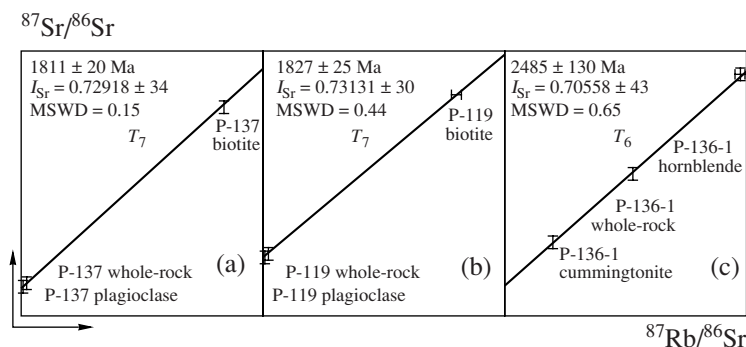


Fig. 4. Rb–Sr isochrons for rocks and minerals. (a) Gneiss of the Kola Group sample 137; (b) garnet- and sillimanite-bearing microcline plagioclase granite veins crossing gneiss of the Kola Group, sample 119; (c) amphibole–biotite tonalite, sample 136-1.

complex with the alteration of isotopic systems is recorded at ~2.50 and 1.82 Ga ago.

ACKNOWLEDGMENTS

This work was supported by the Foundation of the President of the Russian Federation for the Support of Leading Scientific Schools (project no. NSh-1413.2006.5), the Russian Foundation for Basic Research (project no. 05-05-08028), and the Division of Earth Sciences of the Russian Academy of Sciences (program No. 8).

REFERENCES

1. A. I. Tugarinov and E. V. Bibikova, *Geochronology of the Baltic Shield: Evidence from Zirconometry* (Nauka, Moscow, 1980) [in Russian].
2. Yu. A. Balashov, F. P. Mitrofanov, and V. V. Balagansky, in *Correlation of Precambrian Formations of the Kola–Karelian Region and Finland* (Kol. Nauch. Tsentr, Ross. Akad. Nauk, Apatity, 1992), pp. 13–34 [in Russian].
3. K. Kh. Avakyan, *Geology and Petrology of the Archean Central Kola Granulite–Gneiss Domain* (Nauka, Moscow, 1992) [in Russian].
4. V. I. Fonarev, A. N. Konilov, and A. A. Graphchikov, *Int. Geol. Rev.* **35**, 401 (1993).
5. T. A. Myskova, N. G. Berezhnaya, V. A. Glebovitsky, et al., *Dokl. Earth Sci.* **402**, 547 (2005) [*Dokl. Akad. Nauk* **402**, 82 (2005)].
6. L. L. Perchuk, *Dokl. Akad. Nauk SSSR* **256**, 441 (1981).
7. T. D. Ghent, *Am. Mineral.* **61**, 710 (1976).
8. T. N. Krogh, *Geochim. Cosmochim. Acta* **37**, 485 (1973).
9. K. R. Ludwig *PBDAT—A Computer Program for Processing Pb–U–Th Isotope Data* (US Geol. Surv. Open-File Rep. 88-542, 1991).
10. K. R. Ludwig *ISOPLLOT/Ex—A Geochronological Toolkit for Microsoft Excel, Vers. 2.05* (Berkeley Geochronol. Center Spec. Publ., 1999), no. 1a.
11. R. H. Steiger and E. Jäger, *Earth Planet. Sci. Lett.* **36**, 359 (1977).
12. M. I. Dubrovsky, *Paragenetic Analysis of Mineral Assemblages in Granitoids* (Nauka, Leningrad, 1987) [in Russian].
13. M. D. Krylova, V. A. Galibin, and D. P. Krylov, *Major Dark-Colored Minerals of High-Grade Metamorphic Complexes* (Nedra, Leningrad, 1991) [in Russian].
14. A. Zen, T. J. B. Holland, and R. Klemd, *J. Metamorph. Geol.* **23**, 1 (2005).