The Kandalaksha-Kolvitsa gabbro-anorthosite complex: Nd-Sr isotope-geochronological evidence of its affinity to the East-Scandinavian Large Igneous Province

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Abstract. The article provides new Sm-Nd and Nd-Sr isotope-geochronological data on rocks of the Paleoproterozoic Kandalaksha-Kolvitsa gabbro-anorthosite complex. The isotope Sm-Nd dating on metamorphic minerals (apatite, garnet, sulfide) and rock of the Kolvitsa massif yielded the age of 1887±37 Ma (high-temperature metasomatic transformation) and 1692±71 Ma (regional fluid processing). The model Sm-Nd age of metagabbro is 3.3 Ga with a negative value of εNd=-5.5, which indicates processes of crustal contamination or primary enriched mantle reservoir of initial magmas. According to geochronological and Nd-Sr isotope data, rocks of the Kandalaksha-Kolvitsa complex seem to have a common anomalous mantle source with Paleoproterozoic layered intrusions in the Baltic Shield.

1. Geological setting
The Kandalaksha-Kolvitsa zone is the southern part of the Lapland Granulite Belt (LGB) that hosts volcanogenic sequences intercalated by anorthosite bodies. The gabbro-anorthosite magmatism of varied age (from Neoarchean to Paleoproterozoic) is widespread in the Baltic Shield in various structural settings associated with Ti-V (in the Neoarchean) and Cu-Ni-PGE (in Paleoproterozoic) deposits [1]. The Kandalaksha-Kolvitsa gabbro-anorthosite complex occurs on garnet plagioclase amphibolites of the Kandalaksha sequence and is overlapped by garnet-clinopyroxene-plagioclase crystalline schists of the Ploskaya Tundra sequence metamorphosed in conditions of granulite facies [2-3]. The complex is particularly interesting for profound isotope-geochemical research. For the first time, the U-Pb method has been applied with an artificial 205Pb tracer to date single zircon grains from metagabbro of the Kolvitsa massif at 2448±5 Ma. The new precise U-Pb age of metagabbro from the Kandalaksha massif has been estimated at 2453.5±8.4 Ma. It is interpreted as the magmatic formation time of the massif.

2. Sm-Nd data
Main rock varieties of the Kandalaksha-Kolvitsa gabbro-anorthosite complex have been studied with isotope-geochemical Sm-Nd and Rb-Sr analyses (on rock and minerals) at the Centre for Collective Use GI KSC RAS, using standard techniques [4]. The Sm-Nd dating of metagabbro from the Kolvitsa massif has yielded the age of 1985±17 Ga (Fig. 1a), which corresponds with the time of the granulite metamorphism widespread in LGB [5-7].
the range of $^{147}\text{Sm}/^{144}\text{Nd}$ values wider. In general, using sulfides as geochronometers provides positive results for a number of economically valued objects in the Baltic Shield [8].

The model Sm-Nd age of these gabbroids is close to 3.3 Ga (Table 1), which is typical of the Palaeoproterozoic ore-magmatic system in the Baltic Shield [9].

Heavy concentrate of rutile, garnet, plagioclase and clinopyroxene have been sampled from metaanorthosites of the Kandalaksha massif (sample 225/1) for Sm-Nd research. Together with the whole rock, in a Sm-Nd plot in isochron coordinates they show a dependence that complies with the age of 1886±9 Ma (Fig. 1b). The close Sm-Nd age of 1886±9 Ma has been obtained for sillimanite-orthopyroxene-garnet rocks of the Porya Guba cover of LGB. The authors of [10] interpret this age as the time of high-temperature metasomatism.

The Sm-Nd age of metamorphosed leucogabbro from the Kandalaksha massif (sample 183) has been dated on whole rock, apatite, amphibole and garnet at 1692±71 Ma (Fig. 1c). It is close to the U-Pb age of rutile and seems to mark processes of cooling or low-temperature processing of rocks in the Kandalaksha massif at the turn of 1.7 Ga. The age of 1.7 Ga is quite widespread in the Kola Peninsula and seems to be associated with the fluid processing of rocks at temperatures not higher than 450°C [11].

Test plots in coordinates $^{143}\text{Nd}/^{144}\text{Nd}$ vs. $1/[\text{Nd}]$ have been used for some samples to estimate the probability of obtaining false isochrones of mixing (Fig. 2). There is no relation between concentrations of neodymium in the rock and isotope compositions in most samples. However, garnet-plagioclase crystalline schists (sample 276) show a negative trend of $^{143}\text{Nd}/^{144}\text{Nd} – 1/[\text{Nd}]$. It may indicate an open or distorted Sm-Nd isotope system and, as a result, an influx of radiogenic neodymium into the host matrix (losses of Nd are shown by a red arrow in Fig. 2).
In general, no dependence between concentrations of Nd in the rock and the isotope composition indicates high geological value of the obtained geochronological data and corroborates the obtained results.

3. Nd-Sr systematics
The Sm-Nd and Rb-Sr studies have provided data on isotope compositions of neodymium and strontium in rocks of both massifs. The isotope compositions of neodymium (εNd) range from -0.02 in norites of the Kandalaksha massif to -5.53 in lens bodies of gneiss granites of the Kolvitsa massif (Fig. 3, Table 1).

Table 1. Results of isotope Sm-Nd and Rb-Sr analysis of the main rock varieties in the Kandalaksha-Kolvitsa gabbro-anorthosite complex

| Concentration, ppm | Isotope ratios | T, Ma | ISr | Concentration, ppm | Isotope ratios | T(0), Ma | εNd(T) | Age, Ga |
|--------------------|----------------|-------|------|-------------------|----------------|----------|--------|---------|
| Rb                 | Sr             | εRb/86Sr | εSr/86Sr | Sm               | Nd            | εSm/144Nd | εNd/144Nd |
| Sample 220/1, metanorite, Kandalaksha massif | 16.49 | 259.0 | 0.1796 | 0.70744±18 | 2100 | 0.7020 | 0.155 | 0.916 | 0.1025 | 0.51116±31 | 2776 | -0.02 |
| Sample 225/1, anorthosite, Kandalaksha massif | 3.38 | 304.02 | 0.031367 | 0.70299±18 | 2230 | 0.7020 | 0.419 | 2.003 | 0.1265 | 0.51154±8 | 2796 | -1.23 | 1.9 |
| Sample 183, metagabbro, Kandalaksha massif | 7.37 | 367.3 | 0.0566 | 0.70426±16 | 2453 | 0.7023 | 0.459 | 2.553 | 0.1087 | 0.51126±31 | 2728 | -1.25 | 1.7 |
| Sample 185, metaperidotite, Kandalaksha massif | 13.73 | 90.6 | 0.4277 | 0.71758±17 | 2450 | 0.7024 | 1.407 | 6.49 | 0.1310 | 0.511532±7 | 2969 | -0.95 |
| Sample 350 metagabbro, Kandalaksha massif | | | | | | | | | | | |
Weakly radiogenic values of $\varepsilon$Nd = -1.0 – -1.2 dominate, which complies with characteristic values of Paleoproterozoic layered intrusions in Fennoscandia [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]. Isotope compositions of strontium ranging from 0.7013 to 0.7025 (Fig. 3, Table 1) also reflect typical values of a Paleoproterozoic igneous province [12], [13], [14], [15], [21].

| Sample | %Nd | %Hf | $\varepsilon$Nd | Isr | Age (Ga) |
|--------|-----|-----|-----------------|-----|----------|
| Sample 200, metagabbro, Kolvitsa massif | 24.6 | 1.0 | -1.05856 | 0.0945 | 2.45 |
| Sample 205, subalkaline gneiss granite, Kolvitsa massif | 2.78 | 0.0184 | -1.05856 | 0.0945 | 2.45 |
| Sample 194/1, metagabbro, Kolvitsa massif | 0.72950±19 | 2.01 | -1.05856 | 0.0945 | 2.45 |
| Sample 210, gneiss plagiogranite, TTG-?, Kolvitsa massif | 0.72950±19 | 2.01 | -1.05856 | 0.0945 | 2.45 |
| Sample 276, garnet-plagioclase crystalline schist, Kolvitsa massif | 0.72950±19 | 2.01 | -1.05856 | 0.0945 | 2.45 |

**Figure 3.** Variations of $\varepsilon$Nd and Isr in rocks of Proterozoic layered intrusions in the Baltic Shield [22], [23], [24], [25]

New data suggest that the Kandalaksha-Kolvitsa gabbro-anorthosite complex is confined to the East-Scandinavian Large Igneous Province with a protracted evolution at the turn of 2.53-2.39 Ga. According to geochronological [24], [25] and isotope Nd-Sr data, rocks of the Kandalaksha-Kolvitsa complex seem to have the same anomalous mantle source with Paleoproterozoic layered intrusions in the Baltic Shield (Fig. 3). The latter include Cu-Ni-Co-Cr+PGE deposits in the Monchegorsk ore area.
[26], [27] and Pechenga [28-30], Cr ores in the Padnos massif [19], Fe-Ti-V Kolvitsa deposit [31], PGE and Cu-Ni Fedorovo-Pansky layered complex [12], [15], [21], [32] and Burakovskiy intrusion [33], Cu-Ni-Co+PGE deposits in Finland, i.e. Kemi [23, 16], Penikat [24], Akanavaara, Kontelainen [36], Tornio [37] and many other. These deposits formed at two episodes, 2.53-2.39 Ga and 2.0-1.8 Ga, that refer to the beginning of rifting [12], [13], [14], [15], [16], [17], [18], [19], [20], [21] and the late rifting stage of the Fennoscandian Shield evolution [38], [19], respectively.

Rocks of these intrusions referred to the pyroxenite-gabbronormite-anorthosite formation have similar isotope-geochemical features:

1) according to U-Pb and Sm-Nd geochronological data, the formation time span is 2530 to 2380 Ma;
2) the mantle reservoir feeding magmas that formed the massifs is rich in lithophile elements; $I_{Sr}$ values vary from 0.702 to 0.706, $\varepsilon_{Nd}(T)$ varies from +2 to -6;
3) the model Sm-Nd ages of $T_{DM}$ protoliths are 2.8-3.3 Ga.

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