# Keivy alkaline magmatism in the NE Baltic Shield: evidence for the presence of an enriched reservoir in Late Archaean mantle

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Late Archaean alkaline complexes are known from Canada, Australia and Greenland. They are represented by stocks of syenite and nepheline-bearing rocks and carbonatites, as well as by lamprophyre dikes and shoshonitic volcanic suites (Blichert-Toft et al. 1995, Basu et al. 1994, Libby & de Laeter 1980, Bell & Blenkinsop 1987, Sutcliffe et al. 1990). Most of the complexes fall in the age range 2.66-2.70 Ga. The only examples of Archaean alkaline rocks from the Baltic Shield are the Siilinjarvi carbonatite and alkaline syenite with a formation age of 2.58 Ga (Patchet et al. 1981). Peralkaline granites (2760 Ma, Pb-Pb age) and associated syenites and monzonites (2512±42 Ma, Rb-Sr age) occur in the Eastern Goldfields of Western Australia (Libby & de Laeter 1980). A 2.7 Ga age is well established for peralkaline granites and associated syenites from the Superior province. These Late Archaean alkaline complexes belong to the potassic series, are depleted in LIL and HFS elements, are related to subduction and form in compressive tectonic environments (Sutcliffe et al. 1990, Blichert-Toft et al. 1995). The absence of Archaean sodic alkaline complexes forming in extensional environments was mainly ascribed to the absence of metasomatic processes in the mantle and lower lithosphere (Blichert-Toft et al. 1996).

## Geology and petrographic features

The Keivy alkaline province consists of six peralkaline granite bodies with a total exposed area of 2500 $km^2$, alkaline granosyenite dikes and two nepheline syenite fault-type intrusions. The massifs are confined to the margins of Keivy terrane and were emplaced between the tonalite-trondjemite-granodiorite (TTG) basement and the supracrustal Keivy terrane, which is mainly composed of dacite-rhyolite metavolcanics and metasediments (Batijeva 1976). Most of the massifs are sheet-like and dike-like bodies with thicknesses of few hundreds meters. Zapadnokeivskiy and Ponoj mainly have a subhorizontal orientation, the other massifs (Lavrentjevsky, Belaya Tundra, Pacha and Lower Ponoj) are subvertical and have an elongate shape on the surface.

The Zapadnokeivskiy massif (1300 $km^2$) is bounded on the west by the Tzaga gabbro-anorthosites and granite-gneisses (TTG complex) and on the south by the Medvezh'eozero gabbro-anorthosites. The northern contact with the granite-gneisses and granodiorites of the Central-Kola Domain is a steep fault. The massif is split by a sublatitudinal synclinorium composed of the Keivy gneisses and schists which form the roof rocks for the alkaline granites in the eastern part of the massif. The Sakharjok (5-6 $km^2$) and Kuljok fault-type alkaline intrusions occur in the central and southern parts of Zapadnokeivskiy massif and consist of, in order of emplacement, alkaline gabbro, alkaline syenite and nepheline syenite, and metasomatized peralkaline granites.

The Belaya Tundra massif (240 $km^2$) is situated to the southwest of Zapadnokeivskiy massif. The massifs are connected by a granosyenite dike swarm intruded into the TTG complex. To the south the massif is bounded by the 2.49 Ga (Bayanova et al. 1994) Pana layered basic-ultrabasic intrusion, which is a host rock for Pt-Pd deposits.

The Ponoj alkaline granite massif (ca.700 $km^2$) is located at the southern margin of Keivy terrane and was emplaced into TTG complex and metavolcanic-metasedimentary rocks of the Keivy terrane. The smaller Pacha and Lower Ponoj massifs are situated to the east of Ponoj massif. The southern margin of the Pacha massif is a gabbro-anorthosite dike body. The Lavrentjevsky massif (40 $km^2$) is situated to the west of Ponoj massif. It contains highly altered gabbro-anorthosite and amphibolite xenoliths. Granosyenites near the bottom of the Zapadnokeivskiy, Ponoj and Belaya Tundra massifs represent the first phase of peralkaline granite magmatism.

Most the granites are gneissic, but the degree of gneissosity varies both within individual granite massifs and between massifs. The granites are subsolvus and quartz, albite and microcline occur in roughly equal proportions. The absence of perthitic feldspars is believed to be due to metamorphic alteration. The only unmetamorphosed massif is Belaya Tundra, composed of porphyritic massive granites. The granites are subdivided on the basis of their mafic mineralogy into five groups: aegirine-arfvedsonite (most abundant), aenigmatite-arfvedsonite, lepidomelane-arfvedsonite, lepidomelane and aegirine-magnetite granites. The transition between rock types is gradational. The aegirine-magnetite granites tend to be confined to the apical parts of the massifs and the lepidomelane-bearing granites to the bottom of the massifs. The granosyenites are massive, porphyritic rocks that contain the following mafic minerals: ferrohastingsite, lepidomelane, aegirine-augite and occasional fayalite. The alkaline undersaturated rocks are nepheline-bearing phlogopite-omphacite gabbro, ferrohastingsite-lepidomelane syenite and aegirine-lepidomelane nepheline syenite.

Late- and post-magmatic ore-forming processes widely affected the granites and nepheline syenites producing mineralized rocks, hydrothermalites and pegmatites with high concentrations of Zr, Nb, Y and REE. An economically important Zr-Y deposit occurs in the nepheline syenite of the Sakharjok massif. Thick fenitization zones (hundreds of meters) occur over the apical parts of the massifs forming the so-called alkaline gneisses-metasomatites. The country rocks affected by the metasomatism are the TTG complex (rarely) and, commonly, the overlying Keivy gneisses.

## Geochronology

The metamorphic alteration of most of the massifs, and the high alkalinity of the rocks, has made it difficult to determine primary igneous ages. A U-Pb age of 2751±41 Ma was previously obtained for the Ponoj peralkaline granite (, Vetrin et al. 1999). In this study the least metamorphosed and lowest alkalinity rocks were selected for dating. The following U-Pb zircon ages have been obtained: aegirine-augite-ferrohastingsite granosyenite, Zapadnokeivskiy, 2674±6 Ma; non-foliated aegirine-arfvedsonite granite, Belaya Tundra, 2654±5 Ma; and nepheline syenite, 2613±35 Ma, and alkaline syenite, 2682±10 Ma, Sakharjok (Mitrofanov et al. 2000). These ages are the oldest known for alkaline rocks in the Baltic Shield. The Pb-Pb, Rb-Sr and K-Ar isotope systems record metamorphic events at 2.45, 2.35, 1.75 and 1.65 Ga. The following U-Pb zircon ages have been obtained for the spatially associated gabbro-anorthosite complexes: Tsaga gabbro-norite and anorthosite, 2668±10 and 2659±3 Ma, respectively, and the Pike-and-Bear anorthosite, 2663±7 Ma (Bayanova et al. 1998).

## Speculations on tectonic setting and magma source

The Keivy peralkaline granites are highly enriched in LIL and HFS elements, similar to Phanerozoic A-type granitoids. A-type granitoids are emplaced in noncompressive regimes. Two subtypes can be distinguished: post-orogenic or post-collisional A-types (end of an orogenic cycle) and anorogenic A-types (continental rift zones and within plate settings). On standard trace element discriminant diagrams (Pearce et al. 1984, Eby 1990, 1992) the Keivy peralkaline granites plot as post-collisional A-type granitoids. The shape of granite bodies is also in accordance with the extensional environment that existed during their emplacement (Hutton et al. 1990). The nepheline syenites of the Keivy terrane plot inside the OIB fields.

The felsic metavolcanics of Keivy terrane have geochemical features typical of island-arc volcanics (Zozulya 2001). Their eruption took place in the period 2.87-2.83 Ga (Mitrofanov & Bayanova 1999). It is likely, therefore, that mantle metasomatism occurred as a result of the subduction process. A mantle plume may have subsequently formed under the Keivy terrane. The $\varepsilon_{Nd}(T)$ for 16 samples from the Keivy peralkaline granite massifs varies from +4.6 to -10.0 (Balashov et al. 1997), consistent with the high degree of alteration of most of the massifs. A granite sample from the least metamorphosed Belaya Tundra massif gives $\varepsilon_{Nd}(T)$ = –2.02. The presence of an enriched mantle component in the primary magmas is also confirmed by the high $^{3}He/^{4}He$ in ilmenite (0.7 x $10^{-6}$, Vetrin et al. 2001). It is suggested that the enriched mantle source for the Keivy anorogenic peralkaline granites and the OIB-like nepheline syenites was formed prior to 2.8 Ga.

The close temporal and spatial association of the gabbro-anorthosites and the peralkaline granites suggests a genetic relationship. One possible model is protracted fractional crystallization of a primary alkaline basalt magma with the removal of plagioclase during the early stages of crystallization (forming a Ca- and Al-enriched cumulate) leading to alkali and iron enrichment of the residual melt.

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