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GEOCHEMISTRY

Initial Subalkaline Magmatism of the Neoarchean Alkaline Province of the Kola Peninsula

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The Neoarchean alkaline province (~2500 km^2) of the Kola Peninsula is made up of alkali granite and alkali and nepheline syenites that are considered products of basaltic magma fractionation in crustal magma chambers [1]. The Neoarchean age has reliably been estimated by U–Pb zircon datings of various plutons ranging from 2751 ± 41 to 2654 ± 5 Ma [2]. The Neoarchean latite–monzonite association of the province also includes subalkaline rocks that are older than the alkaline granites.

The world's oldest (~2650 Ma) potassic subalkaline volcanics are known from the Yilgarn Craton (Western Australia) and the vicinity of Lake Superior (Canada) [3]. It is evident that recognition and petrologic examination of ancient subalkaline rocks are important for understanding specific features and evolution of subalkaline and alkaline magmatism in the Earth's history.

Rocks of the Neoarchean latite–monzonite association are located in the Upper Ponoi Block, an element of the Keivy segment of the Kola–Keivy Tectonic Belt. This territory is mostly occupied by grainitoids of the tonalite–granodiorite association, which crosscut subalkaline rocks retained as small (3–4 km^2) intrusions, irregular patches, and xenoliths among tonalites. Younger rocks are represented by the West Keivy and Belye Tundry alkali granite plutons (2674 ± 6 and 2654 ± 6 Ma, respectively), gabbroanorthosites (2600–2678 Ma), and alkali and nepheline syenites (2613–2682 Ma) [2]. In the Paleoproterozoic (~2.1 Ga ago), subalkaline rocks and granitoids of the tonalite–granodiorite association were nonuniformly foliated, metamorphosed (epidote–amphibolite and amphibolite facies), and locally replaced by a microcline.

The volcanic facies of the latite–monzonite assemblage is composed of locally recrystallized latites and

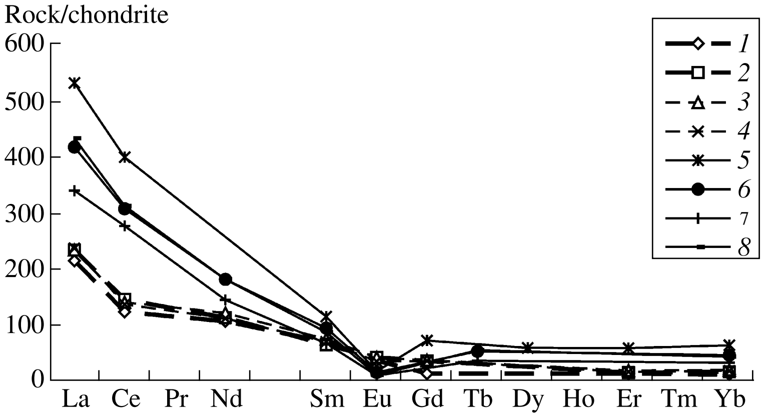

Fig. 1. Chondrite-normalized REE patterns of (*1, 2*) volcanic and (*3, 4*) intrusive rocks of latite–monzonite association and (*5–8*) alkali granites.

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quartz latites with porphyritic, allotriomorphic-granular, microdoleritic, and granophyric textures. The intrusive facies consists of predominant quartz monzonites and less abundant monzonites, quartz syenites, and veins of amphibole-bearing leucogranites. The intrusive rocks are characterized by euhedral, often sharply zonal plagioclase phenocrysts incorporated into the fine-grained micropegmatitic quartz–feldspathic groundmass that contains glomeroblastic aggregates of dark-colored minerals. The major rock-forming minerals are represented by plagioclase (ranging from An_{35-40} in cores to An_{25-27} in marginal zones), quartz, orthoclase, biotite (F = 0.59–0.67), amphibole (ferroedenite, Fe index F = 0.60–0.71), and clinopyroxene (diopside, F = 0.36–0.58). Magnetite, ilmenite, pyrite, zircon, titanite, epidote, apatite, allanite, garnet, hematite, molybdenite, and rutile are accessory minerals.

In chemical composition, latite and quartz latite pertain to the intermediate rocks of the subalkaline series (alkali metals 5.1–7.0 wt %, K_2O/ Na_2O 0.60–0.99). The rocks are enriched in Ti and Fe and depleted in Al and Mg. As a result, their F value is high (0.67–0.77) and the agpaite coefficient Ka is elevated (0.52–0.72). In comparison with metavolcanic rocks, quartz monzonite is enriched in silica (61–65 wt %). The silica content in quartz syenites and leucogranites reaches 68 and 75 wt %, respectively. At the same time, elevated Ti and Fe contents and high values of F (0.77–0.83), Ka (0.90–0.92), and K_2O/Na_2O (0.77–1.33) remain as usual in metavolcanics. A similar trend of fractionation of volcanic and intrusive rocks with increase in the silica content testifies to their common origin related to the crystal fractionation in the melt. In comparison with continental quartz latites [4], the rocks of the latite–monzonite association are enriched in Ti, Fe, P, Zr, Nb, Y, and F. They are characterized by elevated F and Ka values and depletion in Mg, Ca, Al, Sr, Ni, and Cr. The volcanic and intrusive rocks are characterized by elevated REE contents, decrease in the $(La/Yb)_N$ ratio from quartz latites (13–16) to quartz monzonites (11–12), and a negative Eu anomaly (Eu/Eu* = 0.7–0.9). As is evident from Fig. 1, the chondrite-normalized REE patterns of the rocks of the latite–monzonite association and alkali granites are similar, while alkali granite is marked by much higher LREE contents and lower $(La/Yb)_N$ and Eu/Eu* ratios (8–10 and 0.2, respectively).

The U–Pb zircon age of subalkaline rocks and REE contents in zircon were determined with a SHRIMP-II microprobe at the Center for Isotopic Studies, St. Petersburg. Zircon occurs as translucent prismatic golden crystals of the typical zircon habitus with tiny inclusions of dark-colored minerals. The crystals (0.1–0.5 mm, K_{elon} 1–4) are not zonal or roughly zonal, but cores and dissolution signs of edges are absent.

The chondrite-normalized REE patterns are typical of magmatic zircons with a distinct Ce maximum and a Eu minimum (Fig. 2). Zircons are enriched in HREE by

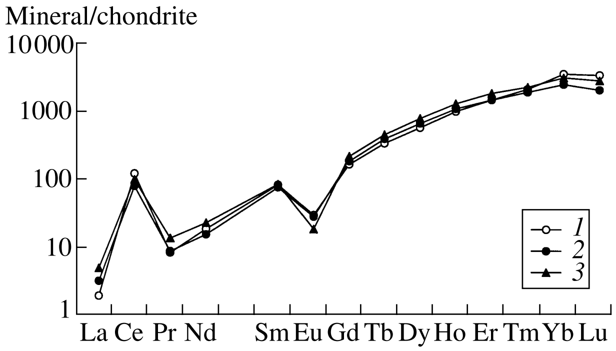

Fig. 2. Chondrite-normalized REE patterns of zircon from (*1*) quartz latite, (*2*) quartz monzonite, and (*3*) quartz syenite.

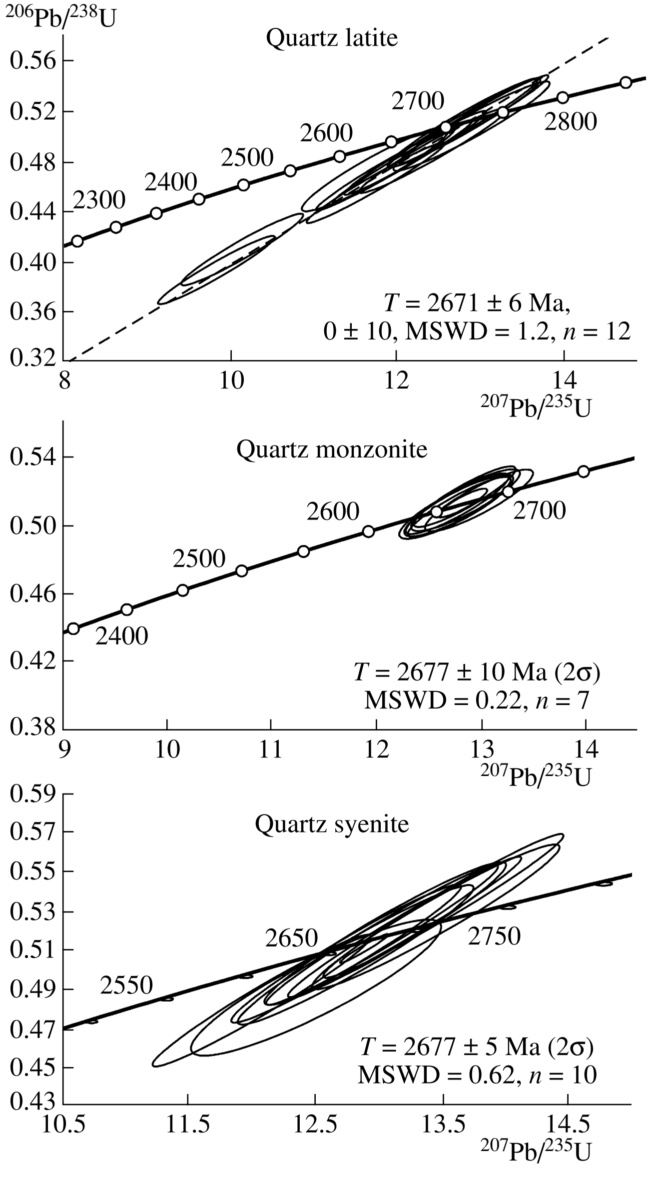

Fig. 3. Diagrams with concordia for zircons from rocks of the latite–monzonite association. Uncertainty ellipses are plotted at a level of 1σ; concordant ages, at a level of 2σ.

Parameters of the Sm–Nd isotopic system of rocks in the latite–monzonite association

Sample no.	Rock	Sm, ppm	Nd, ppm	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	ε_0	ε_{2675}	$t_{(DM)}$
1	Latite	8.757	41.096	0.128817	0.511313 ± 8	–25.8	–2.5	3279
2	Quartz latite	10.756	58.413	0.111310	0.511132 ± 20	–29.4	0.0	2989
3	The same	10.670	56.505	0.114150	0.511198 ± 15	–28.1	0.3	3073
4	Quartz monzonite	10.453	55.885	0.113074	0.511132 ± 6	–29.4	–0.6	3041
5	Quartz syenite	11.437	61.770	0.111924	0.511193 ± 28	–28.2	1.0	2917
6	The same	10.752	60.400	0.107609	0.511073 ± 19	–30.5	0.1	2969
7	Leucogranite	15.637	127.686	0.074030	0.510527 ± 18	–41.2	1.1	2848

Note: Analyses were performed with a Finnigan MAT-262 mass spectrometer. Standards: La Jolla 0.511833 ± 6 (n = 11) and JNdi1 0.512071 ± 10 (n = 61).

more than three orders of magnitude (relative to the chondritic level) with a gradual increase in concentrations from Ho to Lu. The $(Gd/Lu)_N$ ratio varies from 0.05–0.09. Figure 3 shows that most of the dated zircon grains have concordant U–Pb ages (Ma): 2671 ± 6 Ma (quartz latite), 2667 ± 10 Ma (quartz monzonite), and 2677 ± 5 Ma (quartz syenite). Thus, with allowance for uncertainties, the magmatic crystallization of zircon from rocks of the latite–monzonite association is constrained by 2670–2680 Ma.

The Neoarchean latitic and monzonitic rocks of the Kola Peninsula bear petrographic attributes typical of the subalkaline shoshonite–latite–monzonite series: (1) association of zonal plagioclase phenocrysts with Ti- and Al-depleted clinopyroxene and alkali feldspar that occurs as both separate phenocrysts and rims around plagioclase crystals. The insignificant content of hydrous minerals at the initial stage of melt crystallization and close spatiotemporal relations between volcanic and intrusive derivatives indicate that the melt was “dry.” The occurrence of zonal plagioclase phenocrysts incorporated in the fine-grained matrix with monzonitic, granophyric, and micropegmatitic textures indicates nonequilibrium crystallization.

According to [3, 4], magmas of the shoshonite–latite series were formed at different levels of the mantle under conditions of garnet lherzolite (shoshonites) and spinel lherzolite (latites) facies as a result of 5–20% melting and the differentiation of melts in transitional crustal magma chambers with the formation of quartz-normative rocks. The $^{147}Sm/^{144}Nd$ ratio in rocks of the Neoarchean latite–monzonite association is 0.07–0.13; i.e., it is close to the crustal value (0.12). The model Nd age is established at 3.3–2.9 Ga, while $\varepsilon_{Nd(2675)}$ for most intrusive rocks is positive (0.1–1.1), indicating a slight depletion of the mantle source (table). A similar source (in terms of the Nd isotopic composition) is also assumed for younger (based on isotope–geochemical data) alkali granites of the Kola Peninsula [5, 6]. The appearance of negative $\varepsilon_{Nd(2675)}$ values in some volcanic and intrusive rocks is probably related to the contamination of the melt with the upper crustal material. This is suggested by the maximal $T_{(DM)}$ values in these rocks.

The compositional variation of melts in the process of intracrustal fractionation was controlled by the crystallization of pyroxene (to a lesser extent, amphibole and titanomagnetite) and accompanied by gradual depletion in Ca, Mg, Fe, and Ti together with gain of K and Si and insignificant enrichment in Na. The amount of Al in rocks with different contents of SiO_2 is virtually constant, suggesting a negligible participation of plagioclase in the differentiation. The water pressure during the crystallization of volcanics, which contained about 40% quartz in the quartz–orthoclase granophyric aggregate, probably was not higher than 0.5 kbar [7]. The intrusive rocks crystallized under a higher P_{H_2O} (1.0–1.5 kbar), while the temperature of crystallization of coexisting feldspars from quartz monzonites reached 860–870°C. As in volcanic rocks, the quartz–orthoclase micropegmatitic intergrowths with 39–40% quartz crystallized at a lower water pressure (±0.5 kbar) and a temperature no higher than 750–780°C.

The results of geological study of the territory along with data on the chemistry of rocks and minerals allowed us to outline the following scenario of the formation of products of intermediate and felsic magmatism in the region. A mafic asthenolith ascended to the bottom of the lower crust about 2.8 Ga ago, and its offsets reached the upper crust. The crystal fractionation of magma produced rocks of the latite–monzonite association. The subsequent heating of the lower crust at the asthenolith roof promoted its partial melting with the formation of tonalite–granodiorite magmas. Their emplacement into the upper crust diminished substantially the volume of latite–monzonite rocks that were disintegrated and replaced with tonalites and granodiorites. The viscoelastic state of the lower crust owing to the concentration of new portions of palingenetic melts prevented the further penetration of asthenolith matter into the upper crust. The subsequent ascent of deep magma became possible only after the removal of tonalite–granodiorite melts from the lower crust. The mantle-derived magmas were located for ~5–20 Ma under stable tectonic conditions after the formation of the latite–monzonite association and, therefore, were enriched in alkali metals. The fractionation of such magmas 2.65–2.67 Ga ago produced alkali granite plutons in the upper crust.

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