PALEOARCHEAN TO NEOARCHEAN GRANITOIDS AND MIGMATITES DEFINING THE LAYERED CRUSTAL STRUCTURE OF VOLGO-URALIA

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Introduction

Volgo-Uralia is one of the three major crustal segments of the Precambrian East European Craton. It occupies its entire eastern third and is the least known because of a thick Neoproterozoic to Phanerozoic sedimentary cover. However, geophysical data and thousands of deep drillings into the crystalline basement of this high- potential oil and gas province provided valuable information on the crustal structure as well as rock relationships and abundances (Bogdanova, 1986; Muslimov & Lapinskaya, 1996). Volgo-Uralia is a high-grade terrain comprising both Archean and Paleoproterozoic rock belts bounded by zones of shearing. The recent seismic-reflection profile "TATSEIS" (Trofimov, 2006), has revealed an up to 60 km thick strongly stacked crust, in which a "transparent" layer forms upper part of the crystalline crust within the so-called "Bakaly granitoid block". The present study targeted the Bakaly granitoids and associated migmatites for which the U-Pb zircon ages, Lu-Hf isotopic characteristics of the dated zircons, and the rock Sm-Nd isotopic compositions and chemistries were determined. These demonstrate a multistage evolution and recycling of the Archean crust between 3.3 and 2.6 Ga, and a collisional origin of the up to 20 km thick upper crustal layer in Volgo-Uralia.

General

In Volgo-Uralia, granulite- and amphibolite-facies supracrustal and plutonic rocks make up a number of infracrustal belts that trend NE-SW to ENE-WSW. These belts are bounded by zones of strong thrusting and shearing, which also accommodate ca. 2.6 Ga gabbro-anorthositic to monzogranitic intrusions. Altogether, the crust is considered to have been formed mostly during a collisional event at ca. 2.7 Ga. Large Paleoproterozoic belts of metasedimentary and igneous origins surround the Neoarchean proto-craton of Volgo-Uralia and partly branch into its interiors. Seismic profiling and the presence of Paleoproterozoic supracrustal rocks, which werepervasively deformed, migmatized and metamorphosed at conditions up to the granulite facies between ca. 2.1 and 1.8 Ga ago, suggest that the crust and upper mantle consist of both Paleoproterozoic and strongly reworked Archaean rocks (Bogdanova et al. 2005). The Neoarchean shear zones appear to have been reactivated in the Paleoproterozoic. The latest deformation and metamorphic reworking occurred at ca. 1.8 Ga.

The Bakaly granitoids

The Bakaly granitoid complex forms a separate block in eastern Volgo-Uralia. It comprises various mostly plagioclase-rich granitoids, granitic gneisses and migmatites, previously considered to be Neoarchean on the basis of a few TIMS zircon ages (Bibikova et al., 1994). Together, the various granitoids constitute a separate geophysical domain marked by mosaics of mostly negative gravity and magnetic anomalies. As recorded by ca. 800 drillings, this pattern is created by small (70 to 200 km^2) granitic cupolas mostly consisting of K-rich adamellites and granites, and associated migmatites with narrow granodioritic rims. Four different granitoid suites are recognized in the Bakaly block, that also differ in age.

The 3.3-3.2 Ga Tashliar suite

A 3266±7 Ma old monzodiorite and a 3237±11 Ma old quartz-monzonitic mesosome in a migmatite with a leucosome vein aged 2710±19 Ma, contain zircons with ε_{Hf}(T) values ranging between 0.1 and (-) 3.7, which correspond to Hf T(DM) crustal ages of ca. 3.5-3.8 Ga. Nd T(DM) dating of these rocks yielded similar 3.5-3.7 Ga ages for the protoliths. Together with the presence of a 3544-Ma zircon xenocryst in a Neoarchean Bakaly granitoid, this indicates that the crustal history of Volgo-Uralia began in Paleoarchean, possibly even in Eoarchean times. These oldest rocks of the Bakaly block are characterized by high abundances of TiO_2 (up to 0.8 %), P_2O_5 (up to 0.7%), Nb (up to 11 ppm), Y (18-27 ppm), Zr (290-450 ppm), and total REE up to 1000 ppm at $(La/Yb)_N$ ratios of up to 70, all suggesting their affinity to alkaline igneous series. The extent and tectonic setting of this igneous suite, which forms a separate tectonic block among the other granitoids, is difficult to assess, but it may have been intruded in association with a mantle upwelling event and wider spread.

The 2.72- 2.65 Ga Bakaly (Bak-1) and (Bak-2) suites

These two Neoarchean Bakaly suites, one comprising dominant quartz dioritic and tonalitic gneisses (Bak-1), and the other K-rich granodiorites, granites and migmatites (Bak-2), are considered to have been formed sequentially during between ca. 2.72 and 2.65 Ga. Both comprise gneissic as well as massive granitoids, and migmatites that are made up of paleosomes, mesosomes and mostly vein leucosomes occurring in various proportions and representing a range of compositions. The thicknesses of some individual zones of migmatization may exceed 50 m. A gently dipping foliation is characteristic, documented from most drill-cores of the Bakaly granitoids. The Bak 1 quartz diorites and tonalites form numerous sheet-like bodies with thickness up to 20 m. These follow NE-trending deformation zones and have, in turn, are discordantly intruded by Bak-2 granitoids. The latter often compose separate massifs and K-feldspar-rich leucosomes. Both suites scatter chemically due to various protoliths having been involved in melting at different depths, the degrees of melting, and variations of water contents. The host rocks are metasedimentary and metavolcanic gneisses, and amphibolites. The 2.7 Ga Bak-1 rocks with 66 to 72% SiO_2 resemble somewhat Neoarchean TTG (tonalite-trondhjemite-granodiorite) granitoids (Martin, 1994). They have higher Ba (up to 925 ppm), Th (up to 20 ppm), TiO_2 (up to 0.5 %), LILE and LREE at lower #Mg (<37). However, in the dated Bak-1 quartz diorite, the $\varepsilon_{Nd}(T)$ value is –1.3, the $\varepsilon_{Hf}(T)$ of the zircons ranging between 0.2 and -2.5, which corresponds to protolith model ages of 3.4-3.2 Ga and indicates a crustal not juvenile origin of the Bak-1 granitoids. In contrast to the Bak-1 suite, the Bak-2 granodioritic (± tonalitic)-granitic suite generally follows a calc-alkaline trend. These granitoids are often leucocratic, rich in K-feldspar, and some bear two micas and garnet like typical S-type granites. The Bak-2 granitoids differ from the Bak-1 rocks by much higher LILE, Th (up to 50 ppm), LREE and total REE (110-600 ppm) at widely ranging $(La/Yb)_N$ ratios (30-145), which reflect different depths of melting. Among the Bak-2 rocks, the oldest is the 2710±19 Ma vein leucosome in the Tashliar 3.2 Ga mesosome, and the youngest S-type garnet-bearing granite with an age of 2648±33 Ma. Metamorphic overgrowths of the latter age have been found on zircons from the dated Bak-1 quartz diorite. The Bak-2 S-type granite contains zircons with very variable Hf characteristics: the $\varepsilon_{Hf}(T)$ values range between 0.5 and -20, and the T(DM) crustal ages from 3.1 to 4.4 Ga, which can be related to a metasedimentary protolith deposited after ca. 3.1 Ga. In a 2663±33 Ma old granite, zircons with $\varepsilon_{Hf}(T)$ values from +5.0 to -0.3 indicate involvement of mantle-derived melts contaminated by crustal materials. This rock features Hf T(DM) ages between 2.8 and 3.2 Ga.

The 2.6 Ga Aktanysh monzonitic suite

Several small intrusions of quartz-monzonitic and quartz-syenitic to granitic compositions occur in connection with the NE-trending fault zones, which also accommodate gabbro-anorthosite intrusions with ages of ca. 2620 Ma. With a best crystallization age of 2600±11 Ma, they terminated the Archean magmatic evolution in the Bakaly block. The 2.6 Ga granitoids differ markedly from the Bakaly granitoids by their higher abundances of Ti, HFSE (Nb, Ta, Zr and Hf), Y and total REE up to 340 ppm at low $(La/Yb)_N$ ratios of 6 to 20, indicating a shallow derivation. The Hf T(DM) ages of zircons from the 2.6 Ga monzonitic rocks vary between 3.6 and 3.3 Ga, and are thus similar to the source ages of the Bak-1 granitoids. These zircons are characterized by negative $\varepsilon_{Hf}(T)$ values, some as low as -7. Such data suggest that the melts of the 2.6-Ga monzonitic rocks were derived largely from the re-melting of 3.3-3.0 Ga crust, probably with an incorporation of older (up to ~3.6 Ga) crustal materials. The presence of zircon xenocrysts of 3076±9 and 3034±23 Ma confirms this conclusion.

The origin of the Bakaly Archean granitoids and their role in the formation of the Volgo-Uralian crustal structure

The presently available data suggest the following stages of Archean crustal evolution in Volgo-Uralia:

- Before 3.3-3.2 Ga, continental cores/microcontinents with crustal ages from ca. 3.8 to 3.4 Ga were formed, as evidenced by the Tashliar 3.3-3.2 Ga monzonitic rocks. To produce their melt(s), a mantle-crust interaction cannot be ruled out;
- The 3.2-2.8 Ga period was one of plate-tectonic geodynamics with the formation of granite-greenstone terrains resembling Proterozoic and Phanerozoic accretionary belts. They comprise juvenile island arcs, back arcs and continental magmatic arcs, and featuring TTG granitoid magmatism. The TTG associations of different age were major predecessors of the Bakaly granitoids,
- At 2.72-2.65 Ga, collisional tectonics with associated strong deformation, metamorphism, and remelting of the early crust occurred in Volgo-Uralia and defined the successive formation of the Bak-1 and Bak-2 granitoids, gneisses and migmatites. Compositional variations of these rocks appear to image a heterogeneous collisional structure in which the various rock complexes were stacked tectonically. This event was linked to the worldwide Neoarchean supercontinent assembly(ies) (Bleeker, 2003),
- At ca. 2.62-2.60 Ga, intrusions of gabbro-anorthosites and monzonitic granitoids generated due to remelting of the Archean crust and possible mantle underplating took place along the major shear zones related to post-collisional extension.

The Bakaly granitoid block represents part of an up to 20 km thick upper crustal layer (Trofimov, 2006) exposed at the top of the crystalline basement. This seismically “transparent” layer occupies ca. 25% of the total thickness of the Archean-to-Paleoproterozoic crust in Volgo-Uralia. It is composed essentially of Bakaly-type granitoids and migmatites formed during a quite short period of ca. 30 Ma. Similar layers are known from other collisional orogens like, for instance, the Himalayan, where a zone of crustal melting and seismic “transparency” has been discovered by the INDEPTH transect (Nelson et al, 1996). A dominant process in the development of the crustal layering and the formation of the upper crustal layers in the crust of Volgo-Uralia was recurrent recycling of Archean crust.

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