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Vendian–Early Paleozoic granitoid magmatism in Eastern Tuva

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Abstract

We summarize results of geological, geochronological, petrogeochemical, and isotope-geochemical (Sr–Nd) studies of Late Vendian–Early Paleozoic granitoid batholiths in Eastern Tuva (Kaa-Khem, East Tannu-Ola, Khamsara, etc.). Analysis of geochronological (U–Pb, Ar–Ar) data has shown that the Late Vendian–Early Paleozoic granitoids in Eastern Tuva formed in several stages in the time interval 562–450 Ma and at different geodynamic stages of the regional evolution: island-arc (562–518 Ma) and accretion–collision (500–450 Ma), with the latter stage characterized by more intense granitoid magmatism. Diorite–tonalite–plagiogranite associations with different petrogeochemical parameters are the most widespread in the region. Petrogeochemical studies of the Late Vendian–Early Paleozoic plagiogranitoid associations have revealed high- and low-alumina varieties reflecting different conditions of formation of parental melts. At the island-arc stage of the regional evolution, only low-alumina plagiogranites of tholeiitic (*M*-type) and calc-alkalic (*I*-type) series formed. Their parental melts were generated at 3–8 kbar through the partial melting of N-MORB-type metabasalts in equilibrium with amphibole restite. Isotope-geochemical studies have shown positive ε_{Nd} values (6.9–6.3) and low Sr isotope ratios ($(^{87}Sr/^{86}Sr)_0 = 0.7034–0.7046$). The lower (as compared with the depleted mantle) ε_{Nd} values and specific petrogeochemical composition (negative Nb–Ta and Ti anomalies) of the plagiogranites reflect the subduction nature of metabasic substratum and the subordinate role of ancient crustal material. At the accretion–collision stage of the regional evolution, high- and low-alumina plagiogranitoids of calc-alkalic series (*I*-type) formed. The high-alumina plagiogranitoids are products of melting of N-MORB-type metabasalts in equilibrium with garnet restite at ≥15 kbar in the lower part of the collisional structures, and the low-alumina ones formed through the melting of metabasites in equilibrium with amphibole restite at ≤8 kbar in the upper part of the same structures. The Sr–Nd isotope data for the high- and low-alumina plagiogranitoids generated at the accretion–collision stage show that the rejuvenation of rocks is accompanied by the decrease in ε_{Nd} (from 6.2 to 3.4) and the increase in their model Nd age $T_{Nd}(DM)$ (from 0.73 to 0.92 Ga) and $(^{87}Sr/^{86}Sr)_0$ (0.7036–0.7048). This points to the essentially metabasic composition of the parental substratum, as in the case of the island-arc plagiogranitoids, and the progressive supply of ancient crustal material to the magma generation zone.
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Introduction

Late Vendian–Early Paleozoic granitoid associations of tonalite–plagiogranite composition in the Early Caledonian structures of the Central Asian Fold Belt (CAFB) are the most widespread. At the present-day denudation level they occur either within large and small massifs forming vast fields or within large polychronous batholiths (Fig. 1, inset *A*) localized among Vendian–Early Cambrian volcanic and volcanosedimentary deposits (Kovalenko et al., 2004; Rudnev, 2013; Rudnev et al., 2004a; Shokal'skii et al., 2000; Yarmolyuk et al., 2011). In both types of areas of intrusive magmatism, there are particular sets of intrusive associations (granitoids and gabbroids) with specific chemical characteristics and sources, sequence of formation, magmatism intensity, and geodynamic conditions, which mark the particular stages of the regional-crust growth and evolution. Therefore, it is worth performing comprehensive studies of magmatism areas for elucidation of the evolution of intrusive magmatism and the mechanisms of granitoid formation as well as the duration of magmatic processes that led to the formation of large magmatic areas in the particular segments of the CAFB.

Geological and geochronological studies of the batholiths of the Altai–Sayan folded area (ASFA) and Western Mongolia showed their complex structure (Kovalenko et al., 2004; Rudnev, 2013; Rudnev et al., 2004a, 2006, 2008a,b, 2009).

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They are made up of igneous rock associations formed at different stages of the regional evolution. The Vendian–Early Paleozoic granitoid batholiths of Eastern Tuva (Kaa-Khem, East Tannu-Ola, Khamsara, Bii-Khem, etc., Fig. 1, inset *B*), forming large magmatic areas in the Early Caledonian structures of the ASFA, are the most representative. Earlier it was shown that they are polychronous and are composed of granitoid associations of different petrogeochemical types (*M*-, *I*-, and *A*-types) with a strong predominance of tonalite–plagiogranite associations. It was also established that the plagiogranitoid magmatism in the above areas (batholiths) was of different durations and intensities. Geological and geochronological studies performed using igneous rocks from these batholiths (Mongush et al., 2011; Rudnev, 2013; Rudnev et al., 2006) revealed that the plagiogranitoid associations formed in the period from 562 to 450 Ma, at the island-arc (562–518 Ma) and accretion–collision (480–450 Ma) stages of the regional evolution. But the continuous appearance of new data (geological, geochronological, etc.) on these areas (batholiths) gives a detailed insight not only into the evolution of intrusive magmatism but also into the basic mechanisms and the sources of large-scale granite formation.

The goal of this paper was to summarize the results of our and other researchers' detailed studies of the geologic structure, age, petro- and geochemical compositions, and isotope characteristics (Sm–Nd and Rb–Sr dating) of igneous rock associations composing the Vendian–Early Paleozoic batholiths (Kaa-Khem, East Tannu-Ola, and Khamsara) located in the Early Caledonian structures of Eastern Tuva. Using the available data, it was necessary to analyze the scales of granitoid abundance, the age sequence and duration of their formation, and the conditions of generation of their parental melts, the sources of magma, at different stages of the geodynamic development of the region.

Tectonic position and internal structure of Late Vendian–Early Paleozoic granitoid batholiths of Eastern Tuva

The Late Vendian–Early Paleozoic granitoid batholiths of Eastern Tuva (Kaa-Khem, East Tannu-Ola, Khamsara, and Bii-Khem) are the largest in the CAFB. They are located among Early Caledonian volcanic and volcanosedimentary deposits on the southwestern framing of the Siberian craton (Fig. 1, inset *A*). The intrusive rocks composing these batholiths were earlier united into the Tannu-Ola gabbronorite complex of Early–Middle Cambrian age. This complex was first recognized and described in detail by G.V. Pinus, V.A. Kuznetsov, and other researchers during the investigation of the East Tannu-Ola batholith located in the axial part of the East Tannu-Ola Ridge. Later, the intrusive rocks of this complex in the Kaa-Khem (Distanova, 1981), Khamsara, and Bii-Khem batholiths (Fig. 1), like those in the East Tannu-Ola batholith, were regarded as an association of mafic and moderately felsic rocks of mixed gabbro–plagiogranite composition. Recently, the gabbroids have been separated as the Early Cambrian Mazhalyk and Zubovka complexes (Rudnev, 2013). The long history of study of granitoid associations, especially in the last decade, when precise analytical methods (geochronological, geochemical, and isotope) came into active use, led to new concepts of their nature, composition, time of formation, and types. All this was considered in more detail by Kozakov et al. (1998, 1999), Mongush et al. (2011), Rudnev et al. (2006). As new geological and geochronological data on the igneous complexes of the East Tannu-Ola and Kaa-Khem batholiths appeared, we recognized a series of new granitoid associations, which made us to correct the viewpoints of the Vendian–Early Paleozoic history of the regional intrusive magmatism.

The Kaa-Khem batholith is one of the largest (more than 30,000 km^2 in area) igneous plutons of Vendian–Early Paleozoic age not only in Eastern Tuva but also in the entire ASFA. It has been studied in most detail both in terms of geologic structure and chemical composition of igneous rocks and in terms of the sequence of their formation and isotope-geochemical characteristics. The batholith is located in the Ondum subzone of Early Caledonides of Eastern Tuva (Fig. 1, inset *B*). The Vendian–Early Paleozoic intrusions of the batholith break through the volcanic deposits of the Tapsa Formation ($\in_1^2$), volcanosedimentary deposits of the Ondum Formation ($\in_1^1$), and metamorphic and sedimentary rocks of the Tuva–Mongolian massif (PR_{1-2}?) and are overlain by Silurian (S_{1-2}) sedimentary, Devonian (D_1–D_3) volcanic and volcanosedimentary, and Jurassic (J_2) sedimentary deposits. Diorite–tonalite–plagiogranite and granodiorite–granite rocks are predominant among the intrusions and form large and small massifs. Mafic rocks are scarcer; these are peridotites, pyroxenites, troctolites, anorthosites, gabbro, and gabbronorites of the Mazhalyk complex and gabbro, gabbro-monzodiorites, and monzodiorites of the Zubovka complex of Early Cambrian age.

The East Tannu-Ola batholith is an area of Early Paleozoic magmatism in the southern segment (Tannu-Ola subzone) of the Tannu-Ola island arc (Fig. 1, inset *B*). The outcrop of Early Paleozoic igneous rocks in the batholith at the present-day denudation level is more than 10,000 km^2 in area. In plan the batholith is arcuate in the E–W direction and is conform to the general strike of major tectonic structures and the enclosing Vendian–Cambrian volcanosedimentary rocks (Podkamennyi and Sherman, 1983). Granitoids of the East Tannu-Ola batholith are enclosed by the island-arc volcanosedimentary deposits of (from bottom to top) the Kadvoi (V) and Serlig ($\in_1^1$) Formations, tuffaceous-volcanosedimentary deposits of the Dyttyg Formation ($\in_1^1$), and tuffaceous-carbonate deposits of the Irbitei Formation ($\in_1^2$). Granitoids of the Tannu-Ola complex are intruded by Early Devonian granodiorites and granites and are overlain by Early Devonian volcanic and volcanosedimentary deposits. The occurrence of the formations and their petrographic and geochemical compositions were described in detail by Mongush et al. (2011) and Shapovalov (2001). Granitoids of the Tannu-Ola complex in the East Tannu-Ola batholith have been studied at three reference sites, which were chosen not only because of their

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