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GEOLOGY

Merageny of the Ufalei Block (Middle Urals) in Connection with Lithotectonic Complexes of Different Geodynamic Settings

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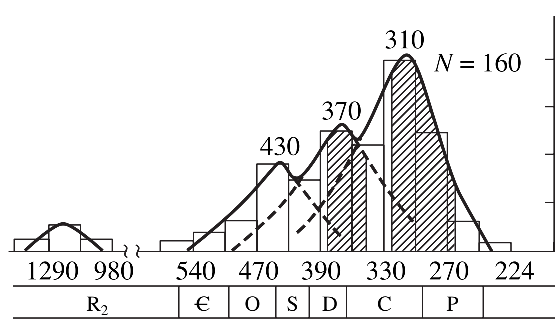
The relatively well-studied Ufalei Block represents a key structure for understanding the genesis and economic potential of other similar blocks: Sysert, Il'menogorsk–Vishnevogorsk, Marunkeu, and others [1, 2]. The available geological and radiological data [1–6 and others] and original materials show that the Ufalei gneiss–amphibolite complex (Fig. 1) underwent several stages of structural–tectonic and metamorphic transformation, each accompanied by the formation of particular igneous complexes, which produced carbonatites, pegmatites, different metasomatites, vein quartz, and other rocks during the postmagmatic stage (table).

The period of 1.35–0.98 Ga corresponds to the Middle Riphean riftogenic transformation of the East European Platform basement. Mineragenic features of Middle Riphean riftogenic structures, which separate Archean–Early Proterozoic blocks (Taratash, Aleksandrov, Ufalei, and Sysert-Il'menogorsk) were determined by the formation of ophiolitic associations in the form of isolated tectonized fragments and represented by the Sait Complex of the Sysert–Il'menogorsk Block, as well as the Kushtumga, Kurtino, and Maksyuta complexes of the Uraltau zone [2, 7], which host several ore and nonore mineral deposits.

This stage was marked by intense magmatism with the formation of several mafic–ultramafic intrusions. They are represented by stratified pyroxenite–gabbro massifs of the Kusino–Kopan Complex and by the Kurtino pyroxenite–gabbro complex in the Ufalei Block area. The formation of massifs was accompanied by titanomagnetite–ilmenite mineralization.

The diaschistic metamorphism was related to the high-pressure injection of the decompressed material from deep levels of the mantle, the formation of the thermal anomaly inside the lithosphere, and the consequent high-temperature metamorphic transformation of rocks of the crystalline basement of the crust and upper mantle.

Processes of ultrametamorphism terminated the Middle Riphean riftogenic metamorphism, which corresponded to granulites of the Aldan facies (hypersthene, diopside, and pyrope garnet assemblages) terminated by ultrametamorphism [1], with the formation of different igneous complexes, such as Slyudyanogorsk alkaline biotite gneiss–granites and potassic granites (1100–1215 Ma based on microcline and biotite [3]; 990–1180 Ma, based on zircons from gneisses [4]), and various migmatites and anorthosite pegmatites with REE (yttroepidote) mineralization dated at 1100–1200 Ma [8]. The hydrothermal postmagmatic stage was marked by the formation of coarse-crystalline calcitic carbonatites, which lack REE mineralization, but concentrate largely Y-bearing REE in calcite (TR_2O_3 0.15–0.29%, Y 0.02–0.05%). In host amphibole–biotite gneisses, the total REE content



Bar chart of absolute ages determined for rocks of the Ufalei gneiss–amphibolite complex. Based on [1] with the addition of original and other data. Hatched areas correspond to ages of *soft* (early) and *rigid* (late) collision.

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Correlation of magmatites, metamorphites, metasomatites, and mineralization of the Ufalei gneiss–amphibolite complex formed in different geodynamic settings

Rifting stage (R_2)	Island-arc stage (O_2–S)	Early collision (D_2–C_1)	Late collision (C_3–P_1)
		Magmatism	
Ophiolitic complex; metamorphosed pyroxenites, hornblendites, gabbroids, alkaline granites	Dunite–clinopyroxenite–gabbroic series; nepheline and alkaline syenites, granosyenites, leucocratic and magnetite-bearing alkaline granites	Plagiogranites, granodiorites	Normal microcline granites
		Metamorphism	
Deep granulite and amphibolite facies, ultrametamorphism	Contact, autometamorphism	Zoned amphibolite and epidote–amphibolite facies, ultrametamorphism	Dislocation, amphibolite and epidote–amphibolite facies
		Metasomatism and mineralization	
Titanomagnetites, anorthosite pegmatites with rare earth mineralization (yttroepidote), calcitic carbonatites	Antigoritization, amphibolitization, and carbonatization of Alpine-type ultramafics with the formation of magnetite lodes and native gold. Albitites with rare earth mineralization (fergusonite, samarskite, columbite). Carbonatization of amphibolites with the formation of magnetite lodes. Recrystallization of Riphean calcitic carbonatites with the formation of magnetite, phlogopite, and pyrrhotite	Mica-bearing pegmatites, metasomatic jaspilites, replacement bodies (metasomatic quartz), recrystallization and filling quartz veins. Icitization, berezitization, and listvenitization accompanied by formation of quartz veins with sulfides	Ceramic pegmatites, metasomatic quartzites (kyanite, graphite, micaceous), calcite, calcite–dolomite carbonatites with phlogopite, apatite, amphibole, rutile, sphene, xenotime. Veins of secondary granular quartz (Kyshtym, Ufalei, and Egustin types) and primary granular glassy quartz of vein filling. Greisenization with the formation of phengite and molybdenite

is 0.003–0.040% (Y 0.008–0.009%). In anorthosite pegmatites, the TR_2O_3 content is 0.001% (Y 0.0005%).

The eventual breakup of the East European Platform and reactivation of Riphean fractures occurred in the Ordovician (480 Ma). The Ordovician–Silurian history of the Uralian paleocean was marked by the formation of mafic–ultramafic complexes in the Middle and South Urals. The Ordovician complex is represented by a standard ophiolitic triad (harzburgite–gabbro–basalt), while the Silurian complex includes the postophiolitic dunite–clinopyroxenite–gabbroic series frequently crowned by syenites, alkaline granitoids, and carbonate metasomatites with accessory niobium–rare metal–iron ore mineralization.

In host amphibolites, biotite gneisses, alkaline granites, and pegmatites, the postmagmatic stage associated with the formation of syenitic rocks and alkaline granites is represented by albite and phlogopite veins in Middle Riphean anorthoclase pegmatites and yttroepidote crystals. The formation of albitites promoted the formation of Y-bearing REE minerals (fergusonite and columbite).

The period of 380–320 Ma corresponds to early collision. The tangential compression resulted in the detachment of the Ufalei Block along lower layers and its westward displacement to higher levels of the crust along the Taganai–Ukazar suture shear zone. The Middle Paleozoic stage is characterized by distinct linear–dome metamorphic zoning related to the development of the Taganai–Ukazar suture shear zone and the eastward migration of the thermal focus. The Main collision suture and Serebraynsk–Slyudyanogorsk suture zone represented a decompressed zone with wide development of different processes, such as granitization, migmatization, formation of numerous metamorphogenic recrystallization (granular quartz) veins, and tonalite–granodiorite intrusions accompanied by the formation of numerous rare metal and micaceous (muscovite) pegmatites with relatively thick extended zones of metasomatic fine-grained quartz and the intrusion of macrocrystalline glassy quartz veins in overlying rocks of buried massifs. Like the quartz–muscovite complex of micaceous pegmatites, the metasomatic fine-grained quartz of replacement bodies (Ufalei type) replaces distinctly folded carbonatites and intersects large magnetite grains in calcite–magnetite carbonatites with the formation of small magnetite octahedrons. Metasomatic quartz–magnetite quartzites are also present. Mica from pegmatites is dated at 330–365 Ma. The REE concentration is usually absent in hydrothermally altered zones of plagiogranite and granodiorite intrusions, as well as in zones of acid leaching and silicification [9]. Therefore, metasomatic carbonatites are not formed at the initial collision stage and REE contents are low in metasomatic quartz veins.

The metamorphic zoning was complicated by Late Paleozoic rigid collision, during which the Main collision suture played a decisive role. The motions of continents at that time fostered almost entire consumption of paleoceanic structures and the transport of the main heat flow into the shear zone of the Main collision suture. These processes promoted the development of a high-temperature (up to the amphibolite facies) and high-pressure eclogite–schist framing of the Ufalei gneiss–amphibolite complex and metamorphism of the intensely deformed sequences of the Mauk–Karabash zone up to the low amphibolite, epidote–amphibolite, and greenschist facies. The high-pressure setting stimulated the formation of granular quartz veins and resulted in deformation and granulation of quartz–muscovite bodies of muscovite pegmatites and migmatites. This stage was marked by the formation of granular quartz due to recrystallization of quartz veins of the early collision stage. In addition to granular quartz veins, the Main collision suture zone hosts quartz veins composed of glassy (less commonly, milky white) quartz. These processes were accompanied by intrusion of microcline granites and the formation of ceramic pegmatites and younger metasomatic calcite–dolomite carbonatites with yttrium mineralization (xenotime). Middle Riphean carbonatite zones superimposed on yttroepidote-containing anorthoclase pegmatites are characterized by recrystallization and formation of large yttroepidote crystals (in granular quartz), xenotime, rutile, apatite, and sphene. The age of normal microcline granites, ceramic pegmatites, metasomatites, and carbonatites is estimated at 330–245 Ma (figure).

Thus, the Ufalei Block composed of differently transformed gneiss–amphibolite rocks demonstrates polygenous and polychronous mineragenу (table). It encloses various deposits of titanomagnetites, rare earth pegmatites and calcitic carbonatites (products of Middle Riphean rifting), jaspilites, micaceous and ceramic pegmatites, calcite–dolomite carbonatites (with apatite, fergusonite, xenotime, and other minerals), greisens (with Mo), and others (products of the island-arc and collision processes). Data presented in this paper can be used in the study of adjacent and remote blocks, e.g., the Polar Urals, where we plan to start research works within the framework of the project “The Polar Urals: The Industrial Urals.”

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