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GEOLOGY

Alkaline and Acid Metasomatic Rocks in Gneiss–Amphibolite Complexes of the Urals: A Case History of the Ufalei Metamorphic Block, Southern Urals

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The realization of the project "The Industrial Urals–the Polar Urals" requires assessment of the northern segment of the Urals for mineral resources related to the lithotectonic complexes formed in different geodynamic settings. In this connection, we have to assess mineragenic specialization and practical implications of widespread gneiss–amphibolite complexes (Fig. 1). Thereby, primary attention should be focused not on the rock complexes but on the suture zones that control virtually all ore and nonore deposits and occurrences [1, 3, 5].

The gneiss–amphibolite complexes in the Urals (Ufalei, Sysert–Ilmenogorsk, and others in the southern and central Urals; Malyk, Marunkeu, Kharbei, Khord'yus, and Nerkayus in the northern segment of the region) (Fig. 1) are complex heterogeneous rock associations formed on fragments of the ancient continental crust in the course of multiple activation of tectonic, magmatic, metamorphic, and other processes within a chronological range from the Middle Riphean to the Early Jurassic (220 Ma) [1–5]. The Ufalei metamorphic block should be regarded as a typical example of these complexes. This block is well studied and may serve as a reference object for further investigations.

The Ufalei metamorphic block is composed of Paleoproterozoic gneisses and amphibolites (products of metamorphism of basic volcanics) (Fig. 2). In the west, the block is bounded by the Middle Riphean metamorphic schists of the Taganai–Ukazar Shear Zone. In the north, the block is bounded by the Sukhovyazovsky Suture Zone marked in some segments by pyroxenite, gabbro, and gabbro-amphibolite bodies with titanomagnetite mineralization (Kurta deposit). Diverse glimmerites, quartzites, blastomylonites, and eclogite-like rocks, as well as numerous deposits of granulated quartz and muscovite, were mapped on the eastern wall of the block within the Slyudyanogorsk–Teplogorsk Suture Zone [6–8].

Four stages of tectonic and metamorphic events are documented in the Ufalei metamorphic block (Fig. 3). Each stage is marked by formation of igneous (mainly silicic, alkaline, and subalkaline) complexes [7–9], which are accompanied by various metasomatic rocks and quartz veins. The quartz veins were considered in special publications [3, 8] and are beyond the scope of this communication. Some indirect data testify to the existence of a fifth stage of tectonomagmatic activation: the age of apodoleritic listvenites (616–650 Ma) in the Bakal ore (siderite) field [10] and amphibolization (580–610 Ma) of the Kuvash metavolcanic rocks and plutonic rocks (660 Ma) of the gabbro–trondhjemite series [11].

In the Middle Riphean (1.32–0.98 Ga ago), the basement of the East European Platform within the Ufalei block developed under conditions of continental rifting. The Kurta pyroxenite–gabbro complex with titanomagnetite mineralization was formed at that time. Metamorphism related to rifting locally reached the grade of ultrametamorphism [1] that led to the formation of the Slyudyanogorsk gneissic alkali granite, normal potassic granite (1.10–1.215 Ga [12] and 0.99–1.18 Ga [13]), and anorthoclase pegmatites dated at 1.1–1.2 Ga [14]. The Riphean granitic and other igneous rocks and pegmatites were then involved in folding and fragmented into boudins in the process of collision [1, 5]. The giant anorthoclase crystals (up to 20 cm or larger in size) with distinct iridescence (moonstone) were found at Slyudorudnik (Mica Mine). Calcitic metasomatic rocks enriched in REE (0.15–0.29 wt %) relative to host gneisses (0.03–0.04 wt %) and anorthoclase from pegmatite (0.01 wt %) were formed in the Slyudyanogorsk and other suture zones at the hydrothermal stage. Epidote-Y (up to 40–70 cm in size),

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which contains 1.07 wt % Y and 2.11 wt % U, is known from anorthoclase pegmatites.

As concerns the oceanic geodynamic setting (480–370 Ma), the following products of magmatism, metamorphism, and metasomatism are known in the Ufalei block (Fig. 2): syenites, granosyenites, leucogranite, and alkali granites with magnetite; genetically related albitites with rare-metal mineralization (fergusonite, samarskite, columbite containing 1.98–3.35 wt % Y and 1.38–1.64 wt % U); and carbonation of amphibolites with the formation of small magnetite bodies [5]. Under these geostructural and physicochemical conditions, the Riphean carbonate metasomatic rocks underwent intense recrystallization with segregation of phlogopite, magnetite, and pyrrhotite. Chlograpites (rodingites) replacing Alpine-type ultramafic rocks transformed into antigorite serpentinites were attributed in [5] to the island-arc geodynamic setting. However, a Sm–Nd isochron age of 368 ± 12 Ma was obtained for this rock by V.V. Murzin and Yu.L. Ronkin. Therefore, rodingites should be regarded as early collision metasomatic rocks.

The period of early collision (375–320 Ma) was characterized by emplacement of tonalite–granodiorite massifs and formation of related gold–quartz deposits. They are characterized by wallrocks of the beresite–listvenites association. These metasomatic rocks and spatially associated aceites are considered products of acid leaching in [3]. In addition, the metasomatic ferruginous quartzites and quartz veins of recrystallization, fissure filling, and replacement were formed in the same time interval in the Ufalei block.

The late collision (325–220 Ma) is marked by formation of normal microcline granites and related ceramic pegmatites, metasomatic quartzites, and molybdenite-bearing phengite greisens (Fig. 3). The recurrent recrystallization of calcite metasomatic rocks in this period produced dolomite, phlogopite, amphibole, apatite, rutile, titanite, xenotime, and newly formed epidote-Y with 1.11 wt % Y and 1.00 wt % U. In addition, the veins of primary-granulated glasslike quartz and secondary-granulated quartz were found in this territory [5].

As temperature and, partly, pressure dropped, the metasomatic rocks were formed in suture zones of the Ufalei metamorphic block in the following succession: microclinites–albitites–greisens–gumbeites–aceites–beresites–listvenites–carbonate metasomatic rocks (table). Two comments should be added to this series. First, this series combines the data obtained from the

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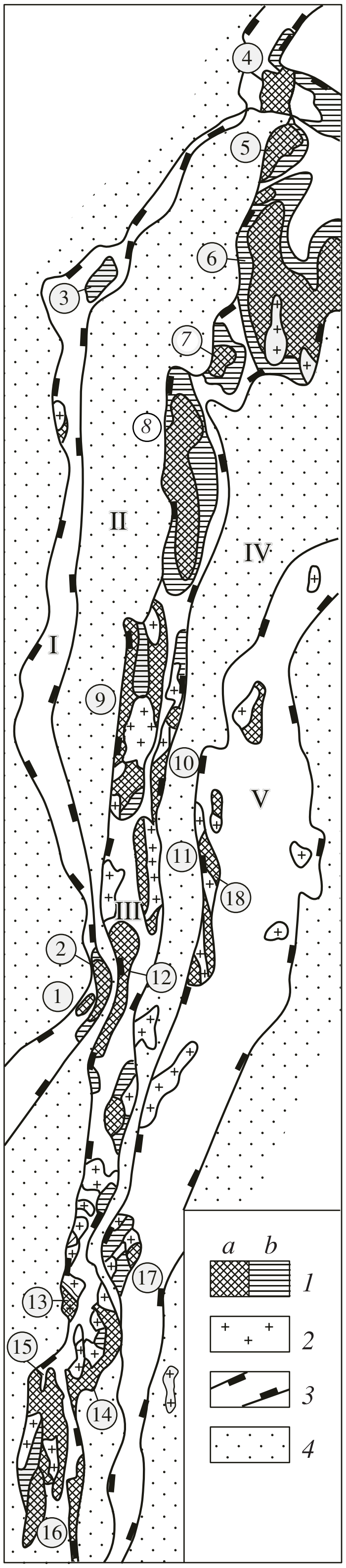

Fig. 1. Index map of gneiss–amphibolite complexes of the Urals, after [1]. (*1*) Gneiss–amphibolite complexes: (*a*) gneisses and amphibolites, (*b*) crystalline schists; (*2*) granite massifs, (*3*) regional uplifts: (I) Central Ural; (III) East Ural; (V) Transural; (*4*) regional troughs: (II) Tagil–Magnitogorsk Megazone; (IV) East Ural Megazone. Major gneiss–amphibolite complexes: (1) Taratash, (2) Ufalei, (3) Khobi; (4) Kharbei, (5) Salekhard, (6) Berezovsk, (7) Vas'kino, (8) Yalbyn'ya, (9) Salda, (10) Gaevsk, (11) Murzinka–Adui, (12) Sysert–Ilmenjgorsk, (13) Adamovo, (14) Tekel'dytau, (15) Kairakty, (16) Taldyk, (17) Mariinsk, (18) Krasnogvardeisk.

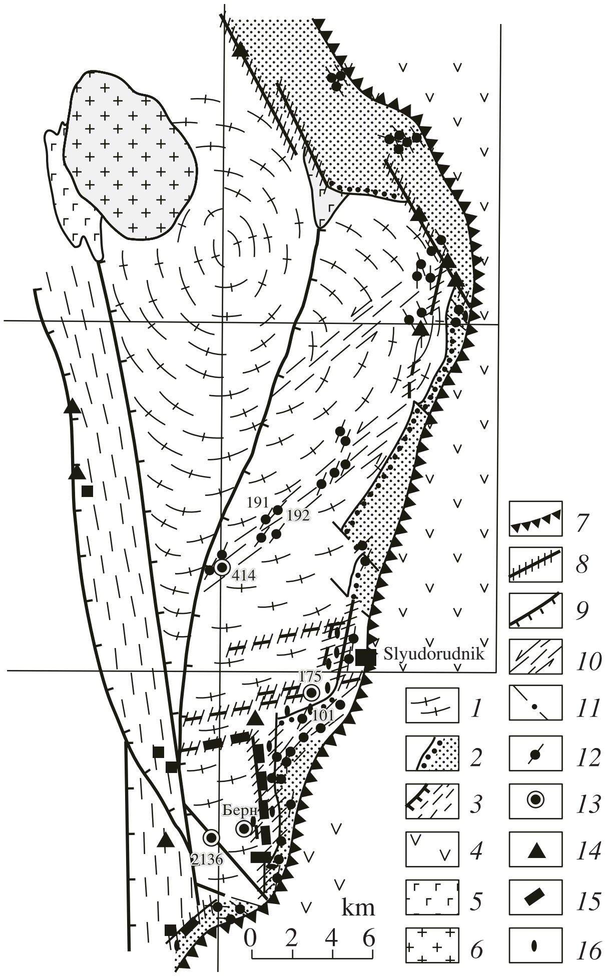

Fig. 2. Geological sketch map of the Ufalei metamorphic block with elements of minerageny, modified after [1, 3]. (*1*) Paleoproterozoic gneisses and amphibolites; (*2*) Middle Riphean Kurta Formation (schists, quartzites, and blastomylonites); (*3*) metamorphic schists of the Taganai–Ukazar Shear Zone; (*4*) Early–Middle Ordovician volcanic complex of the Karabash tectonic block; (*5*) Kurta Complex (pyroxenite, gabbro, and gabbro-amphibolite); (*6*) Lower Ufalei massif of collision granitoids; (*7*) Main Ural collision suture; (*8*) Riphean rift-related fault zones hosting quartzites, older pyroxenites with titanomagnetite mineralization, and granitoids; (*9*) reverse and thrust faults; (*10*) strike-slip fracture zone accompanying the Serebrovsk Thrust Fault; (*11*) normal faults; (*12*) large quartz veins; (*13*) mined quartz veins and their numbers; (*14*) magnetite and hematite deposits and occurrences; (*15*) ancient quartzites; (*16*) muscovite pegmatites with rare-metal mineralization.

sections of suture zones pertaining to different depth levels. Second, carbonate (calcite) and carbonate-bearing metasomatic rocks (gumbeites, aceites, beresite–listvenites, products of quartz–sericite and argillic alteration) are subdivided into two types: (1) calcitic rocks formed at the final stage of the evolution of suture zones and (2) carbonate-bearing metasomatic rocks related to intrusions of the tonalite–granodiorite and syenite–alkali granite associations, which are constituents of suture zones.

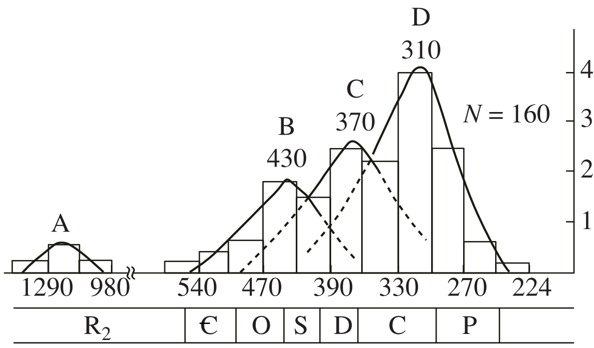

Fig. 3. Timing of the main lithotectonic complexes of the Ufalei metamorphic block, modified after [1] and supplemented with original data and the data from [6–9 and others]. A (riftogenic stage): metapyroxenites, hornblendites, and gabbros with titanomagnetite mineralization; alkali granites; metamorphic rocks of granulite and amphibolite facies; ultrametamorphic rocks; anorthoclasites with epidote-Y and calcitic metasomatic rocks; B (island-arc stage): dunite–clinopyroxenite–gabbro complex; nepheline and alkali syenites; leucogranite and alkali granites with magnetite; albitites with REE mineralization; carbonated amphibolites with magnetite; recrystallized Riphean metasomatic rocks with phlogopite, magnetite, and pyrrhotite; C (early collision stage): plagiogranites, granodiorites, and metamorphic rocks (zonal complex with products of amphibolite and epidote–amphibolite facies); Au-bearing zones of magnetitization in antigorite serpentinites, actinolite metasomatic rocks, and chlograpites (rodingites); mica pegmatites; metasomatic quartzites; quartz veins of recrystallization and fissure veins; aceites, beresite–listvenites conjugated with sulfide-bearing quartz and quartz–carbonate veins; D (late collision stage): microcline granites, metamorphic rocks of amphibolite and epidote–amphibolite facies; ceramic pegmatites; metasomatic quartzites; calcite–dolomite metasomatic rocks with phlogopite, amphibole, rutile, titanite, and xenotime; greisens with molybdenite; veins of primary- and secondary-granulated quartz.

As follows from the table, the fluid responsible for metasomatic alteration was distinguished by an appreciable prevalence of sodium over potassium. The acidity of the fluid first increased with a decrease in temperature and then decreased. The Na/K parameter evolved in the following way due to the decrease in temperature: (1) at the stage of microclinization, the hydrothermal solution contained not only K but also Na, the amount of which increased in the course of the formation of potassium feldspar; (2) albitites crystallized from the solution saturated with Na; (3) gumbeites started to crystallize when Na slightly prevailed over K, while aceites were formed in the case of a significant prevalence of Na over K; (4) beresites could form at a variable Na/K ratio; (5) carbonate metasomatic rocks were formed from a hydrocarbonate solution at a low temperature; (6) at $T = 300°C$, uranium was extracted from wall rocks into solution and precipitated as uranium minerals at lower temperatures; and (7) carbonate metasomatic rocks are enriched in REE, but their own minerals were not identified.

Composition of hydrothermal solutions responsible for the formation of alkaline and acid metasomatic rocks in gneiss–amphibolite complexes of the Urals

Parameter	Microclinite	Albitite	Gumbeite	Aceite	Beresite	Carbonate rocks	Greisen
T, °C	550–450	480–380	470–390	450–390 280–220	400–250 320–180	240–80	480–280
P, kbar	2–3	>2, <3	2.7–1.9	1.2–0.7	1.8–0.6	0.6	~2
pH	>7	>7	6–8	4.5–5.7	5.5–6.0	>7	<7
Type of fluid	Potassium chloride–carbonate	Sodium–calcium chloride–fluoride	Hydrocarbonate–sulfate–chloride	Hydrocarbonate–chloride	Potassium hydrocarbonate–chloride–sulfate	Calcium–magnesium hydrocarbonate	Sodium–calcium chloride–fluoride
Na/K in fluid	1.7	5	1.2	3.2	2.7	1.5–3.4 : 1	1.3–5 : 1
Cl/F in fluid	5–25 : 1	1.1–113 : 1	35 : 1	–	8–110 : 1	8 : 1	1 : 1.8

Note: The table is based on data reported by A.F. Korobeinikov, A.G. Mironov (1992), B.I. Omel'yanenko (1978), V.G. Kushev (1972), V.B. Koval (1977), V.N. Sazonov (1984), and others.

The mantle fluid participated in the metasomatic alteration within suture zones. Initially, this fluid contained a small amount of CO_2. The activity of this component was not high and increased by the end of the hydrothermal process when calcitic metasomatic rocks were formed. The evolution of carbonate metasomatism related to granitoid and syenite massifs was controlled by the depth of the hydrothermal process. If the thickness of overlying rocks was less than 1.5 km, fluid degassed and carbonates did not crystallize or only calcite was crystallized.

Thus, based on the data presented above and published in [1, 3, 7, 8, 14], one may state that nonore occurrences (muscovite, quartz, talc, and anthophyllite asbestos) and ore occurrences (titanomagnetite, molybdenite, uranium, rare-metal and REE mineralization) are known in the Ufalei gneiss–amphibolite block. All these mineral occurrences are related to suture zones and genetically associated fractures (mainly diagonal tensile structures). The suture zones are characteristic of other gneiss–amphibolite complexes in the Urals (Fig. 1) [1, 4, 6, 15]. Rare-metal mineralization is known in the northern part of the region.

In context of realization of the project “The Industrial Urals–the Polar Urals,” the study and evaluation of the mineral resource potential of suture zones in the northern Urals has become an urgent issue. The complex mineralization in these zones should be investigated comprehensively.

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