

Platinum- and Gold-Bearing Rodingites of the Ust'-Dep Ophiolite Block (Middle Amur Region)

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The Ust'-Dep ophiolite block, a part of the Selezha–Zeya Belt, occupies an area of 350 km² and incorporates apoharzburgite serpentinite massifs intruded by numerous (>60) dikes of diabases and granitoids up to 100 m thick and more than 1 km long. Ophiolitic outcrops of this block make up a SW- to NW-trending band extending from the right bank of the Zeya River to the Gar River basin. Only small fragments of ophiolite massifs are preserved in spurs of the Tukuringr Ridge (Fig. 1). The Ust'-Dep and Gar protrusions in this area include dislocation zones with superimposed metasomatic alterations (development of listvenites and rodingites with gold mineralization). The majority of rodingite and listvenite occurrences are confined to outcrops of Lower Paleozoic–Middle Cretaceous granitoid intrusions and dikes. Listvenites usually considered the source of placer gold are scrutinized in [1, 2]. However, data on the gold potential of rodingites in the Ust'-Dep block are lacking, although they are similar to rodingites in the Zolotaya Gora deposit (southern Urals) that was previously proposed as a holotype of the gold–rodingite association [3]. Their similarity is manifested in the development of rodingites among listvenitized serpentinites. Therefore, the gold mineralization of Uralian rodingites is attributed to a younger process of listvenitization [4].

The spatial association of gold deposits with ultrabasic rocks is long known. Recently, the high Au content in Uralian listvenites and rodingites is explained by the tectonic and hydrothermal-metamorphic transformation of ultrabasic rocks under the impact of abyssal fluids [5]. The aim of our work is to study the mineral composition and geochemical specialization of roding-

ites of the Ust'-Dep ophiolite block using the first data on contents of Au, Pt, and Pd therein.

Rodingites represent the metasomatic calc-silicate rocks developed after diabase dikes in apoharzburgite serpentinites. Thin (10–15 cm) diabase dikes are completely replaced by rodingites, while thick dikes include rodingite developed locally along the contact with serpentinites with relicts of the diabase protolith. One can also occasionally see closely spaced dikes of basic rocks and granitoids that crosscut the serpentinites (Fig. 2). In such cases, the granitoids and basic rocks are replaced by albitites and rodingites, respectively, as a result of contact-metasomatic processes. Therefore, one should take into account the influence of metasomatic reactions in the “basite–ultrabasic” and “granite–ultrabasic” systems on the mass transfer of components. Thus, one should not consider the gold potential of rodingites without the examination of other metasomatites. Chemical compositions of serpentinites, rodingites, albitites, and listvenites are presented in Table 1.

Rodingites are composed of garnet (Gr) of the grossular–andradite series, several generations of diopside (Di) with a variable Fe content, vesuvian (Ves), zoisite, tremolite, prehnite, chlorite (Chl), titanite, and relict apatite and magnetite. The higher-temperature diopside–garnet assemblages are replaced by the vesuvian–zoisite–chlorite and less common prehnite–tremolite assemblages. Rodingites are usually characterized by heterogeneous mineral composition and a lack of distinct regressive zonation. The rodingites have a hetero-granoblastic texture with traces of multiple recrystallization. Their metasomatic origin is confirmed by the development of numerous aluminosilicate and chlorite veinlets. Based on microprobe data, diopside, grossular, vesuvian, and chlorite show a wide variation of the Fe content (Table 2), suggesting their multistage formation over a prolonged period.

Physicochemical constraints of rodingites were determined using experimental data on the modeling of Gr–Di–Ves–Chl equilibria [7, 8]. The Di–Gr rodingite formed at 420–450°C under conditions of low mole

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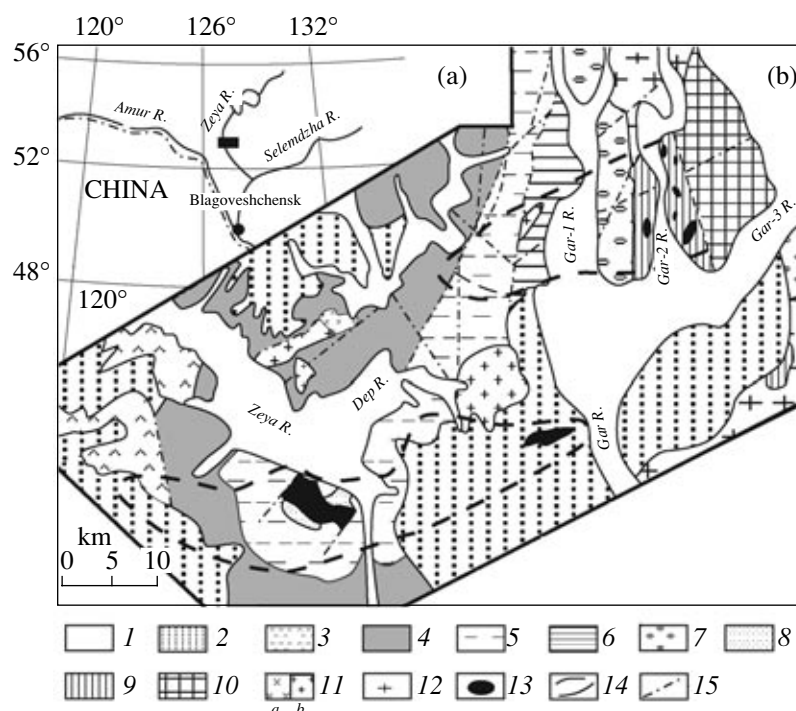


Fig. 1. Schematic geological setting of the Ust'-Dep ophiolite block [1]. (a) Geographic location of objects studied; (b) geological legend. (1) Quaternary sediments; (2) Neogene–Lower Quaternary sediments; (3) sandstone, coal, and tuff of the Molchanov Formation (Upper Jurassic); (4, 5) terrigenous rocks of the Dep and Ayan formations, respectively (Upper Jurassic); (6, 7) terrigenous rocks of the Uskala and Usmankov formations, respectively (Middle–Upper Jurassic); (8) conglomerate and sandstone; (9) green-schist (Upper Proterozoic–Lower Paleozoic); (10) biotite, garnet–biotite, and two-mica gneisses, and quartzite (Lower Paleozoic); (11) Lower Cretaceous (a) granite and (b) granite porphyry; (12) biotite granite (Lower Paleozoic–Middle Cretaceous) (PZ₁–C); (13) ultrabasic rocks (Lower Paleozoic); (14) contours of ultrabasic rock massifs based on geophysical data; (15) faults.

fraction of CO₂ ($X_{CO_2} < 0.03$). The vesuvian-containing rodingite is stable even at a lower CO₂ content in the metamorphosing fluid ($X_{CO_2} < 0.015$). The sporadic prehnite–tremolite assemblage is formed at a temperature of 370°C. Experimental data indicate that even minor variations in T and X_{CO_2} can provoke substitutions of mineral assemblages. The high sensitivity of Ca-aluminosilicates to fluid regime is responsible for the polymineral composition and intricate zonation of rodingites, even within local sectors of mineralization.

Geochemical specialization of metasomatic rocks of the Ust'-Dep block was investigated by X-ray fluorescence analysis (Table 3). Comparison of Tables 1 and 3 shows high Ti and V concentrations in rodingites, relative to other metasomatites. This property of rodingite was previously reported from the Munilkan ophiolite block, Yakutia [6], and was attributed to specific chemical features of the diabase protolith. High concentrations of Cr, Ni, and Co in rodingites are probably related to their input from serpentinites in the course of contact-metasomatism. They reflect a high mobility of ore elements if their concentrations are different in the adjacent rocks.

Placers of the Ust'-Dep and Gar protrusions are characterized by high contents of Au and platinum

group metals (PGM) [2]. Therefore, we analyzed Au, Pt, and Pd contents in the rodingites based on the ICP-AES method. Results presented in Table 4 show that the Au content is high (0.48–4.67 g/t), the Pt content is one order of magnitude lower (0.06–0.59 g/t), and the Pd content is at the detection limit (<0.088 g/t). The AAS method was used in [1] to determine the Au content in listvenites that are characterized by high concentrations of Cr (1400–1600 g/t) and Co (90–130 g/t). The Au content amounts to 0.6, 3.9, and 18.8 g/t, respectively,

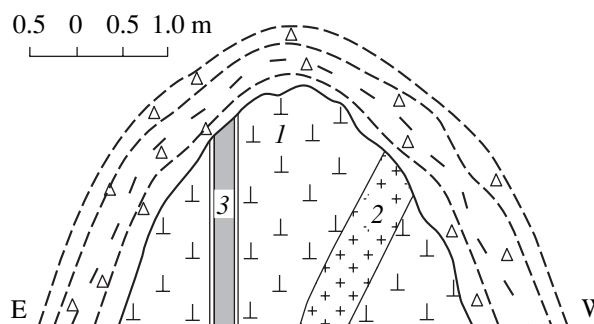


Fig. 2. Outcrops of (1) apoharzburgite serpentinite with cross-cutting dikes of (2) albitite and (3) rodingite at the Smol'nyi Spring (Ust'-Dep protrusion).

Table 1. Chemical composition of metasomatites in the Ust'-Dep ophiolite block

Oxide	Rg46	N57	Su4/6	Su4/8	Rd8	Rd9	100	101
SiO ₂	40.91	38.66	46.16	36.86	38.31	75.69	27.76	29.57
TiO ₂	0.01	0.01	0.27	0.74	1.19	0.04	0.03	0.06
Al ₂ O ₃	1.0	0.87	15.58	1.77	8.74	12.69	1.69	1.32
Fe ₂ O ₃	13.27	6.28	1.8	13.47	8.49	0.91	1.29	1.89
FeO	–	2.2	1.58	1.85	5.45		4.42	4.2
MnO	0.25	0.06	0.04	0.16	0.26	0.05	0.03	0.04
MgO	40.89	37.83	11.8	9.68	8.08	0.87	28.9	25.59
CaO	0.27	0.08	15.7	29.54	24.63	0.9	0.29	1.32
Na ₂ O	0.14	0.02	0.36	0.13	0.14	0.04	0.05	0.11
K ₂ O	0.01	0.02	0.67	0.01	0.02	0.15	0.18	0.39
P ₂ O ₅	0.02	0.01	0.01	–	–	–	0.05	0.05
SO ₃	n.d.	–	–	–	0.01	n.d.	–	–
CO ₂	"	0.2	0.15	1.07	1.03	"	34.92	34.62
H ₂ O	"	12.28	4.82	4.27	3.3	"	0.02	0.03
Total	96.78	98.52	98.96	99.55	99.65	98.93	99.63	99.29

Note: Analyses Rg46 and Rd9 were made by the XFA method; other analyses, by the whole-rock analysis method. (Rg46, N57) Serpentinites; (Su4/6, Su4/8, and Rd8) rodingites; (Rd9) albitite; (100, 101) listvenites. (n.d.) Not determined.

Table 2. Chemical composition of minerals in rodingites, wt %

Oxide	Rd8					Su4/6			Su4/8	
	Di ₁	Di ₂	Gr ₁	Gr ₂	Chl	Ves	Gr	Chl	Di	Gr
SiO ₂	52.75	50.58	38.43	37.34	30.40	36.92	37.01	27.56	54.60	35.73
TiO ₂	0.01	0.12	0.85	0.89	0.12	0.93	0.99	0.03	0.04	3.62
Al ₂ O ₃	0.37	1.65	10.15	11.13	15.00	16.63	12.15	20.05	0.00	1.21
Cr ₂ O ₃	0.05	0.05	0.00	0.03	0.04	0.00	0.11	0.33	0.00	0.15
FeO	5.03	9.38	14.47	16.00	30.75	4.17	12.78	16.13	1.12	27.00
MnO	0.86	0.83	0.08	0.15	0.55	0.13	2.02	0.47	0.51	0.08
MgO	16.29	13.16	0.56	0.35	13.33	2.05	0.09	23.21	17.36	0.72
CaO	24.98	24.62	34.98	34.17	0.61	35.21	34.99	0.07	25.37	32.84
Na ₂ O	0.01	0.07	0.00	0.00	0.00	0.04	0.03	0.00	0.00	0.02
K ₂ O	0.03	0.02	0.00	0.02	0.01	0.07	0.08	0.06	0.00	0.01
NiO	0.01	0.01	0.04	0.04	0.05	0.19	0.21	0.20	0.00	0.00
Total	100.28	100.48	99.54	100.12	90.81	97.18	100.25	87.91	99.01	100.38

in three fresh listvenite samples from the Zolotoi Spring basin (Ust'-Dep block) and decreases to 1.5–3.4 g/t in oxidized listvenite samples from the Gar protrusion. One can see native gold flakes (0.1–0.15 mm) with a Cu and Ag admixture (up to 6.3 at %) in quartz, mica, pyrite, and carbonate aggregates. These data testify to a higher Au potential of listvenites relative to rodingites.

Experimental data can be used to solve the issue of the influence of rodingite development on the mobility of Au and Pt. The influence of contact-metamorphic processes in the basite-ultrabasite and ultrabasite–

granite systems on the mobility of Au and Pt was experimentally studied at 300–500°C and 1 kbar [7, 8]. The results demonstrated that Au solubility decreases at the contact of granitoids and ultrabasic rocks that drastically differ in terms of the SiO₂ content. This geochemical barrier is marked by the formation of SiO₂-supersaturated solutions that promote the precipitation of silicates together with Au at 300°C (if the Au concentration is >0.03 mg/l) or 500°C (Au >0.12 mg/l). At the same time, the experiments showed that reactions in the ultrabasite–granite and basite–ultrabasite systems do not affect the Pt solubility. This behavior of noble met-

Table 3. Contents of microelements (ppm) in metasomatites of the Ust'-Dep ophiolite block (based on XFA data)

Oxide	Su4/6	Su4/8	Rd8	Rd9	Rg46
Rb	1	1	–	1	–
Sr	324	13	11	122	11
Y	18	46	28	10	–
Zr	48	86	60	87	–
Nb	3	4	3	11	2
V	238	305	312	13	49
Cr	41	85	69	10	2958
Co	20	59	38	3	91
Ni	36	67	246	18	1882
Ba	25	19	43	97	25

Note: Sample numbers as in Table 1.

Table 4. Contents of Au and Pt in metasomatites of the Ust'-Dep ophiolite block (g/t)

Sample no.	Au	Pt
Su4/6	0.48	0.307
Su4/8	4.67	0.11
Rd8	0.76	0.59
Rd9	0.48	0.25
Rg46	2.09	0.06
Mo51	1.34	0.11
Mo52	2.56	0.05
Mo25	0.17	2.82

Note: Analyses were performed by the ICP-AES method at the Far East Geological Institute, Vladivostok. Samples: (Mo51) Rodingite, (Mo52) listvenite, (Mo25) chromitite; other samples are as in Table 1.

als at the contact of ultrabasic rocks and granites explains the formation of metasomatic gold rims around platinum metal grains in several deposits of the Russian Far East [9].

The geochemical barrier with auriferous silicates are absent at the contact of ultrabasic rocks and granites with a lesser difference in the SiO₂ content. Bimetasomatic interaction between basic and ultrabasic rocks generates low-alkaline fluids with a high mobility of Ca, Mg, and Al that initiate the formation of rodingites. This process is accompanied by multiple recrystallization, removal of impurities from the newly formed phases, and precipitation of ore components [7, 8]. Thus, the formation of rodingite can only be accompa-

nied by a local transfer of Au and Pt if the ambient basic and ultrabasic rocks are characterized by concentration gradient of these metals. Specific features of the process of rodingite formation (low potential of CO₂, low-alkaline environment, and temperatures of approximately 350–500°C) are significantly different from those of the listvenite development related to the alteration of ultrabasic rocks by younger granitoids that generate acid (potassic) solutions with a high activity of CO₂.

The spatial association of auriferous rodingites of the Ust'-Dep and Gar ophiolite protrusions with granitoids and the superimposed process of listvenite formation testifies to the polygenic and polychronous gold mineralization. Gold and platinum were probably derived from ultrabasic rocks. Serpentinization, listvenitization, and contact-metasomatic reactions of these rocks with dikes of basic rocks and granites promoted the extraction of metals and their concentration in metasomatic bodies confined to dislocation and catclasm zones. In this case, both listvenites and rodingites developed in areas of superimposed listvenitization have a high potential of Au and PGM.

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