UDC 553.411.071:550.42(546.1+546.8)

FEMIC CHEMICAL ELEMENTS IN NEAR-ORE METASOMATIC HALOES OF THE KEDROVSKOYE GOLD-ORE DEPOSIT (THE NORTH TRANSBAIKALIA)

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The results of studying geochemistry of phemophilous group in near-ore apogneiss and aposhale metasomatites of the Kedrovskoye mesothermal deposit in the North Tranbaikalia are presented. According to mineralogy-petrochemical data it was defined that metasomatic haloes belong to beresite metasomatic formation with propylite-like profile of transformations at the area periphery. Silica loss up to the half of its mass from the back zones was stated in the initial ores and conditions of this loss were determined. Silica removed from the ores served as a basis for formation of gold-bearing quartz veins. In the back zones of near-ore metasomatic haloes contrast anomalies of phosphorous, titanium, magnesium, manganese, iron, potassium and calcium were found. Femic orientation of gold-bearing metasomatites demonstrates the generation of metal-bearing fluids in mantle magmatic chambers.

Introduction

Repeatability of results in experiment or observable in space and time empirical data serves, as it is known, as criterion of law. Found earlier [1] phenomenon of contrast anomalies accumulation of femic elements (titan, phosphorus, magnesium) in gold-bearing near-ore beresites of the Irokindinskoye ore field in the North Transbaikalia in a near frame of ore-controlling deep fault – the east seam of the Kilyanskaya zone deep faults and gradual disappearance of this effect further out from the ore field has received acknowledgement in the largest and ordinary mesothermal golden-ores, – Sovietskoye in the Yenisey area, Sukholozhskoye in the Lenskiy area, the Kedrovskoye, the Karalonskoye in the North Transbaikalia [2, 3], in the deposit of the Chertovo Koryto in the Patomskoye uplands. At the same time, in some mesothermal golden-ore fields such anomalies in near-ore metasomatic aureoles and ores have not been noticed.

The problem which has arisen in connection with cited circumstances represents, as it has been shown earlier [1, 3], theoretical and applied interest and, by virtue of it, demands detailed research both in aspect of phenomenon prevalence scales, and in aspect of reasons and conditions of its realization. Some thoughts on this account were offered earlier [3].

The new data about femic elements accumulation in products of the ore-forming process Kedrovsloye deposit are cited and discussed in this paper supplementing earlier found and published in [2, 4] facts.

1. Brief sketch on geological structure of the Kedrovskoye deposit

Based on variety of geological processes in occupied by the deposit block of the Earth's crust and, hence, on complexity of geological structure, on variety of ore-bearing environments providing extensive opportunities for comparisons, the Kedrovskoye mesothermal gold deposit with an area of nearby 40 km^2 is placed in a row of unordinary objects of its class and served as a range where the concept of mesothermal gold deposits formation was developed [5]. The basic features of its geological structure and formation with the appendix of a geological card were resulted earlier [2, 4, etc.], therefore we shall be limited to a brief information.

The deposit is located in the Uzhno-Muyskiy ridge of the North Transbaikalia, 20 km away from the mouth of the Tuldun river – the left inflow of the Vitim river. It is composed of heavy Proterozoic strata of carbonaceous two-mica feldspar-quartz sand-aleuroshales of the Kedrovskoye series carrying out the Tuldun deflection and forming the east wing of the submeridional linear anticlinal fold. The lock part and the western wing of this fold are destroyed by intrusion of the gabbro Riphean age (735±26 million years) [6]. In the central part of the deposit metamorphic shales 335±5 million years ago [4] were subject to local ultrametamorphism with mature chamber-dome structure formation (the Kedrovskoye dome). In the kernel of this dome a rod of quartz diorites and granodiorites is bedded, in the frame – plagiomigmatites and further plagiogneisses gradually changing to metamorphic shales. The ultrametamorphic process was replaced by active magmatism. Small intrusions (dykes) of sour, then average and further moderately alkali subsilicic rocks of several generations were formed during the process. Pre-ore, intraore and late-ore were diagnosed among the latter. Dykes of the basic composition in the extent up to many hundreds meters and capacity up to 1 m have vertical falling and form the meridional belt in width not less than 3 km in the east frame of the Muiskiy Archean base and simultaneously in the hanging (east) side of the Tuldun zone deep fractures which limits the ledge and supervises the mentioned massif of high-titanium gabbro. Subsilicic dykes carry out a role of the numerous subparallel tectonic seams entering into the system of this zone.

Ore bodies – poorly enriched with gold, low in sulfide quartz veins stretched out up to the first...many hundreds of meters and capacity up to 3 m in the majority are bedded in the dyke belt and carry out the interfaced system of chip submeridional cracks (fault), falling under moderate angles (30...50°) to the east in the sedimentary strata according to its stratification, and to the west in magmatic and ultrametamorphic rocks. Formation of ore-bearing faults is caused by decomposition of sublatitudinal tangential compressing forces during the Tuldun zone of deep faults functioning in a mode of upthrow and surface orientation of occurring maximal chipping force at a sharp angle to compressing forces, i. e. such which is generated in the experiment. Surfaces of maximal chipping forces have coincided with surfaces of stratification in the sedimentary strata. Besides veins, mineralized zones of vein-impregnated ores are known to exist in shale strata. These zones are composed of carbonaceous black shales, and in all rocks deposits of massive light metasomatites-beresites and beresitoids (with albite) with capacity up to several ... many tens of meters.

Based on I.V. Popivnyak's et al data (1978), deposit ores are formed in a temperature range of 450...75 °C. Age of the deposit is 282±5 million years [4].

2. Mineral-petrochemical zoning of near-ore metasomatic haloes

Results of mineral-petrochemical studying of near-ore metasomatic haloes are cited. One of this haloes frames gold-bearing quartz vein bedded in the east outskirt of the deposit among plagiogneisses of ultrametamorphic construction (the Kedrovskoye dome). Another halo frames mineralized zone of carbonate-sulfide-quartz streak-interspersed ores formed among carbonaceous sand-aleuroshales in its southern outskirt. Capacity of the first and the second halo reaches up to many tens of meters.

Almandine-two-mica plagiogneisses are motley-grey, dark grey, and at biotite anabundance – brownish-grey coarse-grained (up to 3...5 mm) massive rocks with complex striated texture reminding microfolding and placation and consist of almandine ($1,827<N<1,834$), diopside ($+2V=60°$, $CNg=42°$, optic. sign +, $Ng=1,714$, $Np=1,682$), brown-green biotite, muscovite, quartz, oligoclase – andesine (№ 29...45) in variable quantitative parities with an impurity of microcline, graphite (graphitoid), zircon, apatite, sphene and magnetite. In volume of the halo gneisses are hardly migmatized with content of leucosomes (quartz diorite) no more than 10 vol. %.

Regionally metamorphosed on the level of muscovite-biotite paragenesis carbonaceous (graphite, graphitoid) two-mica feldspar-quartz sand-aleuroshales have dark grey up to black color, shaly structure, inequigranular, from fine-grained sandy up to coarse-grained aleurite structure. Cement, as a result of recrystalization, acquired lepidogranoblastic structure. Fragmental fraction (quartz, feldspars) remained almost completely and its volume varies in significant limits with value scattering up to few tens %. Quartz, as a rule, prevails in fragmental fractions at subordinated participation of sour plagioclases, rare microcline and accessories – zircon, magnetite and apatite. These rocks contain minerals in variable quantities, formed at the stage of regional metamorphism – dark-green, dirty-green biotite, equiponderant with it muscovite in the form of pure and free from impurities plates, pale-green, sometimes polychrome tourmaline, graphite (graphitoid). Based on initial composition, rocks are reconstructed as arkose or feldspar-quartz sand-aleuroshales with basal cement or contiguity.

Near-vein metasomatic haloes in those and other rocks are zonal to similar order of mineral zoning and mineral composition of zones such as external, chlorite, albite, back and axial. The axial zone is composed of gold-bearing carbonate-sulfide-quartz vein or mineralized zone with capacity up to 1 and 3 m respectively. In the latter case the rear zone occupies the biggest part of axial volume. In quartz vein frame the zone spreads out up to several tens of sm. Albite zone has the capacity up to several tens of sm, chlorite – up to the first meters.

The fullest set of neogenic minerals is peculiar to the external zone at their minimal weight. The set includes quartz, sericite, leucoxene, rutile, magnetite, pyrite (not always), calcite, albite, chlorites, zoisite-epidote (not always). The internal border of the external zone lies on a boundary of full dissolution of color mineral in initial rocks – biotite at tourmaline relicts preservation (and in gneisses – garnet) in the rear chlorite zone. Chlorite zone is replaced by albite on the border of chlorite full disappearance. Albite disappears in the rear zone.

In the external and rather rear zones feldspars are replaced by sericite, sericite mixed with calcite, with silica release and quartz crystallization. In rather basic plagioclases zoisite is sometimes formed. Partial deanortization of plagioclases and formation of albite peripheral borders are fixed.

Biotite is replaced by chlorites, and the later by muscovite with release of rutile impurity, leucoxene and magnetite in the form of thin grain units, polluting flakes of micas. Magnesial-ferruterous differences (Tab. 1) prevail among chlorites. Sphene is replaced by leucoxene.

Table 1. *Optical constants and mineral types of chlorites in the external and chlorite mineral zones of near-vein metasomatic haloes of the Kedrovskoye deposit*

Sample number	Initial rock and mineral zone	Optical constants			Mineral type (*F*)
		Nm	Lengthening	Optical sign	
K-418	Two-mica plagiogneiss, external	1,628	+	–	Brunsvigite-delessite (68)
K-375	Two-mica plagiogneiss, chlorite	1,614	+	–	Diabantite (50)
K-307	Two-mica plagiogneiss, chlorite	1,624	–	+	Ripidolite (50)
КЖ-19	Two-mica feldspar-quartz shale, chlorite	1,634	+	–	Brunsvigite-delessite (75)
K-278	Two-mica feldspar-quartz shale, chlorite	1,631	+	–	Brunsvigite-delessite (70)
K-292	Two-mica feldspar-quartz shale, chlorite	1,615	–	+	Ripidolite (45)
K-166	Two-mica feldspar-quartz shale, chlorite	1,628	–	+	Ripidolite (55)
K-336	Two-mica feldspar-quartz shale, chlorite	1,611	–	+	Ripidolite (38)

Reactions of mineral replacements intensify in volume of each zone towards its internal border, and also from the external zone to the rear with synchronous increase in mass of neogenic minerals. It is especially noticeable in the external zone. Because of that, the latter is differentiated on subzones of the weak, moderate and intensive change with neocrystallization volume up to 10, 20, 30 % respectively. The specific structure of minerals within the limits of their groups synchronously changes. Zoisite gradually increases the content of iron and transforms into the epidote before dissolution on the border of the chlorite zone or near to it.

At increase in total mass of carbonates up to several tens of percents the share of magnesial-ferruterous carbonates – dolomite-ankerite, ankerite and siderite sharply increases in rear zones. Manganous calcite apears, and the sizes of their metacrystals-rhombohedrons increase up to 2...3 mm. As a consequence the rock acquires porphyroblastic structure on a background of lepidogranoblastic. The rock is cleared of graphite (graphitoid) and becomes light grey, greenish-light grey. Metasomatite of the zone is always massive and composed of quartz, sericite with relic muscovite, carbonates with an impurity of sulfides, leucoxene, rutile and apatite. From minerals of initial rocks partially quartz and early metamorphic muscovite retain in it.

Petrochemical features of near-ore metasomatism are repeated in both metasomatic columns (Tab. 2, 3).

As it is possible to see on the example of apogneissic metasomatic aureole, (Table 2), mineral transformations of rocks in the peripheral external and chlorite zones occur mainly due to internal (pedigree) resources of chemical elements, – specific mass of displaced substance does not exceed 6–7 %. It is possible to ascertain only insignificant addition on periphery of sulfur and carbonic acid halo.

Significant transformations of rock chemical compound have occurred in the internal zones, especially in the rear where up to half of all the mass of chemical elements have been displaced (43 and 45 %). Almost half of silica and all sodium have been removed from rocks. The behavior of silica and water is unstable, even though 50 percent decrease in silica mass in the apogneissic column is more likely natural than casual because in haloes section, except the rear zone, the content of silica only slightly changes. All the other petrogenic components have been added into haloes from the outside in the quantities excluding redistribution between zones. Additional masses of potassium are cited in sericite, sulfurs – in sulfides, carbonic acids, lime, magnesium, iron, and manganese – in carbonates, titan – in rutile and leucoxene, phosphorus – in apatite.

Table 2. *Change in chemical compositions of almandine-two-mica plagiogneiss and apogneissic metasomatites in mineral zones of near-vein halo of the Kedrovskoye deposit*

Sample number. Mineral zone and subzone	Rock density. Distance from the vein , m	Content: oxides in mass % based on chemical analyses data (first row), elements in grams in 1000 sm³ in the rock (second row). Magnitude of element content change (increase +, decrease −)in % to their mass in 1000 sm³ of the initial rock (third row)															Σ (Δ)
		SiO_2 Si	Al_2O_3 Al	K_2O K	Na_2O Na	S sulfide.	CO_2 $C_{кб}$	CaO Ca	MgO Mg	FeO Fe^{2+}	Fe_2O_3 Fe^{3+}	TiO_2 Ti	P_2O_5 P	MnO Mn	H_2O^+ H	O	
K-603 ВНЕС	2,78 14,0	62,8	17,50	2,30	3,30	0,02	1,06	1,34	3,02	4,41	1,75	0,84	0,12	0,11	1,70		100,27
		814	257	52,8	67,9	0,53	8,04	26,6	50,5	95,1	34,0	14,0	1,44	2,37	5,29	1351	2780,6
K-604 ВНЕУ	2,85 1,4	59,90	17,50	3,70	1,45	0,01	0,54	1,12	3,22	6,17	2,34	0,72	0,28	0,08	2,48		99,51
		798	264	87,5	30,6	0,27	4,21	22,8	55,3	137	46,6	12,3	3,50	1,73	7,91	1364	2835,7
		−2	+2,8	+66	−55	−49	−48	−14	+10	+44	+37	−12	+143	−27	+50	+1	(7)
K-599 1	2,79 1,0	59,90	18,85	2,60	2,60	0,05	0,77	1,82	1,55	5,36	2,35	0,92	0,20	0,07	2,93		99,97
		781	278	60,2	53,8	1,38	5,86	36,3	26,1	116	45,9	15,4	2,42	1,55	9,15	1355	2788,1
		−4	+8,4	+14	−21	+160	−27	+36	−48	+22	+35	+10	+68	−35	+73	+0,3	(6)
K-598 ВНУ	2,89 0,3	31,40	9,05	2,80	0,14	0,41	14,6	10,5	15,6	6,97	2,71	1,60	0,86	0,15	1,24		98,03
		424	138	67,2	3,01	11,9	115	217	272	156	54,8	27,8	10,9	3,37	4,01	1327	2832,0
		-48	-46	+27	−96	2140	1330	+716	+439	+65	+61	+98	+653	+42	−24	−1,8	(45)

Note: Here and in table 3: 1) ВНЕС, ВНЕУ – the external zone, subzones of weak and moderate change respectively; 1, 2, ВНУ – the chlorite, albite and rear zones; 2) petrochemical recalculations were conducted by the volumetric-nuclear method; 3) Δ – specific mass of displaced (addition and loss) substances in % to substance mass of the initial rock (sampl K-603 and K-402) in standard geometrical volume of 1000 sm³; 4) full chemical silicate analyses of rocks was conducted in CL PGU «Zapsibgeologiya» (Novokuznetsk) under I.A. Dubrovskaya's direction

Table 3. *Change in chemical composition of carbonaceous two-mica feldspar-quartz sand-aleuroshales and aposhale metasomatites in mineral zones of near-vein metasomatic halo of the Kedrovskoye deposit*

Sample number Mineral zone and subzone	Rock density Distance from the vein , m	Content: oxides in mass % based on chemical analyses data (first row), elements in grams in 1000 sm^3 in the rock (second row). Magnitude of element content change (increase +, decrease −) in % to their mass in 1000 sm^3 of the initial rock (third row)															Σ (Δ)
		SiO_2 Si	Al_2O_3 Al	K_2O K	Na_2O Na	S sulfide	CO_2 $C_{кб}$	CaO Ca	MgO Mg	FeO Fe^{2+}	Fe_2O_3 Fe^{3+}	TiO_2 Ti	P_2O_5 P	MnO Mn	H_2O^+ H	O	
К-402 ВНЕС	2,69	77,26	12,73	0,64	4,96	0,00	0,18	0,84	0,30	1,42	0,66	0,31	0,03	0,05	0,35		99,73
	4,5	971	181	14,3	99,0	0,00	1,32	16,2	4,88	29,7	12,4	5,01	0,36	1,00	1,05	1345	2682,2
К-401 2	2,77 2,0	62,73	13,07	2,18	3,22	0,25	3,53	1,10	3,40	5,31	2,84	0,55	0,12	0,22	2,27		100,79
		806	190	49,7	65,8	6,92	26,5	21,6	56,3	113	54,6	9,14	1,44	4,74	6,97	1357	2769,7
		−17	+4,9	+248	−34	+	1905	+33	1053	+282	+340	+82	+300	+374	+564	+0,9	(18)
К-400 ВНУ	2,89 1,0	44,13	12,91	3,26	0,32	0,09	11,8	7,68	5,28	7,24	1,38	0,50	0,22	0,20	5,18		100,19
		595	197	77,9	6,87	2,61	92,6	158	91,8	162	27,9	8,67	2,78	4,47	16,7	1444	2888,3
		−39	+8,8	+445	−93	+	6913	+880	1781	+447	+125	+73	+672	+347	1492	+7,4	(43)

1. Discussion of results and conclusion

Redistribution in the system of alkalis metasomatism with replacement with stronger potassium basis of weaker sodium basis, entry and fixing in the system of carbonic acid and restored sulfur in combination with mineral composition of metasomatites in the internal and peripheral zones characterizes the considered haloes as adequate to combination of propylite and beresite formations peculiar to mesothermal gold deposits, including those which were formed in black-shale strata. The latter, besides that, serves as one of the deposit genetic uniformity attributes formed in black-shale crystal substratum.

Loss of significant masses of silica from the rear zones of forming metasomatic haloes, – up to 500 kg from 1 $м^3$ of rock, usually occurs, as it has been marked earlier [1], in case of haloes formation in the highly-siliceous environment, but not always. The proof that it does not always occur is in the Kedrovskoye deposit itself.

Industrial veins of the deposit in the majority (Shamanskie, Osinovie, Promezhutochnie, Pineginskie, Zhiganskie et al) are bedded in strata of highly-siliceous carbonaceous feldspar-quartz and quartz shales, but are not accompanied in gouges by near-vein changes and are separated by a sharp border from containing black shales. To understand the reasons of it, it is necessary to consider «behavior» of quartz and silica in acid and alkaline environments. In the first case quartz is not dissolved, in the second – quartz silica easily becomes a solution [7].

Dissolution of shale basic mineral – quartz as means of space release for carbonates should have preceded a significant, up to several tens %, deposition of carbonate mass in aposhale beresites. As it could occur only under the influence of alkaline solutions, it is necessary to accept that early solutions were alkaline. Having loaded with silica, while cooling, they have transformed to acid mode. The latter has caused mass deposition of silica in cracks accumulated solutions and formation of quartz veins. Acid solutions were not capable to cooperate with essentially quartz veins on crack walls, which caused rocks not to bear attributes of near-vein changes. Possibly, the main silica source for formation of the deposit quartz veins were mapped in the deposit in all the areas thick (up to tens of meters) deposits of aposhale and apogneissic beresites and berisitoids. Solutions transported silica into initiated cracks from these deposits. Feldspars of different rocks, served as additional source of silica for quartz veins formation. Silica was released at decomposition of such feldspars by acid solutions and replacement by sericite. From strong oversaturated by silica, concerning quartz, solutions metastable cristobalite have crystallized which later turned in to quartz [8, 9]. If it was so, and another variant of the process reconstruction is not present, it is necessary to consider that fluids which entered from generation chambers were sterile concerning silica, but not saturated by it up to the brine condition as it follows from [10–13].

Formation of contrast anomalies in femic elements (P, Ti, Mg, Mn, Fe) of apogneissic and aposhale beresites supplements a picture of femic specialization peculiar also to apodiorite, apogabbro beresites (listvenite) and intradyke apodolerite metasomatites of the deposit [2, 4]. It is in accord with miniralization control by deep, composed of dolerite dykes, including intraore fluidoleaders [2] and breaks. Because titanium and phosphorus are most mobile in alkaline environments, their delivery into blocks of oreformation is provided by the alkaline mode of early metalbearing solutions. Transformation of these solutions into acid has caused mass deposition of these elements.

In the adjacent Irokindinskiy deposit near-ore goldbearing beresites are enriched by the triad elements (P, Ti, Mg) in a direct frame of the ore-controlling deep fault – the east seam of the Kilyanskaya zone of deep faults, contents of which are replaced by clark ones [1]. The Kedrovskoye deposit near-ore metasomatites are enriched by femic elements throughout all the territory. It is caused by confinement of the deposit to the wide submeridional belt composed of dykes-fluidoleaders of tectonic seams dolerites – components of the ore-controlling Tuldun zone of deep faults.

Taking geochemical profile of the discussed elements into consideration, their close paragenous connections with basic, alkali-basic and alkaline magmas [12], the fact of phemic elements supply at formation of mesothermal gold deposits with metal-bearing solutions along zones of deep faults and in alternation with moderately alkaline subsilicic melts serves as an additional instruction on participation of mantle components in solutions and the most probable generation of solutions in mantle magmatic shambers.

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Received on 22.01.2007

UDC 552.321.6+552.164

PETROGRAPHY AND MINERALOGY OF ULTRAMAFITES OF OPHIOLITE, SHEETED AND ALKALI-ULTRABASIC COMPLEXES

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Ultramafites of three formation types: of ophiolite complexes, stratified maphite-ultramafite and alkali-ultrabasic intrusions have been studied. Petrographic and mineralogical features of ultramafites demonstrating their evolution in the process of formation and subsequent superimposed plastic deformation were shown. Geodynamic conditions of their formation were defined by the mineral composition of ultramaphites.

Ultramafites of various formational characteristic, being the studying object, constantly drew attention of many researchers. However the data cited by these authors on petrography and mineralogy of ultramafites did not consider features of their deformation microstructure. Therefore the principle of allocation of their laws in the process of rock plastic flow has been set as a basis of the undertaken mineral-petrographic research of ultramafites.

Ultramafites of ophiolite complexes are presented by metamorphic and cumulative formations. Metamorphic dunites and harzburgites are characterized by significant variety of olivine deformation microstructures, reflecting degree of rock plastic deformations and united in seven consistently formed main types: protogranular, mesogranular, porphyroclastic, porphyrolath, mosaic, mosaic-lath and parquet-like [1, 2]. Transition from one type of microstructures to another is characterized by increase in role of plastic deformation attributes: fracture strips, extinction heterogeneity, changes in margin configuration of olivine grains, degree of their orientation and increase in a role of recrystallized individuals. At the analysis of spatial distribution of deformation types of olivine microstructures in massifs from the center to periphery the general tendency of grain size reduction in rocks has been marked, revealing dynamic metamorphic zoning [1–3]. There is a change in chemical composition of olivine and chrome-spinellid during the process of rock plastic deformations. The orientation of mineral composition change is defined by thermodynamic conditions of their metamorphogenetic transformations which can be fixed in the dominating mechanism of plastic deformation [4]. So, for example, in olivines from dunnites of the Paramskiy massif (northeast Pribaikalye), deformed, mainly, by transmitting sliding, an increase in iron has been distinctly marked (6,0→10,5 % Fa) with increase in de-