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GEOCHEMICAL ZONALITY OF SKARN-GOLD DEPOSITS OF THE WESTERN SIBERIA. P. 1.

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Geochemical zonality of Western Siberia gold-skarn deposits has been investigated. Concentric zonal construction of geochemical fields' anomalous structure accompanying studied deposits has been revealed. Groups of concentrating and deconcentrating (in relation to golden-ore bodies) elements have been defined. Close spatial relation between gold and chalcophile satellite elements complex, set of which can vary depending on evolution degree of hydrothermal system, has been established. The set of deconcentrating elements, accumulated on periphery of ore bodies is standard in general and includes Ni, Co, Cr, V, Ba, Mn. In the first part of the article the geochemical zonality of the Sinychinskiy type deposits has been examined, the second is devoted to zonality of the Kazsk ore field and discussion of the results

Skarn-gold deposits are widespread in folded structures of the Altai-Sayansk folded area, but their industrial estimation is always interfaced to significant difficulties. Ore bodies of such deposits, as a rule, are characterized by high concentration of well extracted gold, but have usually very complex morphology and small sizes. In these conditions the objective estimation of new ore-displays is possible with use of complex geochemical criteria developed and tested on well studied deposits.

In correlation to accompanying magnetite mineralization skarn-gold deposits of the Altai-Sayansk folded area form a continuous row within the limits of which it is possible to allocate two extreme types, differing in geo-industrial specialization: 1) golden ore and copper-golden ore and 2) gold-magnetite. As reference objects for research of geochemical zonality we have chosen: for the first group – the Sinyhinskiy ore field (Mountainous Altai), for the second group – the Kazsk ore field (Mountainous Shoriya). In the first part of the article geochemical zonality of the Sinyhinskiy type deposits is considered, the second is devoted to zonality of the Kazsk ore field and discussion of the results.

The earliest geological complexes of the Sinyhinskiy ore field are products of the late-island-arch development stage ($Є_2$–$Є_3$) of the Sarisazskiy sector of the Altai-Severosayanskiy volcano-plutonic belt [1]. The stage is marked by accumulation of volcanogenic-sedimentary strata accompanied by subaerial outpourings of basalt, andesites, andesibasalts of the Ust-Seminskiy retinue ($Є_2$). The main volcanites relate to low-potassium series of normal alkalinity and are classified by lime-alkali basalts of island arches [2]. The stratum contains layers, lenses and biohermic limestone massifs favorable for formation of gold-skarn mineralization.

Intrusive magmatism of that period is presented by the Sarakokshinskiy massif ($Є_3$), where gabbroids and plagiogranites are mapped. According to Sm-Nd isotope dating plagiogranites of the Sarakokshinskiy massif are 587 million years old [3].

Homodromicaly constructed volcanites with high alkalinity of the Nirninsko-saganskiy series and granitoids of the Sinyhinskiy complex relate to formations of the Salairo-Altaiskiy devonian-earlycoal volcano-plutonic belt.

The Sinyhinskiy plutonic diorite-tonalite complex (D_1) is composed of rocks of 4 phases: 1) gabbro; 2) diorites, quartz diorites; 3) tonalites, granodiorites; 4) granites. By means of uranium-lead dating on zircon from quartz diorites the number 400±28 million years has been received [3]. Based on petrogeochemical parameters, complex granitoids relate to weak contaminated granites of the I-type of andesite row. Gold-copper-skarn deposits of the Sinyhinskiy ore field are connected with complex granitoids.

Industrial gold mineralization is dated to stratiform deposits of infiltrational limy skarns that had generated on contacts of limestones and volcanites. Their gold-bearing ability is caused by the imposed processes of silicification and sulfidization. Below, in tables 1, 2 skarns with imposed mineralization for brevity are named «ore», without it – «nonore». Zonal accommodation of skarn and ore minerals, concerning joint knots of brake infringements, detachment planes in folds and other high-permeability structures has been established.

Vollastonite of infiltrational skarns is formed only in sites of solutions intensive circulation (crossing of dispersion systems of various directions, their interface with favorable plicativic structures, etc.). With removal from these structures, vollastonite skarns are replaced by garnet and further – garnet-pyroxenic and pyroxenic. Even further, propilite-like near-skarn metasomatites with actinolite-albite-potassiumspar-epidote-chlorite structure are developing, bordering skarn deposits on prodeleting and capacity. In essence, these metasomatites are column external zone of infiltrational skarns.

Distribution of ore minerals corresponds to skarns composition, which in certain degree is connected with inheritance of fluidopermeable structures in processes of skarnization and ore depositions. On periphery of ore bodies, in garnet-pyroxenic and pyroxenic skarns**,** the magnetite mineralization with secant streaks of later pyrite has been developed, less often pyrrotine and arsenopyrite. Pyrite impregnation has also developed in near-skarn metasomatites. As approaching to golden-ore bodies, in a zone of garnet skarns development, pyrite, pyrrotine, magnetite are replaced essentially by chalcopyrite (with more rare sphalerite, galenite) mineralization. In a zone of spatial overlapping of the named mineral associations, later age of chalcopyrite, galenite and sphalerite in relation to pyrite and magnetite (secant streaks, cementation and accumulation of the shattered grains) has been established. Galenite and sphalerite gravitate to external border of chalcopyrite areas.

Industrial golden-ore bodies concentrate in vollastonite, garnet-vollastonite skarns where the productive mineralization is presented, generally, by bornite-chalcocite association with gold impregnation, frequently with tellurides and sulfosalts. Bornite and chalcocite have been formed simultaneously and are characterized by structures of mutual growing. Their mutual relations with chalcopyrite also testify to synchronism of adjournment of all three minerals. Spatial dissociation is connected with distinctions in structure of the initial substratum: bornite and chalcocite have been depositing in skarns that formed on limestones, and chalcopyrite is characteristic for apotufaceous skarns. The latest ore minerals are tellurides and sulfosalts came across in the form of impregnation and microstreaks in bornite. As a whole, zonality in accommodation of the listed minerals, from periphery of ore bodies to the center, looks as follows: magnetite→pyrite, pyrrotine, magnetite→galenite, sphalerite→chalcopyrite→bornite, chalcocite, tellurides and sulfosalts. The described zonality is the same for various hierarchical levels, from an ore field up to ore columns inclusive and can be classified as combination of centripetal phasic zonality to the zonality of adjournment connected with rock structure.

Research of abnormal geochemical fields has been led by us according to earlier published technique [4]. Initial data are results of geochemical mapping of well core and underground mountain developments, executed by collective of the Sinyhinskiy geoshooting party and the author personally. More than 13000 tests have been used in total. Spectral semiquantitative, spectrogoldmetrical, partially test-tube (for gold and silver) analyses have been executed on all tests. Data of the chemical silicate analysis of the basic versions of rocks and ores have been also used, recounted by J.V. Kazitsyna and V.A. Rudnik by means of the atomic-volumetric method [5].

Because distribution of gold and elements-impurity in all types of rocks mismatches the normal law and is approximated by lognormal model, as estimation of average the average geometrical has been used, and the values spread has been estimated by means of standard multiplier.

According to data of silicate and spectral analyses scarns, in comparison with initial rocks, are enriched by manganese (in 2...3 times), and near-skarn metasomatites by potassium and sodium (in 1,3...1,5 times). At imposing on skarns of quartz-gold-sulphidic mineralization, the essential import, up to 1000...5000 KK (coefficients of concentration relatively to clark), of Au, Ag, Bi, Te, As; up to 500 KK Cu, Sb; up to 200 KK Zn, Pb; up to 10 KK Co, Ni, V has been noticed.

For revealing and characteristics of geochemical zonality next parameters have been used: 1) geochemical associations of correlated elements revealed by the factorial analysis; 2) coefficients of relative concentration (RC) of elements Co:Ni, Pb:Zn [6]; 3) energy of ore formation [7].

Intensity of geochemical associations display has been quantitatively defined as value of factors. By the factorial analysis in the Sinyhinskiy ore field the three geochemical associations of correlated elements which can be presented in the form of the equations of regress have been revealed:

1) F1=0,34Au+0,33Ag+0,32Cu;

2) F2=0,52Ni+0,51V+0,28Co;

3) F3=0,43Zn+0,34Pb.

Elements' content is expressed in geophones (correlation of element content in a test to its background content in corresponding rocks). For sulfidized skarns «no-nore» skarns are accepted as a background. Background values of the calculated parameters and their greatest possible spread in rocks of different structure are calculated according to the Instruction [9] of standard technique (table 1).

The revealed geochemical associations reflect real ore real mineral paragenesys**.** The first association (F1) includes gold and most closely connected with it silver and copper. According to data of monomineral fractions studying, bornite and chalcocite are the most enriched by gold and silver, therefore the maximal values of this parameter (up to 2980) are characteristic for the central parts of golden-ore bodies and naturally decrease in process of their pinch. Background values F1 do not exceed 2,7. Abnormal (higher than 3,62) values of parameter F3 (Pb, Zn) are also characteristic for sulfidized skarns, but are dated to flanks of golden-ore bodies where galenite-sphalerite mineralization has been displayed. Maximal concentrations of Co, Ni, V have been established in

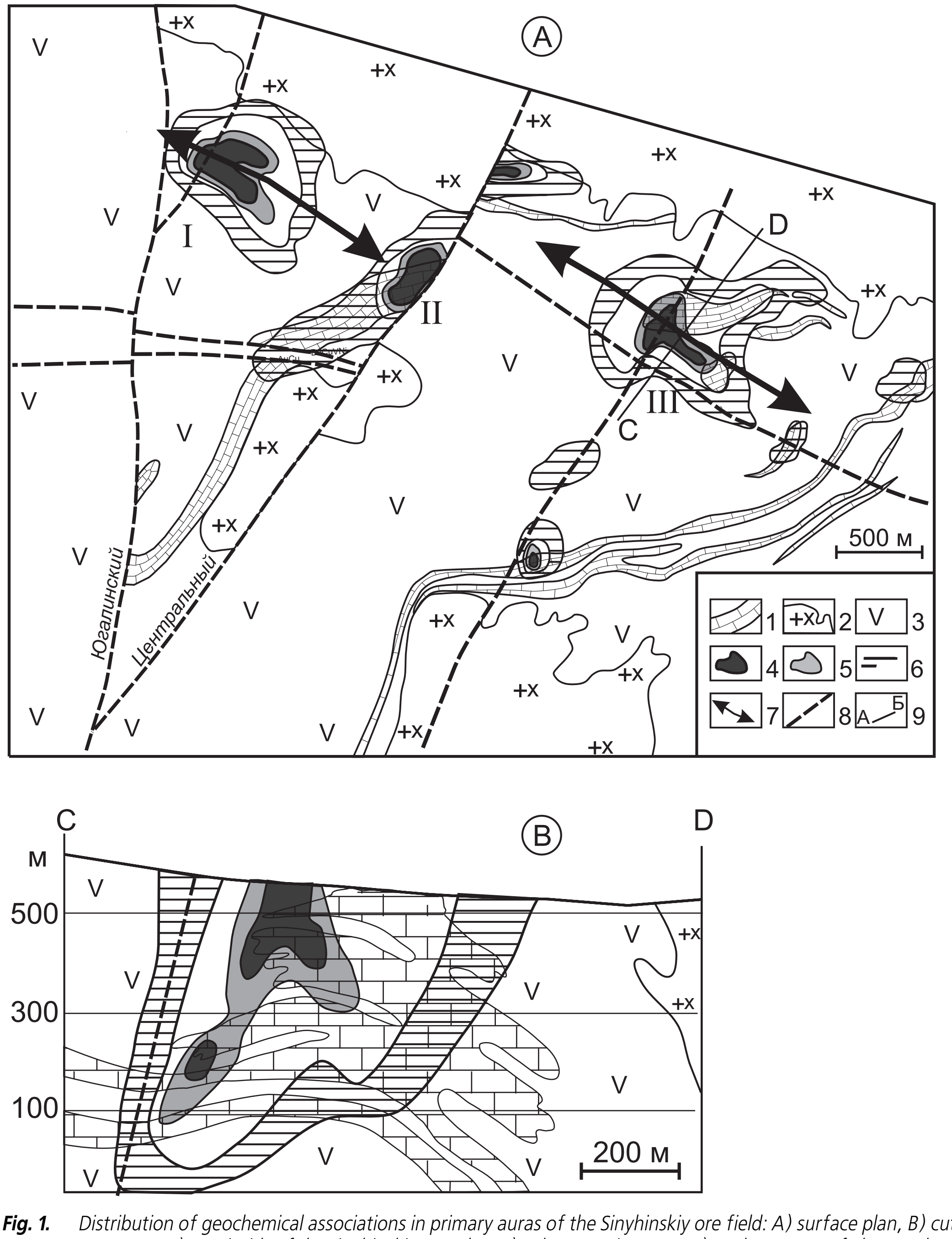

Fig. 1. *Distribution of geochemical associations in primary auras of the Sinyhinskiy ore field: A) surface plan, B) cut on a line CD: 1) limestones; 2) granitoids of the sinyhinskiy complex; 3) volcanogenic strata; 4) nuclear zones of abnormal geochemical structures represented by association Au, Ag, Cu (F1> 2,7) and corresponding to deposits: I) Western, II) First Ore, III) Faifanovskiy; 5) sites of association development Pb, Zn (F3> 3,62); 6) frontal zones of accumulation Co, Ni, V (F2> 8,8); 7) axes of anticlinal folds; 8) main brake infringements; 9) line of a cut*

monomineral fractions of pyrite from an external frame of ore bodies. In other sulphidic minerals the content of these elements is rather small. Anomalies F2 (higher than 8,88) border with gold-skarn bodies in plan and vertical cuts, therefore it is possible to consider the given association as the indicator of ore body periphery.

As a whole, within the limits of the Sinyhinskiy ore field three abnormal structures of geochemical field (ASGF) are geometrizing, corresponding to the most productive golden-ore sites (deposits): Western, First Ore and Faifanovskiy (fig. 1).

Nuclear zones of structures are presented by association Au, Cu, Ag which is bordered with parameter anomalies F2 (Pb, Zn). In frontal zones Co, Ni, V are accumulated. The most productive ore mineralization is dated to crossing knots of hinges of anticlinal folds by cross-section steep breaks. Similar character of geochemical association parity is also noticed in vertical cuts of deposits (fig. 1, B).

The choice of relative concentration coefficients (RC) of close in geochemical properties elements as indicators of zonality is caused by natural increase of their values and dispersions during evolution of hydrothermal systems [6].

Table 1. *Parameters of factors' values distribution (elements associations) in initial rocks, metasomatites and ores of the Sinyhinskiy ore field*

Rocks	F1=0,34Au+0,33Ag+0,32Cu			F2=0,52Ni+0,51V+0,28Co			F3=0,43Zn+0,34Pb		
	$\tilde{\tilde{X}}$	ε	Δ	$\tilde{\tilde{X}}$	ε	Δ	$\tilde{\tilde{X}}$	ε	Δ
Basalts, andebasalts	0,98	1,26	0,49...1,96	0,70	1,7	0,14...3,44	0,63	1,4	0,23...1,73
Limestones	0,96	0,04	0,46...2,01	0,66	1,8	0,11...3,85	0,62	1,7	0,13...3,05
Granodiorites	0,85	0,03	0,45...1,62	0,68	1,6	0,17...2,79	0,71	1,6	0,17...2,91
Near-skarn metasomatites	1,2	1,31	0,53...2,70	0,73	2,3	0,06...8,88	0,62	1,8	0,11...3,62
«nonore» skarns	1,2	1,28	0,57...2,52	0,71	1,8	0,12...4,14	0,65	1,6	0,16...2,66
«ore» skarns	35,0	4,4	0,4...2980	0,45	2,0	0,06...3,6	3,5	5,3	0,02...521

Note. *$\tilde{\tilde{X}}$ – average geometrical; ε – standard multiplier; Δ – spread of values at confidence probability 0,99*

Table 2. *Distribution parameters of coefficients values of relative concentration elements (RC) in rocks of the Sinyhinskiy ore field*

Rocks	RC					
	Co:Ni			Pb:Zn		
	$\tilde{X}$	ε	Δ	$\tilde{X}$	ε	Δ
Basalts, andebasalts	12,2	1,10	9,2...16,1	9,4	1,23	5,0...17,6
Limestones	7,8	1,10	5,8...10,5	9,1	1,26	4,5...18,2
Granodiorites	8,5	1,12	6,0...12,0	8,5	1,32	3,7...19,6
Near-skarn metasomatites	16,4	1,22	9,0...30,0	10,5	1,56	2,8...40,0
«nonore» skarns	18,6	1,39	6,9...50,0	12,2	1,60	2,9...50,6
«ore» skarns	55,3	1,67	11,9...256	35,4	3,24	1,0...1200

Note. *1) Relation of elements' content are normalized on their relation in chondrite; 2) $\tilde{X}$ – average geometrical; ε – standard multiplier; $\bar{X}$ – average arithmetic; S – standard deviation; Δ – spread of values at confidence probability 0,99*

Values of parameters in ore-bearing volcanogenic-carbonate rocks and ore-generating granitoids are close to clark parities. The minimal-abnormal values of parameters in these rocks are accepted by us as initial levels of their geometrization in metasomatites and ores (table 2). Values of considered parameters RC steadily increase in process of intensity growth of hydrothermal process and reach its maxima in sulfidized skarns. At the same time, in relation to golden-ore bodies RC anomalies take peripheral position, bordering them from flanks (fig. 2, I). Thus, the maximal values RC Co:Ni are characteristic for under-ore space, and RC Pb:Zn for top-ore-up-ore. Direct proportional dependence between RC parameters size and scales of golden-ore bodies has been also noted.

The energy of ore-formation $E=\Sigma[KK_i \cdot LN(KK_i)]$ characterizes general intensity of redistribution of chemical elements regarding clark levels. Here, KK_i – clark of an element concentration with number i [7]. As it is a question of elements redistribution within the limits of an ore field, concentration clarks are replaced by us on geophones. Geophones of unchanged volcanogenic-carbonate rocks and granitiods have been calculated according to element background contents in these rocks; therefore average value E is equal to 0. For skarns and near-skarn metasomatites the average background content in rocks of an initial substratum are accepted as a reference point. Theoretically dimensionless parameter E can take both positive (addition elements), and negative (their subtraction) values and at absence of elements essential redistribution aspires to zero. As only 2 element groups are fixed in an ore field, opposite in character to spatial parity with gold mineralization, it is expedient to calculate ore-formation energy separately for groups of concentrating (Au, Cu, Ag, Bi, As, Pb, Zn) and deconcentrating (Ni, Co, V, Ba) elements and to use them for quantitative estimation of substance redistribution scales.

Table 3. *Limits of parameters fluctuations of ore-formation energy for concentrating (E_{conc}) and deconcentrating (E_{deconc}) elements in rocks of the Sinyhinskiy ore field*

Rocks	E_{conc}	E_{deconc}
Basalts, andebasalts	–1,6...62	–0,7...8,5
Limestones	–1,8...68	–1,4...5,6
Granodiorites	–1,2...56	–0,7...7,5
Near-skarn metasomatites	–2,0...70	–0,5...80,0
«nonore» skarns	–1,5...50	–1,5...9,0
«ore» skarns	50...55000	–2,0...5,2

Calculation of background and minimum-abnormal levels for ore-formation energy by a standard technique [8] is impossible because of parameter negative values presence. Therefore, calculation of these borders has been made by proceeding from background and minimal-abnormal values for the elements participating in calculation of ore-formation energy. The calculated limits of a background for E_{conc} are wobbling from –2,0 up to 70, and for E_{deconc} – from –1,5 up to 9,0 (table 3). These borders have been taken by us as minimum-anomalous levels at values geometrization of ore-formation energy. An increase of an average value and dispersion of the calculated parameters has been observed in skarns and near-skarn metasomatites. Maximal values E_{conc} (up to 55000) are characteristic for golden-ore bodies, and minimal (up to –2,0) – for near-skarn metasomatites.

Positive anomalies of parameter E_{deconc} (up to 80,0) are characteristic for near-skarn metasomatites on periphery of skarn-gold bodies, the minimal values (up to –2,0) are marked in the central parts of ore bodies, which allows speaking about subtraction and redistribution of deconcentrating elements during ore deposition.

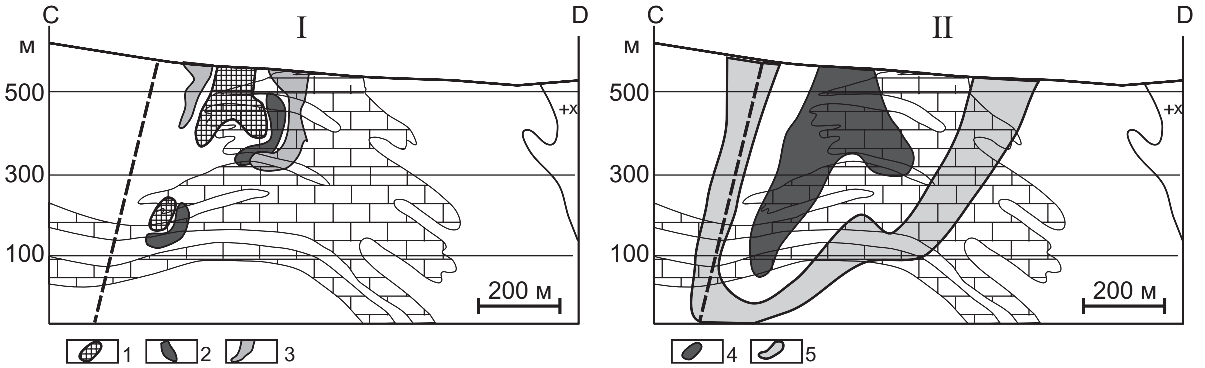

Fig. 2. *Distribution of anomalies I) coefficients of elements' relative concentration (RC) and II) ore-formation energy (E) in a cut through the Faifanovskiy deposit: 1) golden-ore bodies; anomalies of RC: 2) Co:Ni; 3) Pb:Zn; anomalies E_{deconc}: 4) negative (less than –1,5); 5) positive (more than 9,0)*

Conclusion

Skarn-gold deposits of the Sinyhinskiy ore field of the Altai-Sayansk folded area are accompanied by concentric zonal anomalous structures of geochemical fields. Centripetal character of zonality is expressed in change of early mineral paragenesis by late from structures periphery to their centers. Gold is the most closely connected with Cu and Ag.

With growth of intensity of hydrothermal process average values and dispersions of coefficients of relative concentration Co:Ni and Pb:Zn increase, anomalies of which are dated to periphery of ore bodies. Direct connection between the size of these coefficients and scales of golden-ore bodies has been marked.

The spatial antagonism in accommodation of concentrating (Au, Cu, Ag, Bi, As, Pb, Zn) and deconcentrating (Ni, Co, V, Ba) elements has been established. The intensity of redistribution of these elements groups, as a reflection of hydrothermal process scale, is suggested to estimate by means of quantity indicators of ore-formation energy.

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