Statistical analysis of the geological-genetic and search model based on geochemical data

Mamatxon Karabaev[1*], *Isomiddin* Togaev[2], *Elmurod* Amirov[3], and *Rustam* Sadirov[3]

[1]University of Geological Sciences, 64, Olimlar str., 100041, Tashkent, Uzbekistan
[2]National University of Uzbekistan named after Mirzo Ulugbek, 4 University str., 100174, Tashkent, Uzbekistan
[3]Institute of Geology and Geophysics named after Kh.M. Abdullaev, 64, Olimlar str., 100041, Tashkent, Uzbekistan

Abstract: Statistically reconstructed geochemical data on the main and additional elements in different types of rocks, ores and minerals of the Kyzylkum gold mine. Based on the research, editing the project on problems with modern analytical methods (ISP-MS, atomic absorption, etc.). The results of statistical processing of geochemical materials on the content of elements in rocks, ores, near-ore space and minerals showed that they can serve as the basis for creating geological and genetic models used for predictive purposes and identifying the features of the formation of mineral deposits in the region. This paper reveals the possibility of using the results of statistical data processing, by the nature of the distribution of the main ore elements in rocks, ores, near-ore space and minerals to identify the conditions of ore formation, typomorphic features of minerals on gold-rare-metal and gold-silver objects of Central Kyzylkum and the use of data for the development of geological and genetic search models. To solve the tasks, the results of about 6700 definitions of the main and related elements were statistically processed. At the same time, the following statistical parameters were revealed: average contents, degree of content, correlations, intensity of accumulation of elements in various samples that characterize the types of rocks, ores and their spatial manifestation.

1 Introduction

The use of geochemical data in geological surveys makes it possible to solve the most important tasks of exploration work - determining the prospects for mineralization in space [1-3], developing search criteria [4-5], and less often when compiling models of ore formation [6-7]. This paper discloses the possibility of using the results of statistical data processing, according to the nature of the distribution of the main ore elements in rocks, ores, near-ore space and minerals to identify the conditions of ore formation, typomorphic features of minerals in gold-rare-metal and gold-silver objects of the Central Kyzylkum and use data for development geological and genetic exploration models.

* Corresponding author: goodluck_0714@mail.ru

2 Main part

2.1 Research methods

About 6700 statistics of detection results of main and additional elements were processed to solve the specified tasks. At the same time, the following statistical indicators were determined: the average composition, the degree of composition, correlations, the concentration intensity of elements in different samples, describing the rocks, ores and their spatial appearance. We used quantitative analysis methods in date: mass spectrometry (ISP MS 7500 Series), microprobe (Superprobe JXA-8800R, Jeol), atomic absorption (AAS-3300; Perkin Elmar), and quantitative spectral analysis.

2.2 Research objects

Gold-rare metal deposits (Sarytau, Southbay) are spatially and genetically related to intrusive magmatism of C3-P1 age, the main rocks are sedimentary-volcanogenic rocks of the Kokpatas group (PR2 kp) and granitoids [4,8]. Gold-silver objects are located in the volcanogenic-sedimentary layers of the Besapan Mountains (O-S bs) of the Auminzatau Mountains (Shokhetau, Peschanoe, Karabugut on the northern slopes) and the Kokpatas Mountains (Kaskirtau) of the Bukantau Mountains. are limited to their regions. tectonic faults [9].

Geological position of research objects. The Central Kyzylkum mining and ore region is located in the South Tien Shan orogenic belt, which is a regional zone of shearing, shearing and crushing of sublatitudinal-northwest strike [10-11]. The formation of deposits took place in the period of 310-220 Ma, but the period of maximum ore deposition falls on 280-290 Ma, i.e. to the C_3-P_1 boundary [12-13], which confirms the conclusions about a certain synchronism of gold mineralization and granitoid magmatism [14].

It has been established that gold mineralization is superimposed on sedimentary-volcanogenic and igneous rocks of various compositions, from Precambrian to Upper Carboniferous - Lower Permian [12,15], and ore formation lasted about 60-70 million years. The studied Saritau and Sautbay gold-precious metal deposits are the fault of the South Bukantau SFZ, bounded by longitudinal long-range structural intersection nodes of the mantle or crust, and bounded by hidden transverse subsurface faults [8-9]. Mineral spatial and genetic discontinuity is associated with late Paleozoic granitoids and post-collisional outcrops of the main ore-bearing complex (C3-P1s) for South Bukantau.

Auminzatau gold objects (Peschanoe, Karabugut and Shokhetau) are located in the Auminza-Beltau subzone of the Zarafshan-Turkestan structural-formational zone [10]. The structural and tectonic position of the region is determined by the intersection node of regional fault systems that have a deep foundation - sublatitudinal systems (South-Auminzatau zone) and the Kospaktau fault zone of north-western strike [9,16-17], which controls the location of the main gold deposits (Zholdas, Peschanoe, Sentyabrskoe, and others).

3 Research results and discussion

Distribution of elements in different rock types

To identifying the relationship between the contents of elements and the conditions of rock formation, statistical processing of geochemical data was carried out for individual samples, reflecting rocks of various genesis (regional metamorphosed, contact metamorphic and metasomatic) and the composition of gold-rare metal deposits of the Bukantau

Mountains. It has been established [18] that significant contents of elements are confined to metasomatically altered rocks (Table 1), the formation of which is associated with postmagmatic hydrothermal solutions [19]. In theoretical terms, this means that the gold-rare metal mineralization of Eastern Bukantau is genetically related to the formation of granitoid intrusives, and in practical terms, similar ores can be predicted in connection with the aureoles of igneous rocks in favorable geological and structural positions.

Gold mineralization in the Central Kyzylkum is localized in rocks of a wide age range and different composition [12,15] and it seems to us that in the formation of deposits, the presence of a process that contributed to ore formation is most important, which should serve as the basis for judgments in matters of genesis and forecasting of similar deposits.

Table 1. Statistical parameters of the distribution of elements in various genetic types of rocks and ores

	Genetic types of breeds.												
	Regional metamorphic				Contact-metamorphic			Igneous			Postmagmatic (ore-bearing metasomatic		
Elements	**Carbonaceous shales**	**Carbonaceous flints**	**Vulcanite**	**Dolomites**	**Quartzite**	**Horn**	**Magnesium scarns**	**Granitoids**	**Diorite prophyrites**	**Lamprophyres**	**Quartzite**	**Aposcarnic**	**Greisen**
	Number of analysis												
	40	33	19	9	24	55	34	30	6	18	70	24	23
	Content of elements according to quantitative spectral analysis, g/t												
W	11	12	22	To 10*		23	21	21	34	28	2580	4020	1250
Mo	9.5	15	8	2	18	17	18	32	38	35	72	56	386
Sn	5	3	11	2.8	5	13	34	10	21	19	33	43	136
	Number of analysis												
	11	28	12	8	32	21	11	15	6	7	25	10	15
	Content of elements according to atomic absorption analysis, g/t												
Ag	0.60	0.39	0.5	0.3	0.13	0.13	0.18	0.25	0.3	0.3	0.4	1.37	3.56
Cu	73	47	98	38	46	62	137	42	87	83	60	200	420
Au	to 0.1*										0.3	1.05	0.42
Pb	to 10*								22	25	-	-	23
Zn	84	36	89		26		104	32		167	95	86	42
Bi	to 0.1*										3.1	7	5

* - below assay sensitivity

Distribution of elements in gold-rare metal ores (to the paragenesis of gold, tungsten and arsenic in ore formation).

An analysis of the works that dealt with the nature of the relationship between Au and W in endogenous ore formation shows that the conclusions are ambiguous. Along with information about the positive correlation of tungsten and gold in the East Bukantau deposits [2], it was found that in the Muruntau deposit, there is no stable relationship between them [5].

In this regard, let us turn to the distribution of the main and accompanying elements, especially the relationship between gold and tungsten, in the ores of the Sarytau and Sautba deposits.

The geochemical series of the intensity of accumulation of elements is as follows:

- Sautbay- Te-Bi-Au-Se-W-As- Ag-Sb-Mo-Sn-Cu-Zn-Pb;

- Sautbay - Te-Bi-W-Se-Au-As-Ag-Sb-Sn-Cu--Mo-Zn-Pb.

On both deposits, the maximum values of the degree of concentration in ores are characteristic of tellurium and bismuth, but at the Sautbay deposit, in the series of the intensity of accumulation of elements, after them is gold, and at Sarytau - tungsten, and then gold. This indicates the great importance of gold in the ores of the Sautbay deposit.

By analyzing the correlations of the main and accompanying elements in the ores of these deposits, it was established [18] that the elements that form stable positive bonds with gold are divided into the following groups according to their significance: **Au-Bi-Te** (0.90); **Au-As** (0.75); **Au-Ag-Se-Cu-Zn-Pb** (0.50)**;** **Au-W** (0.34); **Au-Sb** (0.28).

These relationships in groups correspond to the manifestation, at these deposits, of Au-rare-metal, Au-bismuth-telleride, Au-pyrite-arsenopyrite, Au-silver-selenide-polysulfide, Au-antimony mineral-geochemical associations, which in various proportions compose gold and gold -rare-metal ores of the Central Kyzylkum [11].

The values of the relationship of geochemical associations show that these deposits represent the most complete complex of sequentially manifesting ore-geochemical column and the main part of gold mineralization is Au-Bi-Te and less Au-As mineral-geochemical paragenesis.

The geochemical properties of Au, Bi, Te, and As have much in common in the ore process, which is reflected in the nature of their distribution. The difference between them is observed in relation to tungsten. So, for example, gold, at the Sarytau and Sautbai deposits, forms positive bonds with tungsten (0.23-0.43), and arsenic does not form significant bonds with tungsten, or forms negative relationships (Fig. 1).

This indicates that part of the gold was deposited in connection with the formation of scheelite mineralization, and bismuth, tellurium, and especially arsenic, which are closely associated with gold, began to concentrate after the formation of the main part of the rare metal mineralization.

The obtained geochemical data confirm the results of mineralogical studies on the study of the composition and temporal relationships of paragenic associations [18]

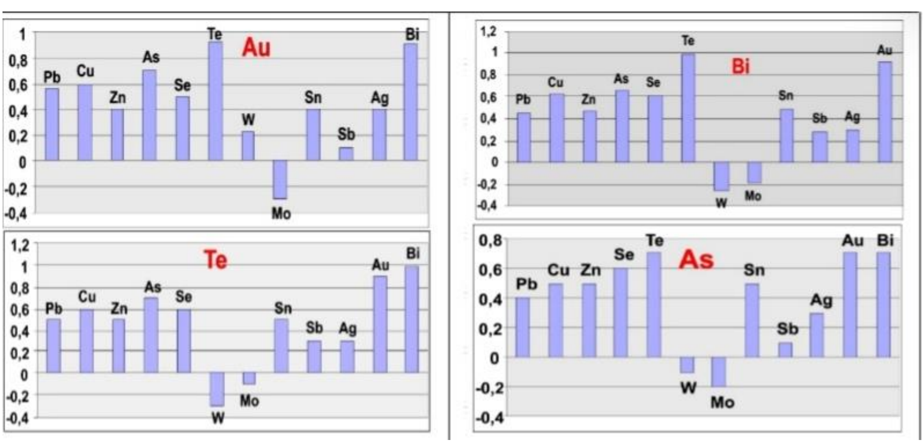


Fig.1. Histograms of correlation relationships of the main elements in ores of gold-rare metal

Statistical analysis of the spatial distribution of elements in gold-rare metal deposits.

Analytical data of well testing have been processed to determine the nature of the distribution of elements in the near-intrusive space of gold-rare-metal deposits, where the most significant ore bodies are located.

The conducted studies show that in the gold-rare-metal deposits, the main ore elements form dispersion halos in the exocontact part of the granitoid stock, where the values of most elements (tungsten, tin, gold, bismuth) are directly dependent on the distance to the contact of the intrusion (Table 2). This is also connected with the spatial and genetic connection of mineralization with the latter.

The identification of correlations of elements throughout the entire interval of the near-intrusive space (up to 350 m from the contact) showed the absence of stable and significant relationships. Therefore, statistical processing of data was carried out on separate samples, characterizing different distances from the contact of the intrusive, in itself, in order to identify changes in the geochemical relationships of elements.

It has been established that, at a distance from the ore-bearing contact, intrusions, the relationship of elements is mainly negative, which is due to the separation of ore-mineral associations of different times in space. Here, gold positively correlates with Cu, Zn, Ag, and Sb, indicating a more intense manifestation of silver-polysulfide-sulfosalt paragenesis.

Table 2. Statistical parameters of the spatial distribution of elements in gold-rare metal deposits (in parentheses are the correlation coefficients of elements in different zones

Removing from a contact a	Composition of host rocks	кол-во проб	Content of elements (in g/t)						
			W	**Mo**	**Sn**	**Cu**	**Bi**	**As**	**Au**
Intrusive before 300-350m	Colonic sedimentary	56	8	39	24	130	1	117	0.2
			(Au-W = -0.21; Mo-W=-0.35; W-Sn=-0.26; Au-Mo, Au-Sn, Cu-Mo, Sn-Cu=от -0.15 до -0.31; Au-Cu- Zn=+0.32; Au-Ag-Sb=+0.29)						
before 200-250m	Contact metamorphic	91	55	45	25	102	3	94	0.5
			(Au-W=+0.69; Au-Bi =+0.60;W-Cu=+0.43; W-Bi= +0.38; CuMo=+0,66;Cu-Sn=+0.21; Au-Mo=-0.31)						
before 80-100m	Ore-bearing metasomatic	96	240	40	54	98	10	86	1.1
			(Au-W=+0.72; Au-Bi=+0.71; Au-Mo=0.28; W-Cu=+0.44; Cu-Mo=+0.59; W-Bi=+0.36; Cu-Sn=+0.22; W-Sn=+0.25)						
Granodiorite porphyry Changed		30	100	38	10	70	5	74	0,4
			(Au-Bi=+0.69; Au-Cu=+0.75; Au-W=+0.51; Au-Mo=+0.57; W-Cu=+0.59; W-Bi=+0.32; W-Mo=+0.25; Sn-W=+26; Au-Sn=+0.39; Cu-Sn=+0.48; Mo-Cu=+0.31)						

In the near-contact parts of the intrusive stock, stronger positive bonds are noted between most pairs of elements. Significant positive bonds of gold with bismuth and tungsten indicate a greater manifestation of gold-rare-metal and gold-bismuth (with tellurium) associations here, which is a reliable evaluation criterion for industrial ores. In the rear part of the ore zones, there is a positive correlation of gold with tungsten and bismuth, in the flanks with arsenic and at a distance with silver and antimony.

The established change in the relationships in the distribution of the main elements (Au, Bi, Te, As, W) is determined by the regular zonal distribution of various mineral-geochemical associations of a single ore-forming system. From the center to the periphery, the relationships of gold change in the series Au-W, Au-Bi-Te, Au-As, Au-Ag-Sb.

The variability of the correlations of gold with other main elements in gold-rare metal deposits is due to the formation of gold mineralization in the Central Kyzylkum, stretched in time and space, consistently manifested by mineral-geochemical associations.

At the same time, the different spatial manifestation of these associations, in separate parts of the deposits, determine the nature of the relationship between the main components of the ores.

The geochemical association of gold, bismuth and tungsten at the sites indicates the scale of ore formation processes and the industrial significance of ores, which is noted at the Muruntau, Zarmitan [9,20] and Sarytau-Sautbay deposits. Statistical analysis of the spatial distribution of elements in gold-silver deposits

Statistical processing of geochemical data was carried out on two samples - in the supra-ore and ore-bearing zones of gold-silver deposits (Table 3).

The geochemical series of intensity of accumulation of elements of the supra-ore zone has the following form:

*(Te- Se-Sb-**Au**-Ag-As)-Mo-Pt- W- Bi- Zn- Cu- Sn- Pb- Ni- Co.*

Table 3. Statistical parameters of the spatial distribution of elements in deep (PR) and surface (SR) parts of gold-silver deposits

	Shokhetau		**Sandy**		**Karabugut**		**Kaskyrtau**		Average for all of them	
	Number of samples									
	56	62	42	51	50	43	39	72	187	228
	The degree of concentration of elements									
	PR	OR	PR	OR	PR	OR	PR	OR	PR	OR
Au	73	142	135	306	42	110	95	344	86	225
Ag	31	25	79	52	47	31	40	23	49	33
As	29	26	85	1,8	52.4	25	55	71	56	31
Se	82	118	267	218	211	77	242	161	201	144
Te	280	240	330	200	310	180	240	201	290	205
Sb	78	48	115	101	77	34	95	599	91	196
Bi	5.6	1.5	6.3	2	5.6	1.5	6.3	1.3	6.2	1.6
Pt	10	12	10	14	8.5	7.2	8	8	9.1	10,3
Cu	1	0.9	2.6	2.4	2	1.1	2.2	1.2	2.0	1.4
Pb	1.1	4.4	1.8	1.6	1.5	1.2	1.7	0.7	1.5	2.0
Zn	1.6	1.6	2.6	5.1	2.3	1.6	2.5	0.7	2.3	2.3
W	5.3	5.5	6	2.6	6.7	1.2	6.1	1	6.0	2.6
Mo	9	6.9	37	16	32	9.7	28	8.4	27	10.3
Sn	1.8	1.1	1.6	1.2	1.8	1.4	1.5	0.8	1.7	1.1
U	21	9	24	12.6	19.6	10	18	13.7	21	11.3

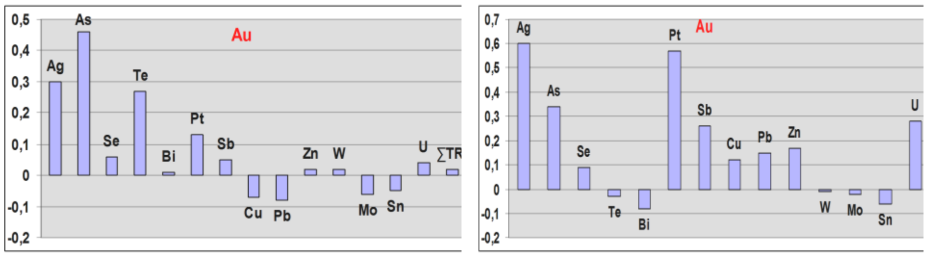
The main part of the elements in this series, highlighted in brackets and strong positive relationships in the Sb-Cu-Pb-Zn-Ag group, indicates the intensive manifestation of the silver-gold-antimony (with Se and Te) mineral-geochemical association in the more remote parts of the ore formation.

In samples taken from the inner part of the ore-bearing zones and the nearest side space, there is a sharp increase, compared with the supra-ore zones, in the contents of silver and gold (by 2-3 times). The average content of arsenic increases by 8 times, indicating a greater importance of the gold-arsenic geochemical association in ores. A number of intensity of accumulation of elements in ore zones: - (Te-Se-Au-Sb-As-Ag)-Pt-Bi-Cu-Zn-Pb.

Directly in the ore bodies and in the nearest near-ore space, gold forms a strong positive relationship in the distribution in two groups (Fig. 2): very strong with arsenic (0.91) and less with silver, tellurium, zinc and antimony (0.40- 0.52). This clearly indicates the manifestation of gold-arsenopyrite and silver-gold-sulfosalt associations of ore formation, which indicates the manifestation of meso-epithermal mineral formation and upper ore levels of mineralization in the studied objects.

Stable geochemical criteria for predicting gold mineralization in areas with gold-silver mineralization are (except for gold) arsenic, selenium, antimony, silver and tellurium. Ore zones with industrial potential are characterized by high levels of arsenic, which directly correlates with gold.

The nature of the distribution of elements in the surface (oxidized) ores of gold-sulfide objects is also studied from individual data samples, since they differ in the conditions of formation, which determine the geochemical features of the elements and the forms of occurrence of useful components, as well as the technological properties of the ores. Geochemical series of intensity of accumulation of elements in surface (oxidized) ores: Au-Te-Sb-Se-Ag-As-Mo-Pt-U-W-Zn-Pb-Bi-Cu-Sn.



a b

Fig.2. Histograms of gold correlations in the lower (endogenous mineralization; a) and surface (exogenous mineralization; b) parts of gold-silver deposits

Comparison of the nature of the distribution of the main elements on the surface of mineralization and oxidized ores developing on them (Table 3), shows the fact of enrichment of ores (on average 3-5 times) in the oxidation zone.

The maximum values of the degree of concentration are typical for gold, indicating that gold accumulates much more intensively in the ore oxidation zone, compared to other elements, which is associated with its geochemical features. When sulfides were replaced by secondary minerals, dispersed gold was released and concentrated in the native form.

Interesting is the strong positive relationship between gold and platinum (see Fig. 2), although the content of the latter in the ores is not high (the average degree of concentration is 10), which is associated with the accumulation of platinum together with gold in the ore oxidation zone.

In oxidized ores, the degrees of concentration of arsenic (by 45%), selenium and tellurium (by 30%) decrease in comparison with primary ores, indicating the transfer of a part of the content of these elements from the oxidation zone. The antimony content is more than double that of the primary ores, indicating a tendency for antimony to accumulate here.

4 Distribution of elements in minerals

On studying the typomorphic features of minerals, we widely used statistical processing of geochemical data - the results of the analysis of the main minerals, which allows us to obtain a digital characteristic of the features of minerals:

- in the pyrites of the gold-silver objects of the Auminzatau and Bukantau mountains, strong positive correlations of gold with arsenic (0.81 on average) were established, which statistically confirms the previously known pattern - elevated gold contents in pyrites are characteristic of their arsenic varieties;

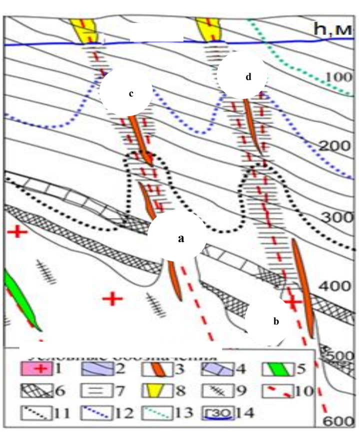
-the existence of positive correlations in the Au-As-Co-Ni group (0.41-0.73), in sulfides, indicates the genetic relationship of these elements in the processes of ore formation (especially epithermal) and, along with arsenic, Ni and Co can serve as a search evaluation criterion of gold-silver mineralization;

-Ni/Co ratio in pyrites is considered to be their type feature. By comparing the quantitative values of Ni/Co in pyrites from the productive associations of gold ore objects of the Central Kyzyl Kum (115 determinations for each element), with different industrial potential, digital indicators of the established relationships were obtained. Thus, in the large deposits of Muruntau, Sarytau, Sautbai, Daugyztau, Vysokovolnoe, this indicator is the highest (equal to 3-5). In less significant gold objects (Shohetau, Kaskyrtau, etc.), the Ni/Co ratio decreases (2-2.2). Ni/Co is minimal in metamorphogenic pyrites, as well as in pyrites from lamprophyre dikes (up to 0.5);

- statistical processing of the results of the analysis of ore minerals makes it possible to reveal the nature of the presence of a certain element in the composition of the mineral. If the elements are mineral-forming (main components), naturally, a negative relationship is observed between them. A negative relationship is also observed between the main component of the mineral and a separate element, if the latter isomorphically replaces it in the structure of the mineral. When the same elements are included in the composition of other ore minerals as an impurity, the relationship between them is positive;
- established positive relationships in the Au-Ag-As-Ni-Sb-Se group, in sulfides, reflect the nature of ore-forming solutions of epithermal deposits;
- -positive correlations of Te with Au, Ag and Sb (0.65) and especially with Cu (0.96) indicate the existence of close geochemical relationships of elements in the formation of meso-epithermal gold associations. In gold-rare-metal deposits, Te, in the composition of minerals, forms positive bonds with Bi.

The indicated geochemical features of minerals are search and evaluation criteria.

The data obtained formed the basis for the development of a predictive-exploratory model, which systematized the main geological and geochemical features of gold-rare metal and gold-silver mineralization of the Central Kyzylkum (Fig. 3).



Geochemical associations	Correlation of elements and their groups
Gold hydroxide	Au-As-U-Sb=0.5; Ag-Au-Pt=0.6
Gold-silver-sulfosalt	Cu-Te=0.5; Ag-As=0.4. Hg-Se-Sb =0.5
Gold-telluride-polymetalic	Au-Te-Cu=0.5; Au-As-Ag=0.4. Au-As-Te =до 0.5
Gold-arsenic	Au-Ag=0.5; Au-Zn,Sb=0.5 Au-As=0.9
Gold-bismuth	Au-Bi=0.7 Au-Wi=0.6
Gold rare metal	Au-Mo=0.6 Au-W=0.7 Au-Bi=0.7

Fig. 3. Predictive-search model of gold-rare metal and gold-silver mineralization of the Central Kyzylkum. Symbols: 1-granitoid intrusion; 2-volcanic-sedimentary rocks; 3 dikes of various compositions; 4-skarn carbonates; ore bodies: 5-greisen-rare metal; 6-aposkarn-rare-metal; 7-gold lower parts (endogenous);; 8-gold ore on the surface (exogenous); 9-quartz-feldspar veins; 10-fault zones and increased fracturing; 11-halos of location of geochemical associations 11-gold-rare metal; 12-gold-arsenic with gold-polymetallic; 13-gold-silver-sulfosalt; 14-boundary of the oxidation zone.

The fundamental basis of the model is an important genetic basis, revealed in the statistical analysis of geochemical data - each type of mineralization is characterized by a certain average content, degree of concentration in ores, correlations of elements that change in space and are due to their formation at different levels of the ore-forming column. The indicated statistical parameters of the distribution of elements reflected in the models of their manifestation and spatial distribution are the predictive basis for prospecting for gold deposits in the region.

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5 Conclusion

The possibility of using the results of statistical processing of geochemical data on the distribution of the main and accompanying elements in various geological systems has been established to solve the genetic issues of the formation of deposits and create predictive models in the search for minerals.

At the same time, statistical processing and analysis of geochemical information should be based on the genetic basis for the formation of the object of study - ore clusters, deposits, rocks, ores and minerals that make them up. Since the genetic features of the object determine the composition, value, nature of the spatial manifestation and other properties of statistical features, and only in this case the results obtained acquire a geological meaning and can be used in prospecting and evaluation work.

Mass processing of geochemical data in geological surveys, analyzed without making appropriate samples, turn out to be uninformative and, as a result, less effective for practical purposes. It is necessary to rank (dismember) the object of research according to various qualities and draw up separate data samples. The latter may reflect different types of rocks, ores, space groups, varieties or generations of minerals, etc.

Some aspects of this approach to statistical data processing and the results obtained are given above as examples of the application of geochemical surveys.

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