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GEOCHEMICAL PECULIARITIES OF THE FILIZCHAY PYRITE-POLYMETALLIC FIELD (GREATER CAUCASUS)

(Представлено членом редакційної колегії д-ром геол. наук, доц. Сергієм ШНЮКОВИМ)

Background. The structural position of the Filizchay deposit is defined by its confinement to the junction region of the northern flank of the Karabchay coffer-shaped anticline with the Kekhamedan upthrow-thrust being complicated by the Belakanchay local transverse inversion uplift. The main elements of the deposit structure are: the core of the Karabchay anticline, its northern flank and part of the Kekhamedan shear zone which are covered by the indicated transverse uplift. The peculiarities of these main elements of the structure determine the main features of the Filizchay deposit structure.

Methods. More than 2000 analyses from exploration wells were used in the article. 3D geochemical models were built for separate elements on the basis of the Leapfrog GEO program. Analytical work was carried out by the X-ray fluorescence method in the laboratories of the Geological Service of the Ministry of Ecology and Natural Resources of Azerbaijan.

Results. The article has been devoted to the distribution of the main ore-forming components in Filizchay field of the southern slope of the Greater Caucasus. 3D model of the mineral elements of Filizchay field has been using "Leapfrog GEO" program. Analysis of the iso-thicknesses map clearly shows that the eastern flank of the deeper, shallow dipping part of the deposit is characterized by the greatest thickness where its thickness exceeds practically universally average value of this parameter according to the field. It has been found that zinc and lead distributions repeat practically each other. The western half of the body differs sharply from the eastern half by stable high (more than average value) contents. The overwhelming majority of zinc concentrations minimums and nearly all lead minimums are located in the eastern half which is generally characterized by the contents being below average. According to the copper concentrations distribution the deposit is very clearly divided into two parts – the southeastern part being thicker and richer and the northwestern part being relatively less thick and with contents being below average according to the field. The comparison of silver and lead isocontents' maps indicates a close relationship of both elements as evidenced by the very similar nature of their spatial distribution within the deposit. As for lead one can generally distinguish two halves in it that are generally differed from each other in the intensity of the silver mineralization - the northwestern being richer and the southeastern being relatively poorer. The boundary between these parts repeats mainly the boundary determined for lead not only according to the spatial position but also according to the main details of the outline. All the maxima of the silver mineralization are located in the northwestern half of the field, the most of which are located on the upper horizons. According to the intensity degree of the zinc, lead and silver mineralization manifestation in the deposit, two parts can be distinguished: the western one is richer where almost all maxima are concentrated and the eastern one is poorer which accounts for the most of the minima. The boundary between them passes approximately in the middle part of the body from the upper to the lower horizons; it nearly coincides with the direction of its fall and it is distinguished by complex outlines. The frequent isolines repeatability of the zinc and lead contents, the close spatial position of their maxima centers suggest a close positive correlation between them.

Conclusions. The Filizchay field developed over a long period, starting from the sedimentation period and up to the formation of ores of copper-pyrrhotite stage. The lower age limit of mineralization is determined by the occurrence of the Upper Pliensbachian hydrothermal-sedimentary ores. The upper age limit is identified by the presence of pebbles of hydrothermally altered rocks and their sulphide ores in conglomerates underlying the lower Upper Jurassic sediments.

Keywords: Filizchay field, the southern slope of the Greater Caucasus, 3D model of elements, "Leapfrog GEO" program, distributions of zinc, lead, copper, silver.

Background

The southern slope of the Greater Caucasus is one of the richest areas in the South Caucasus in terms of polymetallic fields of zinc, lead and other components. From this point of view, the Filizchay pyrite-polymetallic field of the Greater Caucasus is of great interest, as it is a valuable source for the extraction of zinc, lead, silver, as well as associated components such as gold, cadmium, indium, copper, tin, bismuth, antimony, selenium, tellurium, etc.

Despite the fact that the field of the southern slope of the Greater Caucasus has been sufficiently studied, a 3D geochemical model for separate ore elements has not yet been built that would clearly reflect all the main peculiarities of the geological structure of the modeled area of the field. It

is possible to solve many issues with its help – to give a more accurate calculation of ore and metal reserves, to design the next exploration and survey underground mining workings.

So, the development and building of geological and genetic 3D models of ore-forming systems based on geochemical data of drill holes is a new stage in the study of pyrite fields.

The main purpose of the presented article is to build a 3D model for separate ore elements based on a detailed comprehensive geological-mineralogical-geochemical study of ore deposits and separate ore-forming minerals, identify geochemical anomalies and geochemical zoning based on the element concentration ratios. To answer these questions, it is required to study the distribution of trace

elements in ores in order to determine the geochemical zoning along updip ore deposit, geochemical anomalies and to construct a geochemical 3D model for separate ore elements (Zn, Pb, Ag) using the Leapfrog GEO program.

The ore fields of the southern slope of the Greater Caucasus, in particular the Katsdag-Filizchay ore cluster, which includes the Filizchay field, have been studied by many researchers (Agayev, Velizade, & Novruzov, 2005; Baba-zade, & Agayev, 1999, 2005; Geology of Azerbaijan, 2005; Smirnov, Chernitsin, & Ivanov, 1973; Kurbanov, 1986; Kurbanov, Zaitseva, & Gadzhirev, 1976; Novruzov, & Agaev, 2009, 2012; Novruzov, 2011; 2016; Novruzov, & Sattar-zadeh, 2015, 2019; Tvalchrelidze, 1983, Tvalchrelidze, & Ismailova, 1964; Kholodov, & Kiknadze, 1989).

The geological setting of the ore cluster is determined by its arrangement on the western flank of the Balakan-Zagatala ore region (Fig. 1) (www.googleearth.com), where it is confined to the junction area of the Tufan and Mazim-Saribash subzones along the Kohnamedan depth fault zone. The upper (Filizchay series) and lower (Murovdag series) Pliensbachian and upper Toarcian (Jikhikh series) terrigenous sediments are exposed within the ore cluster of the Tufan subzone, which form the Katsdag linear anticline of the first order, which hosts the field of the same name. The lower (Balakan series) and upper (Filizchay series) Pliensbachian and Toarcian sediments (Gubakh series) expose in the Mazim-Saribash subzone, crushed into the Karabchay box anticline, which hosts the ore deposit of the Filizchay field (Fig. 2, 3).

Before proceeding to the lithological and stratigraphic characteristics of the section of the Lower Jurassic terrigenous sediments of the field area, let us briefly review the petrographical peculiarities of the main lithological varieties of rocks.

The clay shales occupying the main volume of the rocks at the Filizchay field are characterized by black, grayish-brown and less often greenish-brown color. Typical structures are pelitic and silty-pelitic. The structures are typically microlepidoblastic with a thin-banded and fibrous-banded texture in metamorphized, thinly laminated varieties (up to phyllites) due to the alternation of submillimeter bands of micas (usually muscovite, sericite, less often chlorite) and dark-brown anisotropic particles. Thinly laminated and micro-laminated textures are also observed. Besides pelitic matter, clay shales contain detrital, authigenic and organic components.

Silty-clayey shales and siltstones are characterized by silty and silty-pelitic structures; the texture is often microbanded, laminated, schistose, micro-curved. A blastoleurolitic structure with a microlepidoblastic structure of cement is observed in metamorphized varieties.

Sandstones belong mainly to small- and medium-grained varieties (up to 60 %) with fragment sizes from 0.1–0.25 to 0.5–1.5 mm. A characteristic feature is the weak rounding of the fragmental material and sorting, the shape of the grains is elongated, less often isometric (up to 30 % – fragments). Sometimes there is an admixture of fragments of siltstone material (10–15 %), cement, which makes up to 50 % of the rock. Quartz is heterogeneous in composition and structure: feldspar, chlorite-sericite-quartz, mica-clayey, mica-siliceous-clayey, clayey-sericite-siliceous.

The sediments of the Filizchay series are represented by a stratum of dark-grey, almost black clay shales, alternating in the form of sequence with units of sandy flyschoid (Fig. 2). This stratum hosts the deposit of the same name, protruding in the core of the Karabchay anticline in the form of a

relatively narrow strip. The base of the strata in the area of the field is not undercut and is established only within the Katsdag-Filizchay ore cluster.

Sediments of the Filizchay series are replaced by the Gubakh sediments up the section, which are divided into two strata: sandy-shale and clayey-shale (Fig. 2). The first of them ($J_{1t^{1+2}}$) plays the role of a supra-ore strata at the field and occupies about half the area of outcrops of the Toarcian sediments. It overlaps conformably the third (upper) ore-bearing sequence of clay shales along the entire sublatitudinal strike, which is the most ancient for the field of the Filizchay series, composing a relatively low northern flank of the Karabchay anticline (Baba-zade, & Agaev, 1999; Kurbanov, 1986; Novruzov, & Agaev, 2012; Baba-zadeh, Agayev, & Chelebi, 2005).

The Toarcian terrigenous complexes of the Tufan structural-formational subzone are exposed further to the north, from the side wall of the Kohnamedan thrust-reverse zone, represented by two strata: clay-shale ($J_{1t^{1+2}}$) and sandy-shale ($J_{1t^{1+2}}$) of the Murovdag series (Agayev, Velizade, & Novruzov, 2005; Baba-zade, & Agayev, 1999, 2005; Geology of Azerbaijan, 2005; Smirnov, Chernitsin, & Ivanov, 1973).

It should be noted that the rhythmic structure of the sections has a defined flyschoid character, most fully represented in the flyschoid units of the Filizchay series of the upper Pliensbachian and least strongly in the Murovdag series of the lower Toarcian. The amount of sulphide impregnations, concretions and nodules (mainly pyrite composition) increases regularly from top to bottom from the Toarcian to the Pliensbachian, reaching a maximum in the third pack of Pliensbachian clay shales (the Filizchay series), which contains the stratiform pyrite deposit of the field.

The main peculiarity of the morphology of the pyrite-polymetallic deposit of the Filizchay field is that it is a single, compact sheet-like body, composed mainly (90–95 %) of aggregates of sulfide ores, the basis of which is pyrite and to a much lesser extent sphalerite, galena, chalcopyrite and pyrrhotite. Carbonate minerals play a subordinate role in the deposit composition, and quartz, sericite and chlorite play an even smaller role.

The ore body is deposited among monotonous clay shales of the upper, third sequence of the Filizchay series. The deposit is confined to a thick ore-bearing horizon here, the boundary of which is laterally determined by the boundaries of the Balakenchay transverse uplift, where ore-bearing clay shales are replaced by sandy flyschoid.

The structural position of the sheet-like pyrite deposit is determined by its confinement to the central part of the northern flank of the Karabchay anticline of sublatitudinal strike. The deposit extends with an azimuth of 80–85° and dips along the general dip of the northern flank to the north-northwest 350–355° at an average angle of 35–45°. The western and eastern boundaries of the deposit are the most extended transverse flexural bends, complicating the northern flank of the anticline in the west and east, respectively.

The following main mineralogical and textural varieties (natural types) are typical for pyrite-polymetallic ores of the field: laminated-banded pyrite-polymetallic, massive sulfur-pyrite, massive pyrite-polymetallic, spotted-impregnated pyrite-polymetallic and veinlet-impregnated pyrite-polymetallic. Veinlet-impregnated ores are adjacent to the deposit from the side of the footwall and are considered as independent bodies (Baba-zade, & Agayev, 1999).

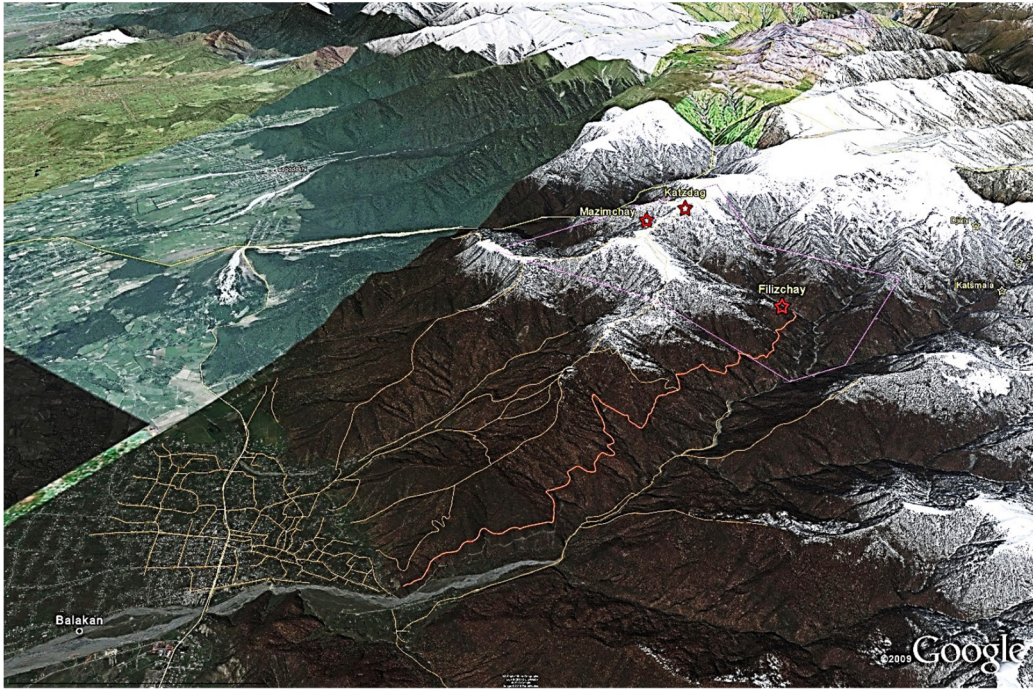


Fig. 1. Location (North-East to South-West view) of the Filizchay field area (www.googleearth.com)

System	Stage	Epoch	Series	Index	Column	Thickness	Characteristics of rocks
Jurassic	Lower	Toarcian	Gubakh	J ₁ t _{1,2}		750-970	Sandstones are massive, fine-coarse-grained (thickness from 2-3 to 10-20 m) with units of clay shales, are interchanged in the area by alternating layers of fine-medium-grained, sorted sandstones (thickness from 1-2 to 3-5 m), units of clay shales (from 10 to 30 m) and packages of fine and coarse flyscholds (from 5 to 20 m)
						550-710	Clayey and silty clayey shales with units of fine- and coarse-rhythmic sandy-argillite flyscholds (from 10 to 70 m and more) with four ore-bearing horizons. The Filizchay ore deposit (shaded) is confined to the upper (4) horizon
		Pliensbachian	Balakenchay	J ₁ p ₁		450-530	Alternating units of fine-medium-grained sandstones (20-50 m), fine and coarse flyscholds (from 10 to 80 m) and unit of clay shales containing horizons of clay-siderite concretions (from 40 to 100 m or more)

Fig. 2. Stratigraphic column of ore-bearing sediments of the Filizchay-Attagay facial subzone of the Saribash structural-formational zone (southern part of the Katsdag of Filizchay ore cluster). Scale 1:10,000 (compiled by N.A. Sattarzadeh)

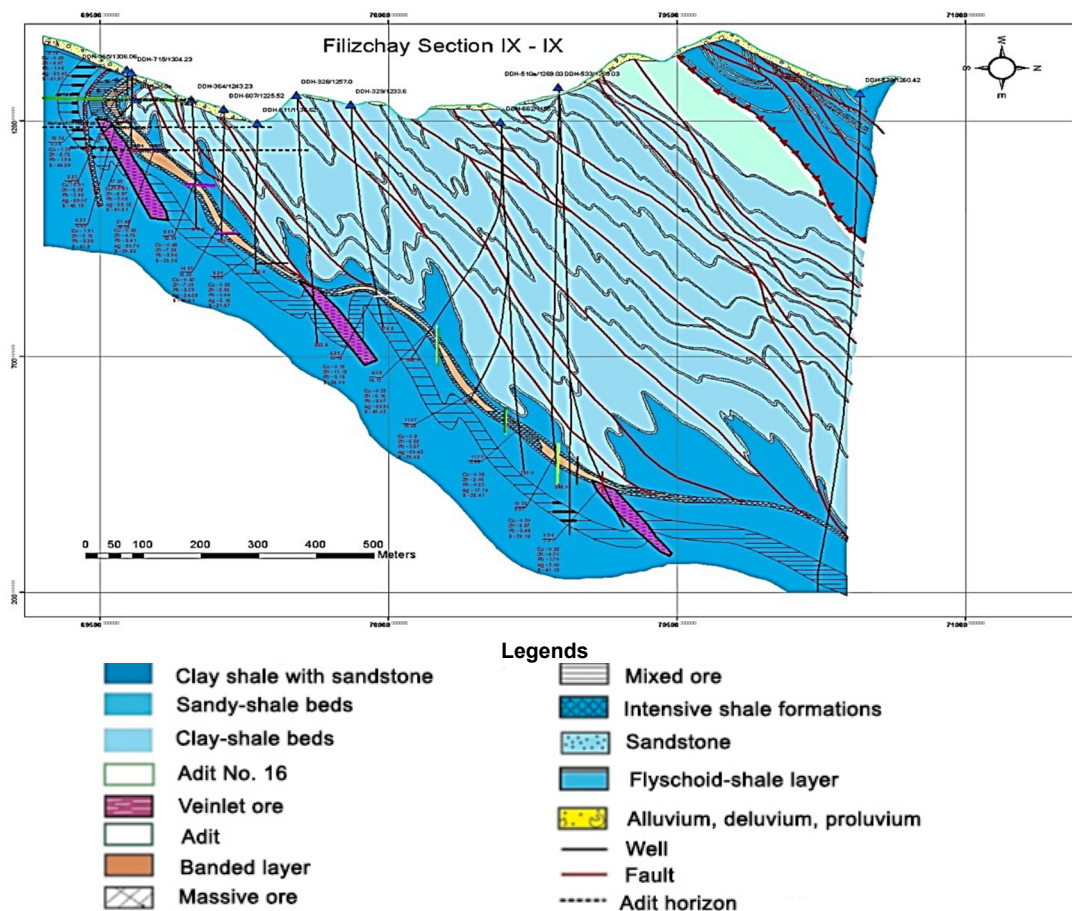


Fig. 3. Schematic geological section of the Filizchay field

Methods

More than 2000 analyses from exploration wells were used in the article. 3D geochemical models were built for separate elements on the basis of the Leapfrog GEO program. Analytical work was carried out by the X-ray fluorescence method in the laboratories of the Geological Service of the Ministry of Ecology and Natural Resources of Azerbaijan.

Results

The main work phase when creating a 3D model is the precise checks of the entered data. When creating the model of the Filizchay field, it turned out that a minimal error yielded large anomalies. It took more than 2 months to find and correct the errors. In the end, all data was corrected and entered quite accurately.

The corrected data is displayed in 3D space, and you can once again check the well pattern and the correctness of the display of the geological setting.

After creating a 3D model of the selected elements of the Filizchay field, a geochemical model is built for separate elements or for a set of certain elements (for example, Cu+Zn+Pb). This block diagram can be rotated in different directions and view the full 3D model of the field. There are some shortcomings that do not allow the model to be expanded and various geological layers to be viewed. But the Leapfrog GEO program eliminates these shortcomings. The model reflects clearly all the main peculiarities of the geological structure of the model area of the field.

According to this program, we have created a 3D model of the deposit of the Filizchay field. The geological structure of the field is represented by a three-dimensional model of ore elements (3D model) (Fig. 4). Using a 3D model and structures embodied in the integrated Leapfrog GEO software

package (www.leapfrog3d.com), a mineralogical and geochemical model of one ore deposit at different azimuths was created. This model can be used to calculate the ore reserves and its metals. Many issues of designing the next exploration and excavation underground mine workings can be solved with its help. This model reflects much more clearly all the main peculiarities of the geological structure of the modeled area of the field.

Below are the spatial distributions of valuable components Cu, Zn, Pb (Table 1, Figs. 5–7), their sum, as well as the distributions of S and Ag for the Filizchay field, created using the Leapfrog GEO program.

There is a certain pattern in the distribution of ore-forming components and trace elements in the deposit, which is associated with the general scheme of mineralogical zoning. The issues of zoning of ore deposits of pyrite and pyrite-polymetallic fields and the patterns of distribution of the main and trace elements in them are covered in numerous publications (Smirnov, Chernitsyn, & Ivanov, 1973).

It has been established that regional ore zoning is observed in the Azerbaijan part of the southern slope of the Greater Caucasus, as it moves from the northwest to the southeast, expressed in the shift of chalcopyrite-pyrrhotite ores by pyrite-polymetallic ores, as a result of which there is a decrease in the copper concentration and accordingly, an increase in the amount of zinc and especially lead (Agayev, Velizade, & Novruzov, 2005; Kurbanov, 1986; Kurbanov, Zaitseva, & Gadzhirev, 1976; Novruzov, & Agaev, 2009, 2012; Novruzov, & Sattar-zadeh, 2015, 2019). Alteration of the mineral composition of ores are reflected in the distribution patterns of trace elements, as well as in the values of indicator ratios of components.

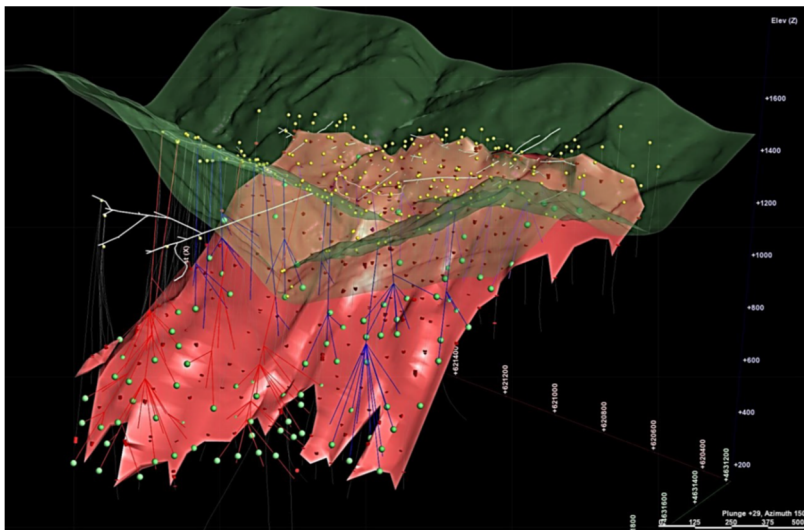


Fig. 4. 3D model of the orebody of Filizchay fdeposit. Viewpoint from South-East to North-West (using the Leapfrog GEO program)

Table 1

Analysis of combined samples for compiling a geochemical model of the Filizchay field

Well No.	Size, m	Cu, %	Zn, %	Pb, %	S, %	Ag, ppm
26	117,3–126	0,48	10,5	3,95	40	90
30	400,9–411,9	0,3	9,9	5,75	42,9	140
56	409–412	0,29	3,74	0,88	42,9	90
57	383–388,3	0,68	3,3	1,2	38,9	25,8
67	554,3–564	0,56	4	1,47	38,9	29
68	303–309,5	0,81	3,88	1,5	41,8	44
70	253,8–264,5	3,7	0,55	0,28	39,5	150
310	189,2–199,1	0,51	7,12	3,3	45,5	43,4
312	119,7–131	0,7	6,25	2,55	39,1	48
314	251–260,3	0,53	4,12	1,74	36,8	36,8
315	151,1–163	0,55	3,85	1,6	38,2	43,8
342	303,9–313,3	0,63	1,63	0,44	35,3	22,6
349	385,9–391,5	0,8	2,2	0,76	38,7	36
360	134,6–144,5	0,53	5	1,9	43	62
374	202–216,4	0,53	6,75	1,65	42,7	36
404	335–346,6	0,41	4,75	2,24	43,6	46
416	86,1–90,4	0,3	2,24	0,24	29,3	25,6
443	458,3–469,4	0,8	1,81	0,55	36,7	23,2
444	290,6–303,6	0,48	4,95	1,42	39,5	60,3
469	302,8–316,3	1,22	2,57	0,64	36,3	9,1
515	756,3–762	0,53	3,65	1,87	45,1	80
528	505,6–513	0,48	2,7	1,55	29,7	46,6
555	657–661,6	0,34	0,8	0,22	30,5	40
558	199–206	0,78	2,9	0,96	40	24,6
560	860,8–864,9	0,4	1,57	0,27	42	21
575	781–785	0,43	6,6	0,52	37,2	47,2
583	876,2–877,1	0,47	1,16	0,71	42,4	3,1
584	664–667,2	0,9	1,84	0,42	34,6	20
592	756–762,8	2,4	1,05	0,08	38,5	10,4
594	952–960	0,63	0,13	0,28	45,8	28,8
600	836,1–844	0,42	1,73	0,44	37,9	16
605	188,8–192,9	0,42	5,39	1,82	37,3	72
606	197,6–202,6	0,32	8,25	3,09	41,1	71,4
608	273–280,4	0,47	1,03	0,25	43,3	2
611	273,6–275,5	0,33	3,13	0,93	40,4	17,8
620	252,4–254	0,38	6,12	2,87	37	82
624	178–188	0,96	0,03	0,84	41,7	20,5
644	245,4–258	0,37	10,52	2,81	37,6	67,8
659	475,4–476,6	0,43	7,02	2,28	39,7	45
668	288,5–297	0,54	1,31	1,3	42	60
670	709,1–710,3	0,16	0,48	1	40,9	55
676	731,4–737	0,63	0,69	0,14	41,4	600
696	522,8–530	0,33	5,86	1,82	38	70
698	344–352,4	0,7	5,66	3,04	34,1	80
703	581–588,9	0,29	2,37	0,64	39	35,4

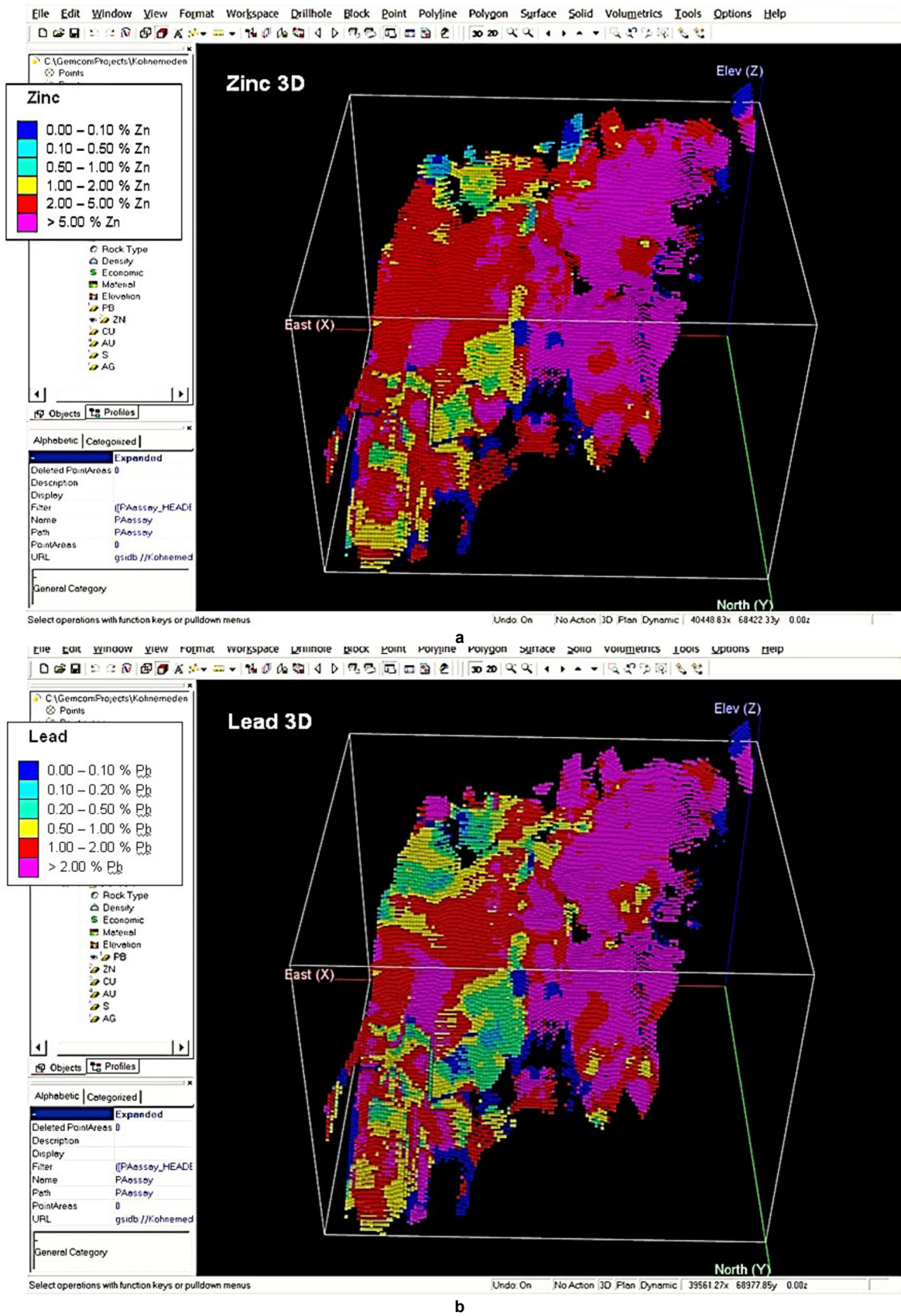


Fig. 5. Metal zoning at the Filizchay field – lead enrichment along the western part of the field: a – zinc; b – lead (3D model)

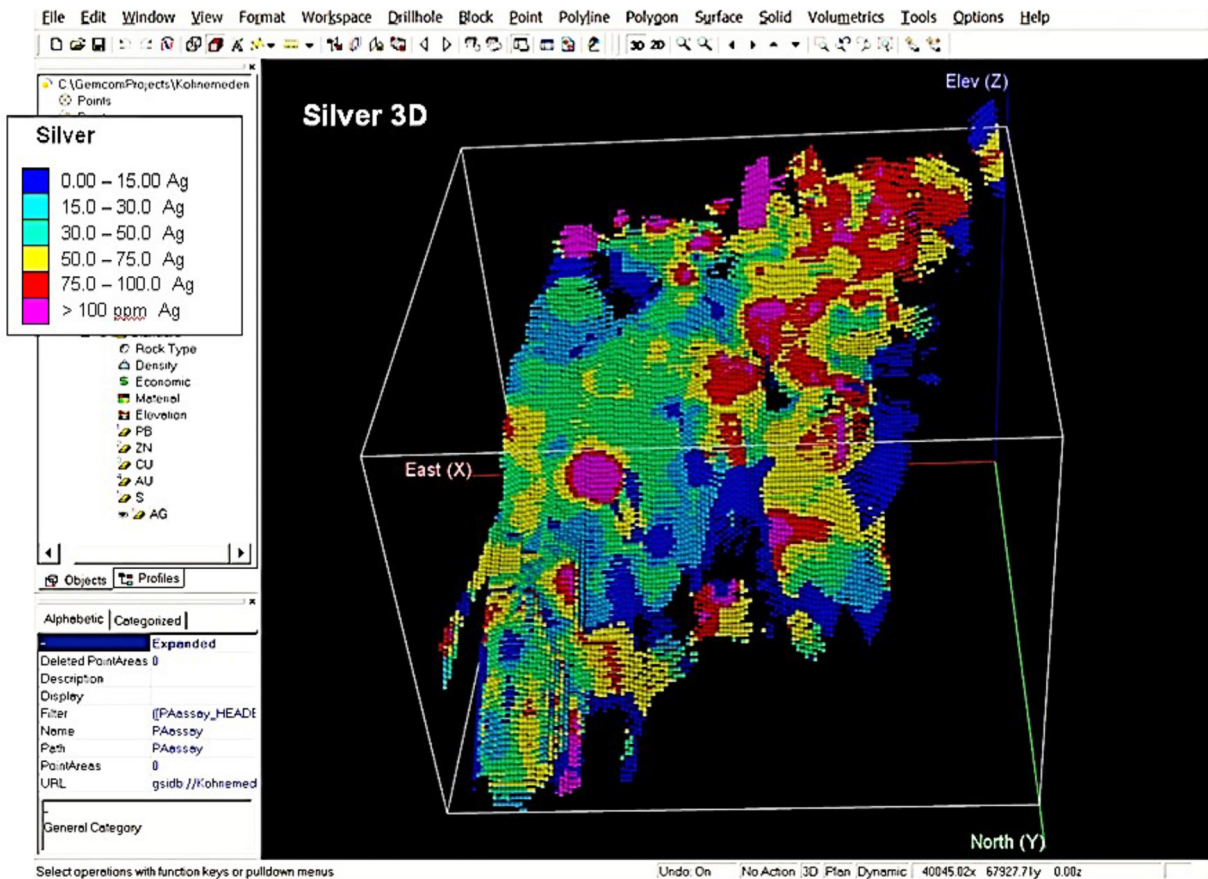


Fig. 6. Metal zoning at the Filizchay field – silver enrichment along the western part of the field (3D model)

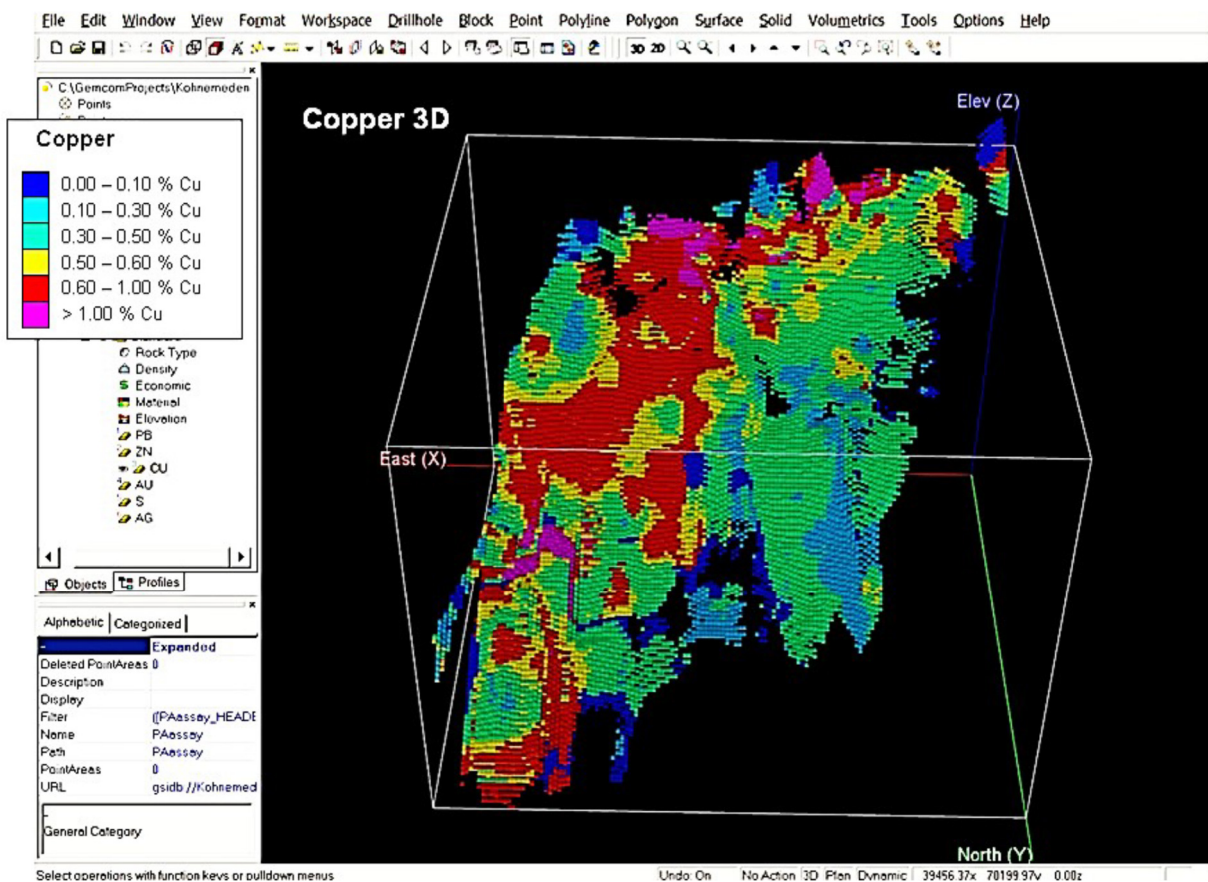


Fig. 7. Metal zoning at the Filizchay field – copper enrichment along the eastern part of the field (3D model) /

Some geochemical peculiarities of the distribution of ore components and precious metals in the composition of a single sheetlike deposit of the Filizchay pyrite-polymetallic field are reflected in the works (Novruzov, & Agaev, 2009, 2012; Novruzov, 2011). It is found that the maximum concentrations of zinc and lead occupy almost the entire western part of the deposit, while copper occupies local areas on the eastern flank and in the central part. The distribution pattern of silver is very similar to lead, while gold is similar to copper mineralization. In general, there is an increase in copper content and a decrease in zinc and lead concentrations from the western flank of the ore deposit to the eastern one (fig. 5–7).

The estimated reserves of the Filizchay field amount to 94.2 million tons, with the following average metal content: Zn – 3.61 %, Pb – 1.48 %, Cu – 0.58 %, Ag – 44.7 ppm, Au – 0.6 ppm. The metallic zoning inside the ore body is clearly visible through computer 3D modelling (fig. 5–7), which provides additional opportunities for future mining planning and process assessment.

As can be seen from the 3D models, the average copper content is 0.6 % in the upper horizon (in mixed ores), and enrichment of this element is also observed on the eastern flank.

Zinc also does not correspond to the thickness of the ore's capacity and averages 4–6%. There are ore accumulations with a zinc content of up to 6–8 % in the central part of the ore deposit from the horizon surface 1120 m to the horizon 500 m. The width of such accumulations is 10–30 m. They extend to the east at an angle of 70–80°. These ore accumulations contain high concentration of zinc – zinc "lenses". The percentage of zinc increases towards the western flank.

The most zinc-enriched part is observed in the center closer to the surface in the form of small accumulations. The lead content is 2–4 % on the eastern flank of the field.

Based on the results of the conducted correlation analysis, the possibility of grouping geochemical data using cluster analysis was considered. Using the latter, a group of elements characterized by a certain closeness of relationship was identified in the pyrite-polymetallic ores of the deposit. As can be seen from the R-type dendrogram (Fig. 8), zinc exhibits a close correlation with lead ($r = +0.864$). Copper's relationship with zinc and lead is negative (respectively, $r_{Cu-Zn} = -0.409$ $r_{Cu-Pb} = -0.315$) (table 2).

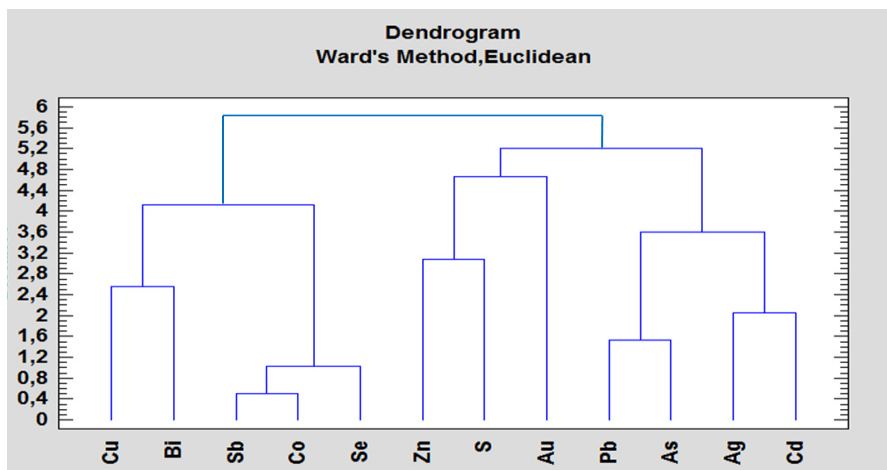


Fig. 8 Correlation between elements of pyrite-polymetallic ores of the Filizchay deposit

Table 2

Estimates of the correlation coefficients between components in pyrite-polymetallic ores of the Filizchay deposit (n=97)

	Zn	Pb	S	Au	Ag	Bi	Cd	Sb	As
Cu	-0.4092	-0.3148	-0.0508	0.0131	0.0859	-0.0132	-0.4140	-0.1902	-0.1793
Zn		0.8642	0.3730	-0.1027	0.5683	0.0048	0.7899	0.5348	0.4304
Pb			0.4023	0.0093	0.6277	0.1030	0.6163	0.6584	0.5256
S				-0.0594	0.2210	-0.1766	0.2449	0.3580	0.1726
Au					0.0498	0.3384	-0.0450	0.1324	0.0848
Ag						0.0812	0.4756	0.3803	0.2811
Bi							0.0623	0.2020	0.2321
Cd								0.4628	0.3809
Sb									0.6628

A clear mineralogical and geochemical zoning has been established along the dip and strike of the stratiform ore deposit of the Filizchay pyrite-polymetallic field, mainly due to the sequence of ore deposition. It is expressed by a regular alteration of the mineral and associated chemical composition of textural-mineralogical types of ores. The polymetallic composition of pyrite-polymetallic ores with a relatively elevated concentration of impurity components indicates a complex multicomponent composition of ore-forming solutions. The composition of impurity elements in minerals is a typomorphic peculiarity reflecting the

composition of mineral-forming solutions and the physicochemical conditions of ore formation. The distribution patterns of textural and mineralogical ore types at the Filizchay field are a reflection of the primary zonality of the distribution of ore-forming elements and impurity components. The distribution of rare and trace elements is determined by the spatial arrangement of various mineral associations distributed regularly in the ore deposit. As a result, mineralogical and geochemical zoning occurs. As mentioned above, the Filizchay field is characterized by zonality in the distribution of textural and mineralogical types

of ores and ore-forming components in the ore deposit (Imamverdiyev, Sattar-zadeh, 2023).

The results of numerous analytical data were processed to identify patterns in the distribution of chemical elements. It has been established that the content of zinc (Fig. 9a), lead, cadmium, indium, thallium, silver, gold, bismuth, mercury, antimony, arsenic decreases from the western flank to the eastern one in the main deposit of the studied field, while the concentrations of copper (Fig. 9b), cobalt, nickel and selenium increase. Geochemical zoning is expressed by decreasing concentrations of zinc, lead, cadmium, indium, bismuth, antimony, arsenic down-dip of deposit and increasing content of copper, cobalt, nickel and manganese. Models compiled on the basis of boreholes show that the upper (200 m) parts and the eastern flank of the field are enriched in copper and silver.

The distribution of elements in separate boreholes has established a clear zonality by the thickness of the ore deposit, occurred in a regular alteration of the mineral and chemical composition of the ores from the footwall to the side wall. This leads to the accumulation of copper, cobalt, tin and manganese in the footwall and the concentration of zinc, lead, cadmium, thallium, mercury, antimony, etc. in the side wall of the ore deposit.

Discussion and conclusions

Geochemical zoning associated with a regular alteration of the concentrations of separate elements in space is clearly expressed quantitatively using the values of indicator ratios (Zn Pb) / (Cu Co), Zn / Cd, Ag / Au, Co / Ni, etc. at the Filizchay field (Table 3). A regular alteration of the value of indicator ratios of elements is also observed in the depth horizons (upper, middle and deep horizons) (Novruzov, & Sattar-zadeh, 2015, 2019; Ovchinnikov, & Lutkov, 1983).

Table 3

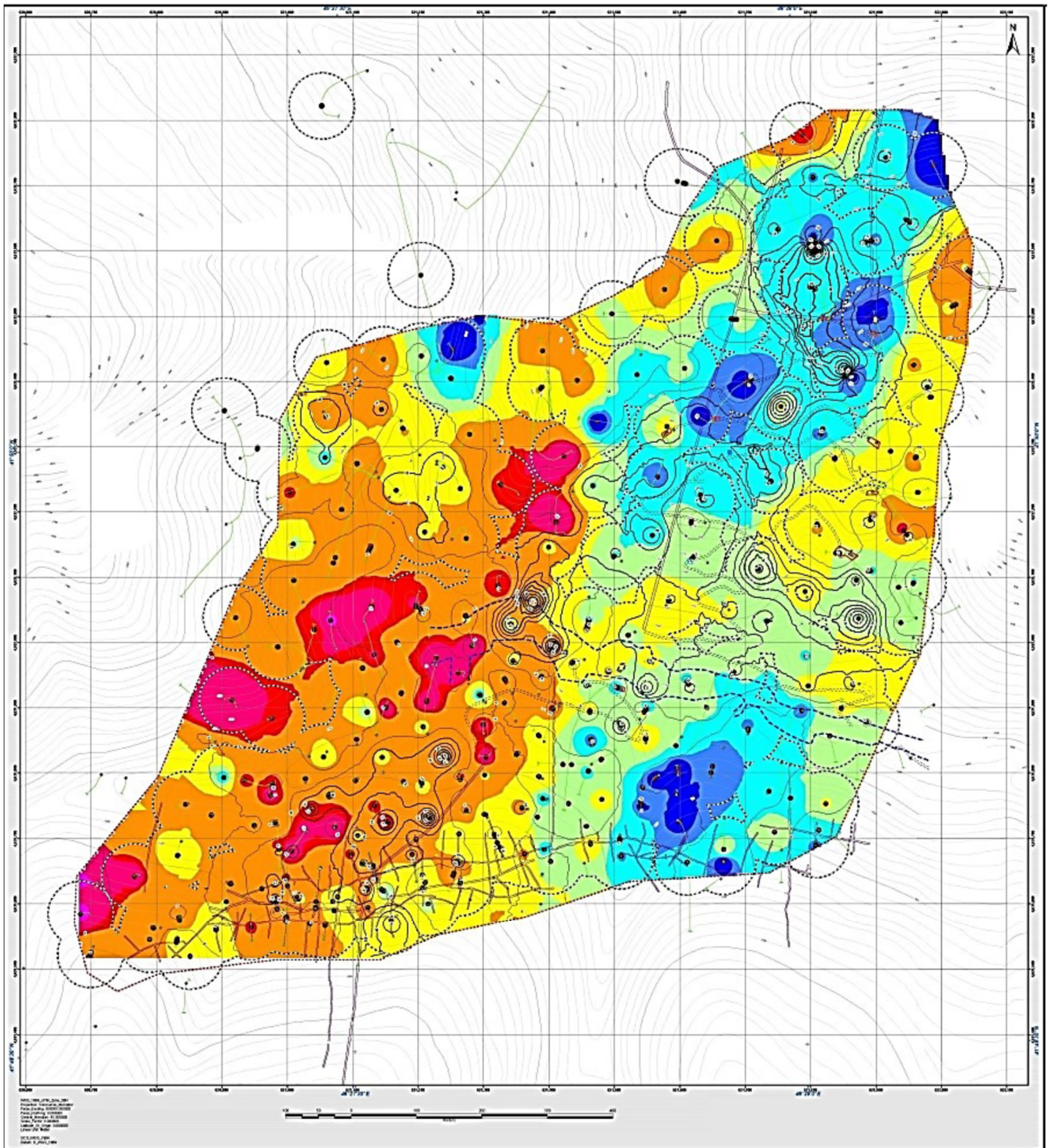
Average content of ore-forming and impurity components, values of indicator ratios of zonality index in pyrite-polymetallic ores of the Filizchay field

Element	Western flank (prof. IV–XI)	Central part (prof. XII–XIX)	Eastern flank (prof. XX–XXVI)
Cu	0,57 (150)	0,58 (185)	0,61 (114)
Zn	5,59 (150)	4,84 (185)	3,50 (114)
Pb	2,52 (150)	1,93 (185)	1,31 (114)
S	40,25 (150)	39,71 (183)	38,82 (114)
Au	0,9 (140)	0,8 (173)	0,7 (103)
Ag	75,6 (97)	55,2 (118)	43,3 (92)
Bi	102,4 (93)	83,7 (130)	70,8 (82)
Co	181 (151)	247 (186)	252 (116)
Ni	76 (88)	114,5 (141)	145 (143)
Cd	78 (114)	73,5 (113)	53 (79)
Se	5,5 (113)	7,0 (135)	6,3 (85)
Te	2,0 (130)	1,4 (156)	1,7 (110)
Sb	0,031 (132)	0,023 (165)	0,022 (108)
As	0,25 (137)	0,20 (171)	0,15 (111)
Mn	0,32 (137)	0,27 (152)	0,24 (113)
Zn:Cd	717	658,5	660
$\frac{Zn \cdot Pb}{Cu \cdot Co}$	1365	652	298
Ag:Au	84	69	62
S:Se	$73,2 \cdot 10^3$	$56,7 \cdot 10^3$	$61,6 \cdot 10^3$
Se:Te	2,75	5	3,7
Co:Ni	2,4	2,2	1,7
$\frac{Ag \cdot Pb \cdot Zn}{Cu \cdot Co \cdot Mn}$	32,26	13,33	5,38
$\frac{Ag \cdot Pb \cdot Zn}{Cu^3}$	0,58	0,26	0,09
$\frac{Ag \cdot Pb \cdot Zn}{Co^3}$	$1,8 \cdot 10^4$	$3,4 \cdot 10^3$	$1,2 \cdot 10^3$

To quantitatively express the zonality, the geochemical zonality index (Eremin et al, 2000; Lapukhov, 1975; Loginov, 1974) (Table 3) was calculated based on the ratios of the concentrations of elements accumulated in the upper part (Zn, Pb, Ag) and the lower part of the deposit (Cu, Co, Mn). Taking the minimum value of this indicator per unit, we obtained the following values of the zonality coefficient for the main ore deposit in separate hypsometric levels from the upper horizon (absolute marks 1300–1200 m) to the deep (500–400 m) along 100-meter depth horizons: 15; 12.8; 10.5; 5.9; 4.8; 1.8; 1; 1.8; 7.2. The regular alteration of the concentrations of elements down-dip of the Filizchay ore deposit is most clearly observed when comparing the zonality index, which increases from the central part of the deposit in the direction of the upper and deep horizons.

Geochemical zoning updip of the ore deposit is also observed. For quantitative characteristics of zonality, average content was calculated for boreholes intersecting

the ore deposit at different levels. Based on these data, graphs of alterations of geochemical indicators were built. The most rational are the following geochemical indicators: $V_1 = \frac{Zn \cdot Pb \cdot Ag}{Cu \cdot Co \cdot Mn}$, $V_2 = \frac{Zn \cdot Pb \cdot Ag}{Cu^3}$, $V_3 = \frac{Zn \cdot Pb \cdot Ag}{Co^3}$. They increase monotonously updip of the ore deposit by tens and hundreds of times (Fig. 10). In general, horizontal and vertical geochemical zoning is established in the ore deposit of the Filizchay pyrite-polymetallic field. So, zonality in the arrangement of textural and mineralogical types of ores and distinct geochemical zonality in the distribution of the main ore-forming components and impurity elements by thickness, updip and strike in the ore deposit have been established at the field. The latter is expressed in the values of zoning indicators, indicator ratios of elements, as well as in changes in the concentration levels of impurity elements in sulfides.



Legend

- Borehole coordinates
- Well tracking
- Ore body intersection
- Edge intersection of ore
- Ore contour projection

Ore Zn%

- 0.07-1.00
- 1.01-1.50
- 1.51-2.50
- 2.51-3.50

Topographic survey

- Borehole area
- Concreted area

Isolines (m)

- 5-10
- 11-25
- 26-45
- 46-65
- 66-85

Zn Content Legend

- 3.51-5.00
- 5.01-7.00
- 7.01-7.50
- 7.51-10.00
- >10% Zn color swatch"/> >10% Zn

a

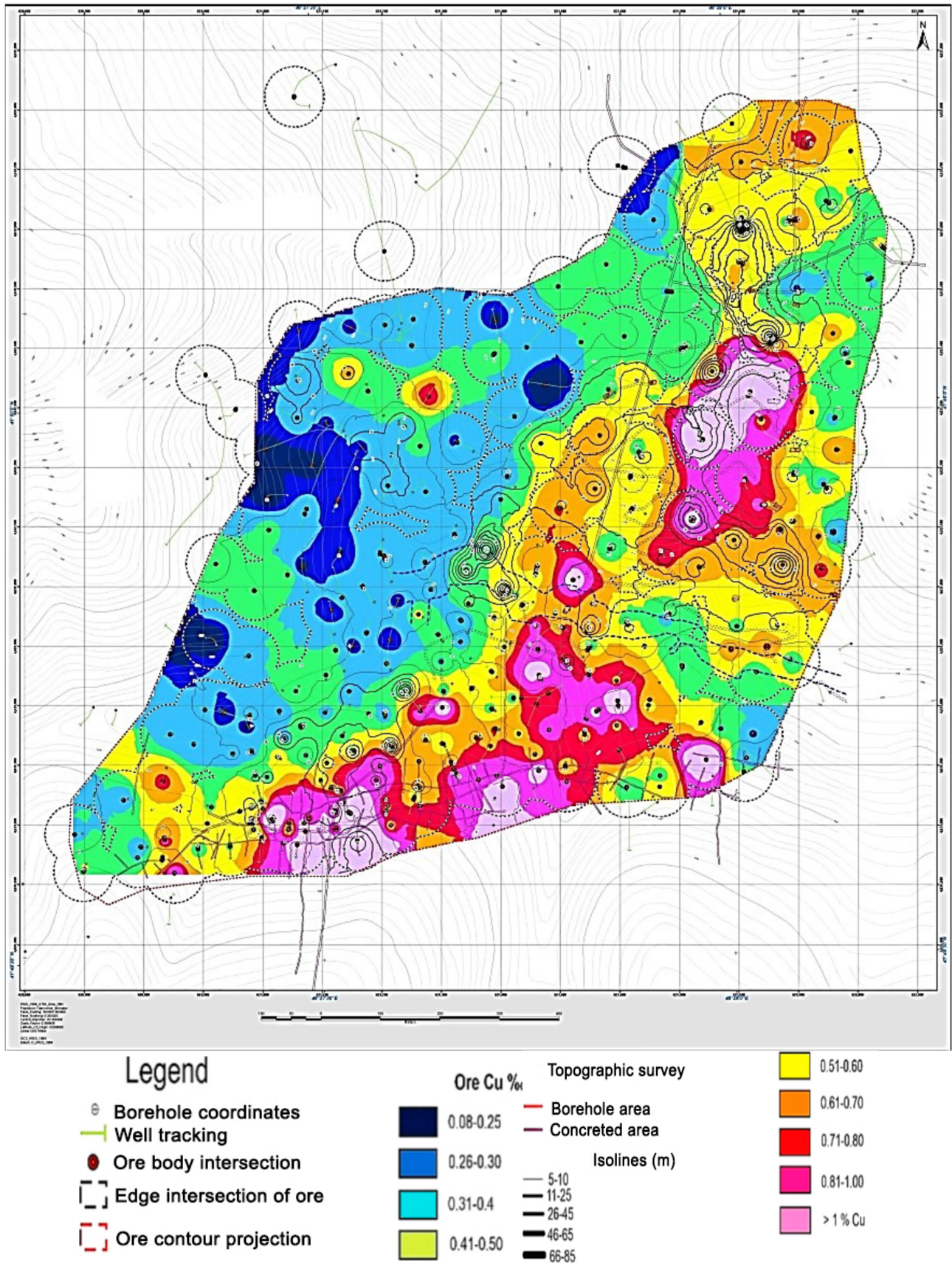


Fig. 9 Geochemical anomaly at the Filizchay field (2D): a – zinc; b – copper. Scale 1:2000

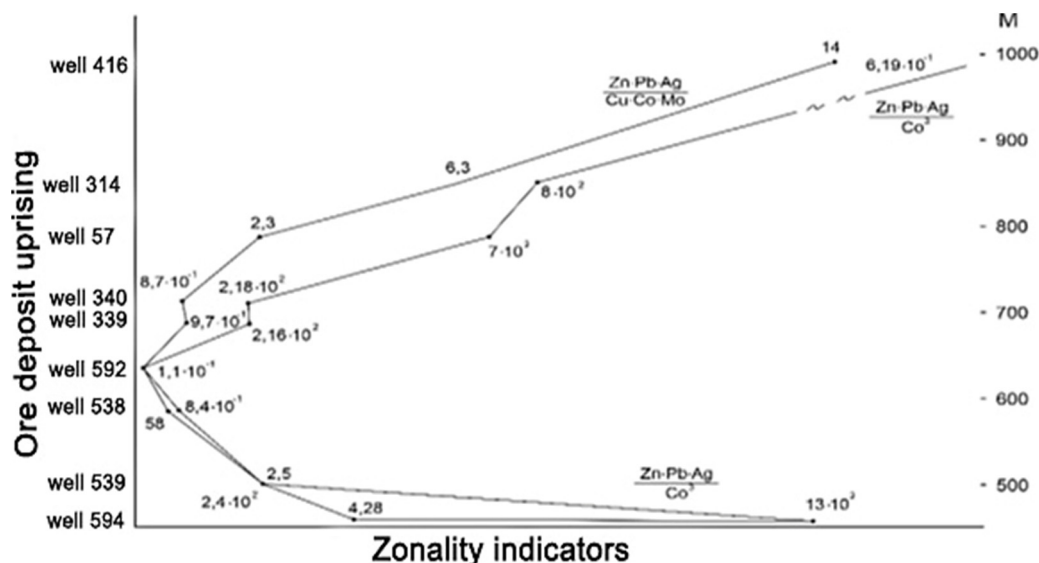


Fig. 10. Graph of changes in zoning indicators up dip of ore deposit

According to the analysis of the factual material, the most contrasting is the variability of the distribution of thicknesses and copper content, for which the inclination of the deposit in the north-east direction with its dip to the north is very clearly occurred. This inclination is expressed by maxima and bands of increased values of the named indicators in the form of separate bands or a chain passing in the plane of the body from its southwestern to northeastern flanks. In term of thickness and copper content, the deposit is clearly divided diagonally into two parts – the south-eastern, thicker and richer, and the north-western, relatively less thick and with contents below the average for the field. According to occurrence of the intensity of zinc, lead and silver mineralization, two parts can be distinguished in the deposit: the western part is richer, where almost all the maxima are concentrated, and the eastern part is poorer, where most of the minima are located. The boundary between them passes approximately in the middle part of the body from the upper to the lower horizons; approximately coincides with the direction of its dip and is distinguished by complex outlines. The most complex is the distribution of gold. An extensive area of low and minimum metal concentrations is distinguished in the middle part of the field, starting approximately from the level of the change in the dip angle and down to the hypsometric mark of about 500 m. This area is framed (except for the northwestern and southeastern corners) by a wide aureole of elevated contents, which occupies the entire remaining area of the deposit and within which many small-space maxima are distributed. The distribution of the main ore-forming components (zinc, lead and copper) in a horizontal section is illustrated in the plans of three horizons representing the upper, middle and deep parts of the field.

So, the Filizchay field developed over a long period, starting from the sedimentation period and up to the formation of ores of copper-pyrrhotite stage. The lower age limit of mineralization is determined by the occurrence of the Upper Pliensbachian hydrothermal-sedimentary ores. The upper age limit is identified by the presence of pebbles of hydrothermally altered rocks and their sulphide ores in conglomerates underlying the lower Upper Jurassic sediments.

According to the occurrence intensity of zinc, lead and silver mineralization, the deposit can be divided into two parts: the western part, which is richer and contains almost all the highs, and the eastern part, which is poorer and contains most of the lows. Additional geological exploration work is recommended in the eastern part.

Authors' contribution: Sattar-zadeh Nigar – using Leapfrog GEO program, constructed a 3D model for various elements and interpreted the resulting data. Nazim Imamverdiyev – described the geological structure of the area, calculated correlation coefficients for ore elements, and participated in the interpretation of the obtained data.

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ГЕОХІМІЧНІ ОСОБЛИВОСТІ ФІЛІЗЧАЙСЬКОГО ПІРИТ-ПОЛІМЕТАЛІЧНОГО ПОЛЯ (ВЕЛИКИЙ КАВКАЗ)

В с т у п . Структурне положення родовища Філізчай визначається його прив'язаністю до області стику північного схилу Карабчайської кесоноподібної антикліналі з Кехнамеданським насуванням, ускладненим Белаканчайським локальним поперечним інверсійним підняттям. Основними елементами структури родовища є: ядро Карабчайської антикліналі, її північний схил та частина Кехнамеданської зони зсуву, які перекриваються зазначеним поперечним підняттям. Особливості цих основних елементів визначають основні риси структури родовища Філізчай.

М е т о д и . Використано понад 2000 аналізів з розвідувальних свердловин. Для окремих елементів побудовано 3D-геохімічні моделі на основі програми Leapfrog GEO. Аналітичну роботу проведено методом рентгенофлуоресценції в лабораторіях Геологічної служби Міністерства екології та природних ресурсів Азербайджану.

Р е з у л ь т а т и . Роботу присвячено розподілу основних рудотвірних компонентів у Філізчайському родовищі південного схилу Великого Кавказу. 3D-модель мінеральних елементів Філізчайського родовища було створено з використанням програми "Leapfrog GEO". Аналіз карти чітко показує, що східний фланг глибиною, неглибоко занурюваної частини родовища характеризується найбільшою потужністю, де цей параметр майже повсюдно вищий за середнє значення по родовищу. Виявлено, що розподіли цинку та свинцю практично повторюються. Західна половина тіла різко відрізняється від східної стабільно високою (більше за середнє значення) вмістом. Переважна більшість мінімумів концентрацій цинку та майже всі мінімуми концентрацій свинцю розташовані у східній половині, яка загалом характеризується вмістом, нижчим за середній. Згідно з розподілом концентрацій міді, родовище дуже чітко поділяється на дві частини: південно-східну, яка є потужнішою та багатшою, та північно-західну, яка є відносно меншою та має вміст, нижчий за середній за родовищем. Порівняння карт ізовмісту срібла та свинцю вказує на тісний зв'язок обох елементів, про що свідчить дуже схожий характер їх просторового розподілу в межах родовища. Так само, як і для свинцю, в ньому можна загалом виділити дві половини, які загалом відрізняються одна від одної інтенсивністю срібного зруденіння – північно-західну, яка є багатшою, та південно-східну, яка є відносно біднішою. Межа між цими частинами в основному повторює межу, визначену для свинцю не лише за просторовим положенням, але й за основними деталями контуру. Усі максимуми срібного зруденіння розташовані в північно-західній половині родовища, більшість з яких – на верхніх горизонтах. За ступенем інтенсивності прояву цинкового, свинцевого та срібного зруденіння в родовищі можна виділити дві частини: західну, багатшу, де зосереджені майже всі максимуми, та східну, біднішу, на яку припадає більшість мінімумів. Межа між ними проходить приблизно в середній частині тіла від верхнього до нижнього горизонтів; вона майже збігається з напрямком його падіння та вирізняється складними контурами. Часта повторюваність ізольовані вмісту цинку та свинцю, близьке просторове розташування центрів їхніх максимумів свідчать про тісну позитивну кореляцію між ними.

В и с н о в к и . Філізчайське родовище розвивалося протягом тривалого періоду, починаючи з періоду седиментації і до формування руд мідно-піротинної стадії. Нижня вікова межа зруденіння визначається залляганням верхньоплісбахських гідротермально-осадових руд. Верхня вікова межа визначається наявністю гальки гідротермально змінених порід та їх сульфідних руд у конгломератах, що підстилають нижні верхньоюрські відкладення.

К л ю ч о в і с л о в а : Філізчайське родовище, південний схил Великого Кавказу, 3D-модель елементів, програма "Leapfrog GEO", розподіл цинку, свинцю, міді, срібла.

Автори заявляють про відсутність конфлікту інтересів. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

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