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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy
of Earth sciences

MINERALOGICAL AND GEOCHEMICAL MODEL OF THE FILIZCHAY PYRITE-POLYMETALLIC FIELD

Speciality:	2503.01 – Geochemistry, geochemical methods of prospecting for minerals
Field of science:	Earth sciences
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BAKU – 2024

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INTRODUCTION

Relevance of the work. Almost all commercial deposits and the most of ore occurrences of pyrite-polymetallic ores of the Saribash structural-formational zone are concentrated in its central part, corresponding to the Katsdag-Filizchay ore cluster on the southern slope of the Greater Caucasus. It is located mainly in the section of black shale strata of the Upper Pliensbachian and the Toarcian of the Early Jurassic and Aalenian of the Middle Jurassic. These formations contain two genetically related ore formations: pyrite-polymetallic and copper-pyrrhotite. Deposits of both formations are the objects of exploitation, in this case, the greatest practical importance is given to pyrite-polymetallic mineralization.

The state of study of majority of ore objects in the region does not allow for an unambiguous assessment of their practical significance. Therefore, the mineralogical and geochemical modelling of the Filizchay pyrite-polymetallic deposit is a main aim. Solving this issue will allow for more focused and efficient geological exploration, which will contribute to the successful fulfillment of the task at hand.

Based on the above, the development and construction of geological-genetic 3D models of ore-forming systems based on geochemical data of drill holes is a new stage in the study of pyrite deposits. Based on detailed mineralogical and geochemical data, identifying the stages of ore formation, assigning deposits to any type of pyrite objects (*VMS or SEDEX*) and elucidating the sources of ore matter is a very relevant area in modern geology.

The purpose of the research is the mineralogical and geochemical modelling of the Filizchay pyrite-polymetallic deposit, more specifically:

- Building 3D models for individual ore-forming elements based on detailed complex geological-mineralogical-geochemical data;

- identification of geochemical anomalies, geochemical zoning based on the ratios of element concentrations;

- elucidation of the formation mechanism of the pyrite-polymetallic deposit of the Filizchay field.

The dissertation work provides solving the following objectives to achieve this aim:

1) detailed study of the distribution of ore-forming and accompanying elements in ores to identify geochemical zoning along the up-dip of the ore field and geochemical anomalies;

2) study of textural and structural features, mineral composition and paragenetic mineral associations;

3) building geochemical 3D models for individual ore-forming elements (Zn, Pb, Ag) using the “Leapfrog Geo” program;

4) based on complex mineralogical and geochemical data, elucidation of the genesis of the Filizchay field.

Factual material and research method. The dissertation work is based on factual material obtained by the author at the prospecting stage and throughout the preliminary exploration stage, as well as during the process of thematic work in 2014-2024. The work methodology consists of geological mapping of the field, compiling a stratigraphic column of ore-bearing sediments of the deposit area, geological and structural observations in surface and underground mining using petrographic, mineralogical and geochemical research methods. More than 250 thin sections and 100 polished sections, as well as numerous lump samples, were studied. The structural and textural features of the ores are characterized. The contents of the main ore-forming elements of the field and some impurity elements of its main sulfides were determined using X-ray fluorescence Microspectroscopy. The results of more than 8000 spectral and 850 chemical analyzes of ores obtained from the core material of exploratory wells were studied and analyzed, and geochemical 3D models for individual elements were built on the basis of the program “Leapfrog Geo”. Data on the sulfur isotopic composition of pyrite, sphalerite, galena and pyrrhotite were used to elucidate the genesis of the field. Parallel to this, an analysis of the materials of geological surveying, prospecting, exploration, geophysical and thematic work was carried out in the area by teams of geologists of the Main Caucasus Expedition of the National Geological Service of the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. Histograms in the distribution of these elements were created and computer programs were used to identify correlations between various chemical elements. According to the value of the correlation coefficients, two associations of chemical elements were observed in the ores of the fields using cluster analysis: 1) Cu-Bi-Sb-Co-Se and 2) Zn-S-Au-Pb-As-Ag-Cd. Analytical work was carried out in the laboratories of the Geological Service of the Ministry of Ecology and Natural Resources of Azerbaijan, the Caucasian Institute of Mineral Raw Materials (Tbilisi) and in the laboratory of X-ray fluorescence micro-spectroscopy analysis of the State Control Service for Precious Metals and Stones of the Ministry of Finance of the Republic.

Scientific novelty of the research:

1. It has been established that the number of sulfide impregnations, concretions and nodules (mainly pyrite composition) in the geological section of the Jurassic deposits increases naturally from top to bottom from the Toarcian to the Pliensbachian, reaching a maximum in the third series of the Pliensbachian shales (Filizchay series), which hosts the stratiform pyrite deposit of the Filizchay field;

2. It was observed that the maximum concentrations of zinc and lead occupy almost the entire western part of the deposit, and copper – local areas on its eastern flank and in the central part of the deposit. The distribution pattern of silver is very close to that of lead, and gold is generally similar to the distribution of copper mineralization. In general, a decrease in zinc and lead concentrations and an increase in copper value are observed from the western flank of the ore deposit to the eastern flank.

3. The Filizchay field, the deposit of which is represented by thinly bedded massive sulfides with interbedded shales, aleurolites or sandstones (“ore flysch”), is combined according to the type of formation and belongs to the *SEDEX* type, the ores of which are among the most important sources of lead, zinc and silver.

The main points of the defense:

1. Substantiation of the mineralogical and geochemical zoning of mineralization at the Filizchay pyrite-polymetallic field

2. Geochemical model of the field

3. Sedimentary-exhalation genesis (SEDEX type fields) of the field, then subjected to hydrothermal-metosomatic and metamorphogenic processes.

Practical significance is determined by the focus of the research on solving applied problems on the mineral-geochemical modelling of the Filizchay field. The main ore-forming metals of the Filizchay field are Fe, Cu, Zn, Pb, Ag, with a whole series of associated components (Cd, In, Bi, Sb, Se, etc.). The proposed research complex of ore minerals with the help of modern methods will allow to solve more purposefully the forms of occurrence of rare elements in them and accelerate the assessment of the area's prospects for pyrite-polymetallic mineralization, which can be used to develop schemes for their extraction from ores. The geochemical 3D model for individual ore elements of the Filizchay field can be used in calculating ore and metal reserves, in laying out upcoming exploration and survey underground mining workings, as well as in solving theoretical issues to determine the conditions for the formation of pyrite-polymetallic deposits.

Approbation of the research and publication. The main points of the dissertation were presented at republican (Baku – 2015, 2016, 2018, 2019, 2022, 2023) and international conferences (Baku - 2014, Almaty -2015, 2019). 20 academic papers *(including 3 articles based on the Emerging Sources Citation Index, Web of Science Core Collection (Ukraine), 1 article based on the RSCI on the Web of Science platform and 2 articles in the journal "Recommended periodical academic publication on Earth sciences for awarding academic degrees and academic titles in Russia")* have been published on the topic of the dissertation, which reflect the main defended points.

The dissertation was carried out under the supervision of Doctors of Geological and Mineralogical Sciences, Professors N.A. Novruzov and N.A. Imamverdiyev. Various points of the dissertation were discussed by academician V.M.Baba-zadeh, professors B.H.Galandarov, V.Sh.Gurbanov, Sh.F.Abdullayeva, associate professors M.I.Mansurov, S.F.Veli-zadeh, G.J.Babayeva, M.Y.Hasanguliyeva, g.-m.s. F.J.Guseynov, Doctor of Earth Sciences A.A.Veliyev, S.S.Mursalov, R.G.Askerov, leading geologist and database engineer S.M.Mamedov. The author expresses sincere gratitude to all these researchers, who provided great assistance in processing the materials and layout of the work.

Scope and structure of the work. The dissertation consists of 189 pages, including introduction, 5 chapters, conclusions and suggestions, a list of references containing 115 titles, 43 figures, 17 tables. The total volume of the dissertation is 223013 characters, including the introductory part – 8018, Chapter I – 25369, Chapter II – 43153, Chapter III – 45462, Chapter IV – 41077, Chapter V – 52564, Conclusion and practical recommendations **–** 5687.

THE GENERAL CHARACTERISTICS OF THE WORK

CHAPTER 1. TECTONIC STRUCTURE OF THE GREATER CAUCASUS

1.1. Areas of the folded mountain system of the Greater Caucasus

The Alpine folded mountain structure of the Greater Caucasus occupies the northern part of the Caucasian Isthmus and extends from the Taman to the Absheron Peninsula over a distance of 1300 km with a maximum width of 150 km (Geology of Azerbaijan, 2005[1], Kengerli, 2009[2]). The Greater Caucasus appears as a complex nappe-folded structure in the modern structure, which was formed as a result of late Alpine tectonic movements from three main Mesozoic structures – the North Caucasus and South Caucasus (Transcaucasian) continental microplates and the vast Tethys marginal marine basin separating them.

All known pyrite-polymetallic and copper-pyrrhotite deposits and ore occurrences on the southern slope of the Greater Caucasus are concentrated in the Lower-Middle Jurassic terrigenous strata of two longitudinal subzones - Tfan and Sarybash, the geological structure of which is distinguished by a number of specific features.

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[1] Геология Азербайджана: [в 10 томах]. / Под ред. академика А.А.Ализаде. – Баку: Нафта-Пресс, – т.4, Тектоника – 2005. – 505 с.

2 Кенгерли, Т.Н. Тектоническая расслоенность альпийского чехла Большого Кавказа в пределах Азербайджана: / автореферат дисс. докт. геол.-мин. наук / – Баку, 2009. – 61 с.

1.2. Geological structure and lithological-facies characteristics of ore-bearing deposits

All known fields and ore occurrences of the pyrite-bearing province of the Eastern segment of the Greater Caucasus on the southern slope and in its watershed part in the territory of Azerbaijan and the adjacent territory of Dagestan are concentrated in Lower and Middle Jurassic deposits, which are described in detail in the defended dissertation.

The area under consideration is characterized by a relatively small distribution of eruptive rocks developed within the Tfan and Vandam anticlinoriums, separated by the Zagatala-Govdag (Intermediate) synclinorium and absent in the Saribash zone. Magmatism occurs by the volcanic associations, penetration of small sill intrusions and dike formations in the Tfan zone[3,4,5,6]. The latter are the eastern continuation of the southern (Kakheti) diabase belt of the Greater Caucasus. Volcanic formations also develop insignificantly in the watershed part of the ridge adjacent to Dagestan. These magmatic bodies cut the sandy- argillaceous strata of the Lower and Upper Toarcian, and in some places of the Lower Aalenian substages, but they are not observed anywhere among the Bajocian and higher deposits. So, the age of dikes and small intrusions of the gabbro-diabasic formation is pre-Bajocian and is associated with pre-Bajocian folding movements. The outcrops of magmatic formations are controlled by faults.

Magmatic formations are represented by two extreme members - basic and acidic rocks. The first – gabbro-diabase, diabase and diabase porphyrites of the “diabase” formation are extremely wide-

[3] Абдуллаев, Р.Н., Курбанов, Н.К., Алиев, Г.И. Магматизм и колчеданное оруденениеДжихих-Чугакской зоны Балакенского рудного района (Большой Кавказ) // – М.: Известия АН СССР, сер. геологическая, – 1975. №4, – с. 70-89

[4] Геология Азербайджана: [в 10 томах]. / Под ред. академика А.А.Ализаде. – Баку: Нафта-Пресс, – т. 3, Магматизм – 2001. – 434 с.

[5] Керимов, Г.И., Ширалиев А.Б. Магматические формации Южного склона Большого Кавказа и их рудоносность // –Баку: Известия АН Азерб. ССР. Сер. наук о Земле, – 1984. – с. 17-23

[6] Керимов, Р.Б. Петрология и рудоносность магматических комплексов Балакяно-Закатальского рудного района (Южный склон Б.Кавказа): / автореферат дис. канд. геол.-мин. наук / – Баку, 1991. – 20 с.

spread and, belong to the tholeiitic series in terms of the composition of the magma. The thickness of dikes and sills varies from 1 to 20 m, the length of dikes varies from tens to 150 m or more. Acidic and intermediate intrusions are represented mainly by dacites, andesites and diorite porphyrites. Small intrusions have a contact effect on the host sandy-argillaceous deposit of the Toarcian and partly Aalenian and are accompanied by an endocontact aureole of hornfelsed rocks with a thickness of 1-2 m.

Deposits of the copper-pyrrhotite formation are concentrated in the northern part of the Tfan zone, bounded from the north by the Main Caucasian thrust, and from the south by the Kohnamedan reverse-thrust, and ores of pyrite-polymetallic composition are found in separate isolated blocks, being almost completely replaced by the chalcopyrite-pyrrhotite association (fields Jihikh, Chugak, Katsdag, Katsmala, Somalit, Gudurdag, Gizildara, etc.).

The Saribash structural-formational zone can be traced directly to south of the zone of concentration of copper-pyrrhotite ores of the Tfan block, characterized by the predominant development of ores of the pyrite-polymetallic formation. The main ore-controlling elements of the zone are the Kohnamedan deep fault in the north and the Saribash fault in the south. Deposits of the Filizchay field are concentrated within the zone, where the volume of ores of copper-pyrrhotite composition does not exceed 1-1.5%. The most promising fields of the Saribash zone are Katekh, Akhkeman, Saribash, Gumbulchay, etc. Intense hydrothermal-metasomatic changes are clearly expressed within the zone, which are developed mainly within the sub-ore strata, where they coincide with the development aureole of veinlet ores in scale.

CHAPTER 2. GEOLOGICAL POSITION OF THE KASDAG-FILIZCHAY ORE CLUSTER

2.1. Geological characteristics of the Filizchay ore field

Features of the geological structure, magmatism and ore deposits of the Southern slope of the Greater Caucasus, in particular the Katsdag-Filizchay ore cluster, which includes the Filizchay field, were studied by R.N. Abdullaev, S.A. Agayev, V.B. Agayev, A.A.

Aliyev, G.I. Aliyev, R.M. Aliyev, D.M. Akhmedov, R.A. Akhundov, V.M. Baba-zadeh, S.F. Babayev, A.M. Babayeva, A.A. Bayramov, E.T. Bayramalibeyli, M.B. Borodaevskaya, S.F. Velizadeh, G.A. Veliyev, A.S. Heydarov, L.N. Grinenko, T.G. Gajhiyev, M.G. Dobrovolsky, N.M. Zairi, A.G. Zlotnik- Khotkevich, B.I. Isayev, S.B. Zulfugarov, M.A. Kashkay, G.I. Kerimov, N.K. Gurbanov, R.B. Kerimov, N.M. Ilyasov, N.A. Ismailova, T.M.Mammadov, D.D.Mazanov, A.I. Mahmudov, K.I. Museyibov, B.V. Mustafa-zadeh, G.V. Mustafayev, V.N. Nagiyev, N.A. Novruzov, V.I. Smirnov, N.Sh. Yusifov, G.A. Tvalchrelidze, A.G. Tvalchrelidze, G.A. Chalabiyev, Ch.M. Khalifa-zadeh, A.B. Shiraliyev, E.Sh. Shikhalibeyli and other researchers at different times.

The ore cluster covers the western flank of the Balaken-Zagatala ore region and is confined to the intersection of the Tfan and Saribash structural-formational zones along the Kohnamedan system of reverse-thrust dislocations. Terrigenous sediments of the Upper Pliensbachian (Filizchay series), Lower (Murovdag series) and Upper Toarcian (Jikhikh series) are exposed within the ore cluster in the Tufan subzone, which form the Kasdag first order linear anticline, which hosts the deposit of the same name. There are sediments of the Lower (Balakan series), Upper Pliensbachian (Filizchay series) and Toarcian (Gubakh series) in the Mazym-Sarybash subzone, which are crushed into the Karabchay box anticline, which hosts the ore deposit of the Filizchay field.

So, the horizontal zonality and metallogenic specialization of the abovementioned structural-formational zones are clearly established.

The pyrite-polymetallic formation was formed in two stages - early, hydrothermal-sedimentary (essentially pyritic) and late, hydrothermal-metasomatic (productive polymetallic). The formation of the copper-pyrrhotite formation is associated with the later hydrothermal-metamorphogenic alteration of stratiform pyrite ores, accompanied by the input of copper and the loss of base metals.

2.1.1. Geological structure of the Filizchay field

The geological structure of the field includes terrigenous sediments of the Upper Pliensbachian (Filizchay series (J_1p_2)) and Toarcian (Gubakh (J_1t_{1+2}) and Murovdag (J_1t_1) series) of Lower Jurassic.

The dissertation describes in detail the lithological and stratigraphic characteristics of terrigenous sediments and the petrographic peculiarities of the main varieties of rocks, which led to the following:

a) all selected series are distinguished by stability of facies and, to a lesser extent, thickness;

b) the rhythmic structure of the sections has a sharply defined flyschoid character, which are most fully represented in the flyschoids and packets of the Filizchay series of the Upper Pliensbachian and least clearly in the Murovdag series of the Lower Toarcian;

c) the number of sulfide impregnations, concretions and nodules (mainly pyrite composition) increases naturally from top to bottom – from the Toarcian to the Pliensbachian, reaching a maximum in the third packet of the Pliensbachian shales (Filizchay series), which hosts the stratiform pyrite deposit of the field;

d) on the contrary, metamorphism increases in the opposite direction – from the Pliensbachian to the Toarcian, which is explained by the coverage of the Toarcian terrigenous strata by the Kohnamedan shear zone.

2.2. Structure of the field

The Filizchay field is the only large pyrite-polymetallic field not only within the Balakan-Zagatala ore region, but also in the metallogenic region of the Greater Caucasus. The structural position of the Filizchay field is determined by its location at the junction of the northern flank of the Karabchay chest anticline with the Kohnamedan reverse-thrust fault, which is complicated by the Balakanchay local transverse inversion uplift. The main elements of the structure of the field are the core of the Karabchay anticline, its northern wing and part of the Kohnamedan shear zone, covered by the indicated transverse uplift. The features of these main structural elements determine the main peculiarities of the structure of the Filizchay field.

Longitudinal fault structures play no less a role than plicative structures in the structure of the deposit. In this case, the dominant ones are reverse-thrust faults, oriented along the strike subparallel to the longitudinal folded structures. The main longitudinal fault structures of the field include the Kohnamedan reverse- thrust and the Filizchay thrust.

2.2.1. Morphology and internal structure of the ore deposit

The main feature of the morphology of the pyrite-polymetallic deposit of the Filizchay field is that it is a relatively simple and single sheet-like body with sharp, almost subparallel contacts. It is composed predominantly (by 90-95%) of aggregates of sulfide ores, the basis of which is pyrite, sphalerite, galena, chalcopyrite and pyrrhotite. A subordinate role in the composition of the deposit is played by carbonates and even less by quartz, sericite and chlorite (Babazadeh, 2005)[7].

The ore deposit can be conditionally divided into two parts: the upper part, which is more stable throughout its entire length, steeply dipping, having a step structure both in dip and along strike, and the lower part (main one in area), which is relatively flat-dipping. Everywhere the top of the deposit is complicated by the Filizchay ore-bearing thrust, and the top of the deposit in space repeats the morphology of the thrust, which is especially clearly observed in the upper, steep part of the deposit. The base of the bedding deposit is characterized by a more complex structure while maintaining sharp contacts with the host rocks.

The ore body lies among the monotonous clayey shales of the upper – third packet of the Filizchay series. Here, the deposit is associated with a thick ore-bearing horizon, the lateral boundary of which is determined by the boundaries of the Balakanchay transverse uplift, where ore-bearing clayey shales are faciesally replaced by sandy flyschoid.

The ore deposit of the field consists of the following textural types, which are spatially and clearly separated and characterized by their morphological peculiarities: layered-banded, massive and spotted-impregnated ores. According to geologists working here, the first two natural types are balance ores, and spotted-impregnated ores, which are gradually turning into veinlet-impregnated ores or host

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[7] Свинец и цинк. Металлогеническая провинция Большого Кавказа. / В.М. Баба-заде, С.А.Агаев, Г.А.Челаби [и др.] // Минерально-сырьевые ресурсы Азербайджана, – Баку: Озан, – 2005. – с. 294-340

rocks and significantly complicating the morphology of the ore deposit, are off-balance[8,9,10]. It is interesting that the transition from layered-banded to massive pyrite-polymetallic and sulfur-pyrite ores occurs through slightly banded and mixed ores.

Two industrial and technological types of ores are distinguished at the Filizchay field: oxidized and pyrite-polymetallic. The latter is divided into two grades: mixed and primary ores. These three types of ores differ in the content of oxidized forms of lead. Ores with a content of oxidized forms of lead of more than 60%, mixed - from 60% to 20% and primary - less than 20% are classified as oxidized.

CHAPTER 3. MINERALOGICAL CHARACTERISTICS OF ORES

3.1. Mineral composition of ores

According to N.A.Novruzov, S.F.Velizadeh, S.A.Agayev, A.G.Zlotnik-Khotkevich and others, about 100 minerals have been identified in the ores of the field. Pyrite is dominant, comprising 60 to 95% of the ore volume. The main minerals also include sphalerite (6-8%), galena (up to 3-5%) and chalcopyrite (up to 2-4%), which constitute the main industrial value of the ores. The occurrence of pyrrhotite, arsenopyrite, cobaltine, and magnetite is common. Sulfosalts of bismuth, silver, arsenic, antimony, and tellurides of gold, silver, bismuth and lead are found rarely. Quartz and calcite, as well as siderite, chlorite and sericite were observed among the non-metallic minerals. Cadmium, indium, selenium, tellurium, bismuth, silver, gold, cobalt, etc. were observed in the ores of impurity elements,

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[8] Акберов, М.А. Об особенностях морфологии и природных типах руд Филизчайского месторождения / М.А. Акберов, А.М. Самедов, Г.Ш. Мамедов, [и др.] // Труды ЦНИГРИ, – М.: – 1982. вып. 168, – с. 44-49

[9] Баба-заде, В.М., Агаев, С.А. Особенности структурных условий локализации и морфологии рудной залежи Филизчайского месторождения // – Баку: Вестник Бакинского Университета, серия естественных наук, – 1999. №1, – с. 91-108

[10] Новрузов, Н.А., Саттар-заде, Н.А.Характеристика минералого-геохимических особенностей стратиформного колчеданного месторождения Филизчай (Большой Кавказ, Азербайджан)// *–Владикавказ: Вестник Владикавказского научного центра РАН, –2022. 31 (4)* –с. 69-79

which can be extracted on occasion. Depending on which mineral forms the basis of the ores, pyrite-polymetallic, pyrite-pyrrhotite and copper-pyrrhotite (no more than 2-5% of the total volume of ores) ores are distinguished.

The predominant ores at the field are pyrite and sulphide-polymetallic ores. Copper-pyrrhotite ores with predominant pyrrhotite are significantly less developed (Table 1).

Table 1

Mineral composition of ores of the Filizchay deposit (according to A.G. Zlotnik-Khotkevich[11])

Types of ores	Minerals		
	Main	Accessory	Rare
Pyrite and sulphide-polymetallic	pyrite, sphalerite, galena, chalcopyrite, carbonates	faded ores, pyrrhotite, arsenopyrite, bournonite, chlorites, quartz, sericite	jamesonite, boulangerite, gudmundite, wolfsbergite, meneghinite, emplectite, beegerite, cemseite, cosalite, famatinite, dyscrasite, geocronite, tellurobismuthite, hessite, petzite, altaite, nagyagite, native gold and silver
Copper-pyrrhotite	pyrrhotite, pyrite	magnetite, musketovite, sphalerite, galena, siderite, biotite, actinolite	hematite, arsenopyrite, cobaltine, ilmenite

Pyrite and sulphide-polymetallic ores are characterized by banded, massive, spotted-impregnated and veinlet textures. Copper-pyrrhotite ores are characterized by brecciated, breccia-like, porphyric and veinlet textures.

[11] Злотник-Хоткевич, А.Г. Вещественный состав и генезис Филизчайского колчеданно-полиметаллического месторождения на Южном склоне Большого Кавказа: / автореферат дисс. канд. геол.-мин. наук / – Москва, 1970. – 24 с.

Below is a brief description of the main ore-forming minerals of the Filizchay field.

Pyrite. The early generation predominates among the varieties of iron disulfide, which composes massive sulfur pyrites and layered banded pyrite-polymetallic ores. *Pyrite I* is presented in the form of fine- and fine-grained aggregates with relics of a metacolloidal structure. The grain sizes range from small inclusions to large crystals (0.3-1.0 cm).

Pyrite II differs sharply from pyrite I in typomorphic features, and also contains relict grains of the latter, on the basis of which it is classified into the second generation. It is represented by well facetted pentagon-dodecahedrons and cubes. It is associated with early generations of sulfides (sphalerite, galena and chalcopyrite), they participate in the structure of layered-banded sulphide-polymetallic ores.

Pyrite III contains relics grains of pyrite of the first generation and forms close, closely simultaneous intergrowths with chalcopyrite, galena and arsenopyrite, forming a uniform impregnation against the background of the galena-chalcopyrite aggregate.

Pyrite IV corrodes pyrite segregations of all three abovementioned generations. It occurs in all types of essential pyrite ores with different amounts. It is especially characteristic of pyrite ores of massive formation. A common feature of pyrite of the forth generation is metacolloidal composition and low degree of crystallization. The most common forms of pyrite of the fourth generation are concentrically zoned aggregates of spherical and more complex shapes up to 2-3 mm in size, radial fibrous, openwork framework, framboids, undulated accumulations, crusts, finely-banded aggregates.

Sphalerite. Several generations of this mineral have been observed. *Sphalerite I* is an iron-bearing variety of sphalerite – *marmatite*.

Sphalerite of the first generation forms the ground mass of polymetallic bands in the form of irregular, sometimes some elongated allotriomorphic granular aggregates in layered-banded pyrite-polymetallic ores.

Sphalerite (wurtzite) II occurs in small quantities in layered ores with pyrite IV, forming central parts or peripheral zones in these aggregates. Sphalerite of second generation in veinlet-impregnated ores differs from sphalerite I by lighter shade, forming single segregations.

Sphalerite III is observed in small quantities in association with quartz, chalcopyrite, pyrrhotite, galena, and fahlore and other minerals of sulfosalt group. It is characterized by irregularly shaped, relatively large aggregates (up to 1-3 mm) of allotriomorphic grains.

Galena is a widespread mineral of pyrite-polymetallic ores. It should be noted that all identified generations of zinc sulfide are accompanied by corresponding generations of galena.

Galena I is observed in constant association with sphalerite of the first and pyrite of third generations. It is represented by small xenomorphic segregations of irregular shape, occupying intergranular spaces in sphalerite aggregates.

Galena II occurs occasionally in the form of various intergrowths with pyrite of the fourth generation and carbonate. A characteristic feature of galena of the second generation is the distribution of thin and drop-shaped sphalerite inclusions in them, apparently formed as a result of redeposition of the early generation of zinc sulfide.

Galena III is constantly associated with sphalerite of the third generation, quartz, chalcopyrite, fahlore, bournonite, jamesonite, and boulangerite.

Chalcopyrite is constantly associated with fahlore, pyrrhotite, sphalerite of the third generation, galena of the third generation. It crystallizes after fahlore and sphalerite.

Pyrrhotite occurs constantly in small quantities in association with chalcopyrite, fahlore, sphalerite of the third generation, galena of the third generation, etc. In relation to the abovementioned minerals, it is a substitute, as it crosses the boundaries of their intergrowths and is often located on the contacts of sphalerite with chalcopyrite or fahlore.

The dissertation also provides a brief description of some minor ore and non-metallic minerals of the Filizchay field.

3.2. Paragenetic associations of minerals and sequence of segregation

The process of formation of the ore deposit occurred in two stages. The first stage begins with the sediments of pyrite masses from solutions, followed by the overlay of lead, zinc and copper sulfides and ends with the formation of pyrite-polymetallic ores. The second stage corresponds to the formation of copper-pyrrhotite ores. In general, the ore deposition of the second stage occurred at high temperatures, as evidenced by the association with pyrrhotite and chalcopyrite of such high-temperature minerals as biotite, actinolite and magnetite.

Detailed mineralogical mapping of individual types of ores and microscopic examination of their constituent minerals showed that the formation of the ore deposit occurred in several pulsating stages of mineral formation.

The main pyrite mass of the deposit was formed with non-metallic minerals represented by quartz, carbonate and, in subordinate quantities, chlorite and sericite in the first stage.

The second stage, more productive, is characterized first by the sediments of Cu, Pb, Zn sulfides and later by a decrease in the concentration of these metals and an increase in the content of As, Sb and Bi. After crystallization and recrystallization of pyrite gels and slight crushing of the transformed aggregates, circulation of solutions enriched in lead and zinc occurred, which was accompanied by partial dissolution and redeposition of pyrite with the formation of characteristic skeletal metacrystals.

The third stage of mineral formation is characterized by the occurrence of rare metal ore formations of the vein type, the formation of which was preceded by the crushing of previously formed ore masses.

The fourth, final stage, includes the formation of a complex of minerals of copper-pyrrhotite ores, which are intersecting relative to pyrite ores.

Paragenetic associations of minerals of the Filizchay pyrite-polymetallic ores reveal significant similarities with the mineral parageneses of classical pyrite fields formed in sedimentary basins. The only differences are that there is no high-temperature chalcopyrite in the pyrites of the early generation of Filizchay and there is a complex of compound sulfosalts that separate into an independent paragenetic mineral association.

Analysis of the structural and spatial relationships of minerals allowed A.G.Zlotnik-Khotkevich (1970)[11] to observe seven successively formed paragenetic mineral associations (early pyrite; pyrite-arsenopyrite; sphalerite-galena; late pyrite; chalcopyrite-tetrahedrite; sulfoantimonide; telluride association) in the sulfide-polymetallic ores of the field, and three mineral associations (magnetite-siderite; chalcopyrite-pyrrhotite; pyrite-chlorite) in the copper-pyrrhotite ores.

3.3. Textural and structural peculiarities of ores

The main volume of the Filizchay field is occupied by sulfide-polymetallic ores, the main textural types of which are layered-banded, massive and spotted- impregnated, which can be traced from the side of the footwall of the ore deposit and are accompanied by a halo of veined- impregnated ores. Each of the listed main types of ores is divided into a number of varieties.

Copper-pyrrhotite ores, which are confined to the footwall of the stratiform deposit in the eastern part of the field, are characterized by massive, breccia-like, brecciated, porphyritic and vein-impregnated textures.

The ore structures observed at the field are combined into three groups: 1) sediments from solutions; 2) replacement; 3) metamorphic (recrystallization, cataclasis, redeposition, etc.).

CHAPTER 4. REGULARITIES OF SPACE DISTRIBUTION OF CHEMICAL ELEMENTS IN ORE DEPOSITS

4.1. The main peculiarities of the distribution of rare and trace elements in ores

The ores of the Filizchay sulfide-polymetallic field are characterized by a wide spectrum of chemical elements. The most important industrially valuable components of ores are *zinc, lead, copper and silver* (Table 2). Impurity components that deserve associated extraction include gold, cadmium, indium, selenium, tellurium, bismuth, cobalt, etc.

Table 2

Limits and weighted average contents of industrially valuable components in the ores of the Filizchay field

Types of ores / Components, %	Commercial ore			Non-commercial ores
	Primary	Mixed	Oxidized	
Copper	0.01 – 8.90 / 0.58	0.05 – 11.0 / 1.56	< 0.01 – 0.27 / 0.12	0.04-2.17 / 0.50
Zinc	0.10 – 14.70 / 3.66	0.10 – 15.80 / 4.26	< 0.01 – 0.45 / 0.19	0.01-9.50 / 1.10
Lead	0.01 – 7.50 / 1.41	0.03 – 11.90 / 2.32	< 0.01 – 55.5 / 3.45	IR-5.90 / 0.15
Silver, g/t	IR-280.0 / 44.08	IR-240.0 / 67.95	5.5-772.9 / 160.1	IR-83.0 / 13.98

Note: the numerator is the content limits, the denominator is the average content.

Zinc is the most common main valuable component of ores of field. The layered-banded variety of sulfide-polymetallic ores is characterized by the highest average content of the element. In pyrite-polymetallic ores with banded and massive textures, the average zinc content is higher three times than in spotted- impregnated and veinlet ores. The lowest concentration of the element is confined to oxidized ores, which is due to the fact that sphalerite, oxidizing to easily soluble zinc sulfate, is removed from the oxidation zone. As a result, zinc is found in the range of 0.01 - 0.45%, on average - 0.19% in the oxidized ores of Filizchay. The limits of zinc content in primary and mixed ores are similar: 0.10 – 14.70% and 0.10 – 15.82% respectively. However, these ores differ in the average zinc content: 3.66% in primary ores and 4.26% in mixed ores. The clarke concentration of zinc decreases from west to east (CC = 673; 583; 422). The weighted average zinc content among natural types of commercial ores is expressed by the following values: banded sulfide-polymetallic ores – 4.99%, massive sulfide-polymetallic ores – 3.31%, massive sulfur-sulfide ores – 0.85%. The fluctuations ranges of zinc content in non-commercial ores are quite large – from 0.01 to 9.50%, on average – 1.10%. At the same time, samples with a zinc content of more than 6% are found sporadically.

In terms of the concentration level of weighted average content of **lead**, the following increasing series is noted in the industrial-technological types of ores of the Filizchay field: primary – mixed – oxidized ores. The latter are characterized by fairly wide limits of element concentrations. A similar series is also established for silver. The highest content of lead and silver among the various textural and mineralogical types of ores is found in layered-banded sulfide-polymetallic ores, and the lowest in spotted-impregnated and veinlet ores.

The distribution character of lead in the ores of the Filizchay field is similar in many ways to the distribution of zinc. The average content of lead in oxidized ores is 3.45%, which is higher than that of primary and mixed ores. The concentration of lead varies from 0.03 to 11.90% in mixed ores, and from 0.01 to 7.49% in primary ores, 2.32 and 1.41% at average contents respectively. The clarke concentrations of lead are significantly high (CC=1575; 1206; 819). In natural types of balance ores, the weighted average contents of lead in banded and massive sulfide-polymetallic and massive sulfur-sulfide ores are respectively: 2.03; 1.48 and 0.31%. The concentration of lead drops sharply and averages 0.15% in noncommercial ores. Samples with a lead content of more than 1.5% are found sporadically.

The concentration of **copper** in the ores of the field varies over a wide range: from 0.01 to 11.0%. The distribution of average copper content in certain technological types and grades of pulp ores establishes the following descending series: mixed (1.56%) – primary (0.58%) – oxidized (0.12%). This regularity reflects the actual picture of the structure of the ore deposit fully and the geochemical peculiarities of the distribution of copper. Clarke concentration (CC) of copper increases from west to east 121; 123; 130. Mixed ores are represented by layered-banded massive sulfide-polymetallic ores, which were partially subjected to oxidation. The area of distribution of these ores covers the zone of secondary sulfide enrichment. It was in this zone that supergene copper minerals developed: chalcosine, covellite, bornite. This explains the increase in copper concentrations in mixed ores by almost three times compared to primary ones. The copper content in the latter ranges from 0.01 to 8.90%, and the weighted average content of this element in primary ores is 0.58%. The weighted average contents of copper in individual natural types of commercial ores are similar and amount to: 0.70% in banded sulfide-polymetallic ores, 0.81% in massive sulfide-polymetallic ores, 0.71% in massive sulfur-sulfide ores. It should be noted that despite the wide limits of copper content in commercial ores, 80% of the samples involved in calculating reserves contain this element in an amount of 0.3-1.0%.

Oxidized ores differ sharply in terms of **silver** concentration among the technological types and varieties of Filizchay, with an average content of 160.1 g/t. The limits of silver content are similar in primary and mixed ores. In terms of average contents, primary ores (44.08 g/t) are inferior to mixed ores (67.95 g/t). The average silver content in natural types of ores decreases, similar to lead, in the following order: in banded sulfide-polymetallic ores – 60.15 g/t, in massive sulfide-polymetallic ores – 43.46 g/t, in massive sulfur-sulfide ores – 19.11 g/t. Noncommercial ores contain, on average, 13.98 g/t of silver. Moreover, the vast majority of samples cover intervals up to 30 g/t. The maximum isoconcentrations of this element are confined to the upper horizons of the northwestern half of the field, where the average content is 75.6 g/t. The average silver content is 55.2 and 43.3 respectively in the central and eastern parts. CC = 1080; 788; 618 decreases in the same series.

The close geochemical relationship between silver and lead is indicated by the high correlation coefficient between these elements (r=+0.628) in sulfide-polymetallic ores, which is significant. A significant correlation in the ores under consideration is also established between silver and zinc: r = +0.568[12]. The equation of connection

[12] Новрузов, Н.А., Саттар-заде, Н.А. Особенности химизма колчеданных руд Филизчайского месторождения // – Баку: Вестник Бакинского Университета, Серия естественных наук, – 2015. № 1, – с. 121-127.

between these elements is expressed as following: Ag=16.7097+8.2638 Zn. There is no correlation between silver and copper, gold and copper. The dissertation also describes in detail the peculiarities of the distribution of associated elements in ores and in wallrocks. Histograms of the frequency distribution of the contents of these elements are presented and the correlation coefficients between their contents are estimated[13].

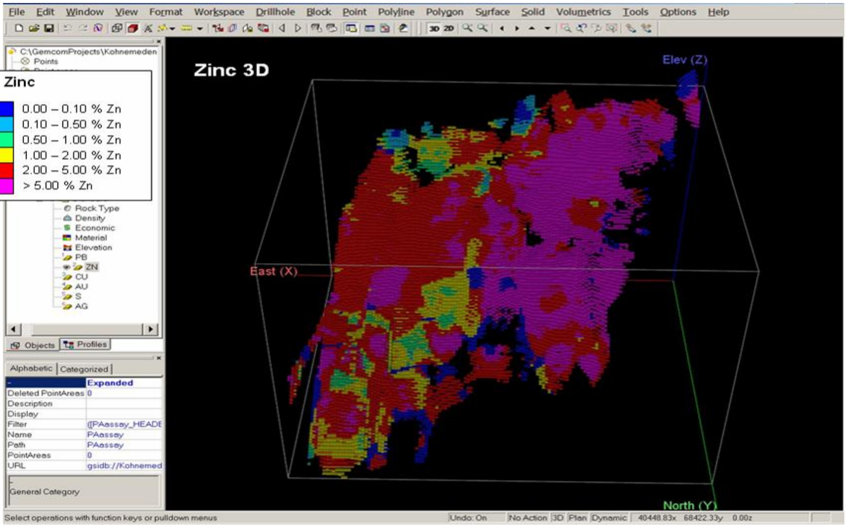
4.2. Peculiarities of the mineralogical and geochemical zoning of the ore deposit of the Filizchay field

To identify regularity in the distribution of chemical elements, the results of numerous analytical data were processed and 3D models were built for ore-forming elements. It has been established that there is a decrease in the contents of zinc, lead (Fig.1), cadmium, indium, thallium, silver, gold, bismuth, antimony, arsenic in the main deposit of the studied field from the western flank to the eastern flank and an increase in the concentrations of copper, cobalt, mercury, nickel and selenium. Along the dip of the ore deposit, geochemical zoning is expressed in a decrease of the concentrations of zinc, lead, cadmium, indium, bismuth, antimony, arsenic and an increase of the contents of copper, cobalt, nickel and manganese[14]. A block model, which was compiled on the basis of drill hole data, shows that the upper 200 m part and the eastern flank of the field are enriched in copper and silver.

Due to 3D computer modeling, mineralization zoning within the ore body is clearly observed, providing additional opportunities for future metal production planning and deposit assessment.

[13] Səttar-zadə, N.A. Filizçay yatağinin filiz komponentlərinin geokimyəvi xüsusiyyətləri // – Bakı: Bakı Universitetinin xəbərləri, təbiət elmləri seriyası, – 2019. №2, – s. 59-65.

[14] Новрузов, Н.А., Саттар-заде, Н.А. Основные черты минералого-геохимических особенностей руд месторождения Филизчай (Азербайджан) // – Москва: Отечественная геология, – 2019. №2, – с. 50-54.



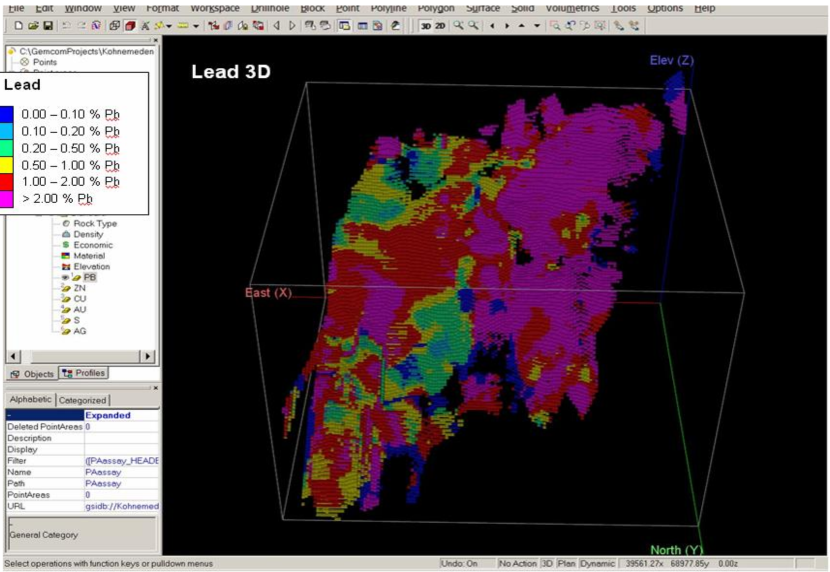


Figure 1. Zoning of zinc and lead along the western part of the Filiz-chay field (3D model)

CHAPTER 5. GEOCHEMICAL MODEL OF THE FILIZCHAY FIELD AND ORE GENESIS

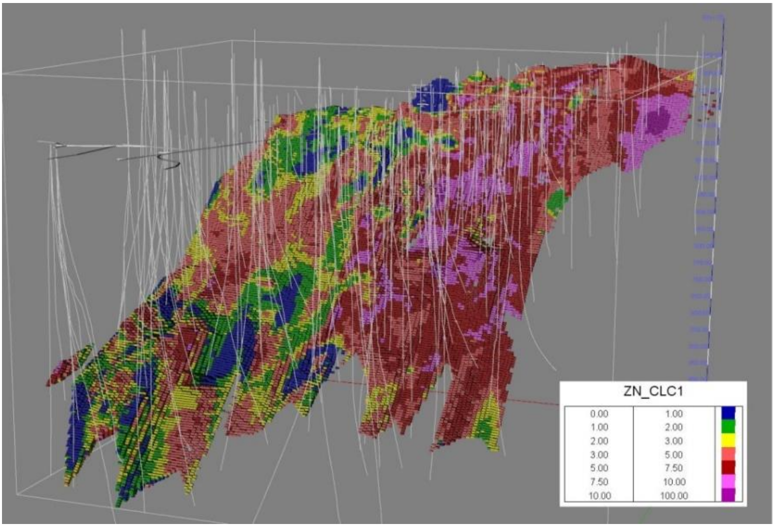
5.1. General concepts about the "Leapfrog Geo" program and methods for setting up a geochemical model

Using the 3D model and structures embodied in the integrated "Leapfrog Geo" program, a mineralogical and geochemical model of not only the ore deposit, but also all elements of the field was created.

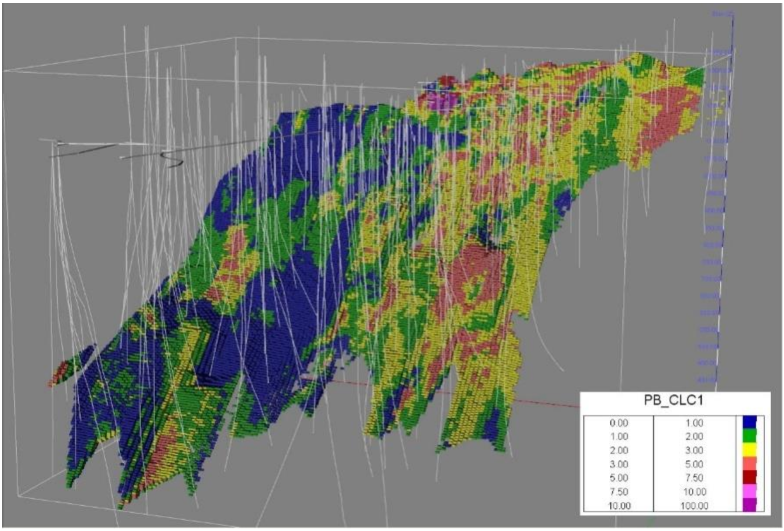
5.2. Geochemical model of the Filizchay deposit

Based on the "Leapfrog Geo" program, the spatial distribution of valuable components (Cu, Zn, Pb), their sum, as well as the distribution of S, Ag, which have a high content for the deposit of the Filizchay field, were constructed.

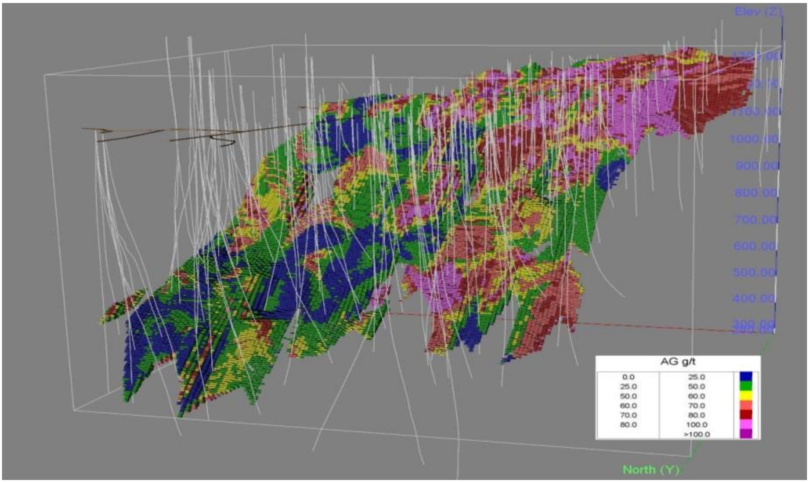
A comparison of the lead and zinc models shows that most of their local maxima and minima coincide (Fig. 2). Here, a comparison of the lead and zinc model with the copper model shows that the maxima and minima of lead and zinc contents do not always coincide with areas of high and low contents of copper. The pattern of spatial distribution of silver is similar to the distribution of lead and zinc.



a



b



c

Figure 2. Spatial distribution of zinc (a), lead (b) and silver (c) at the Filizchay field

In order to characterize the spatial variability of mineralization, an analysis of the content of useful components along the lateral, normal and dip of the deposit was carried out. To do this, isolines of the true thicknesses and contents of zinc, lead, copper, silver and gold were constructed on the projection of the ore deposit onto a horizontal plane. Analysis of the iso-thickness map shows clearly that the greatest thickness is characterized by the eastern flank of the deeper, shallow dipping part of the deposit, where its thickness almost everywhere exceeds the average value of this parameter for the field.

The isoconcentration maps of *zinc and lead* clearly show that the distributions of these elements practically repeat each other (Fig.1,2). The western half of the body differs sharply from the eastern half in its persistently high (more than average) concentration of these elements. The eastern half, which is generally characterized by below-average concentrations, contains the vast majority of minima zinc concentration and almost all minima of lead concentration. So, according to the degree of intensity of manifestation of zinc, lead and silver mineralization in the deposit, two parts can be distinguished: the western – richer, where almost all the maxima are concentrated, and the eastern – poorer, which accounts for most of the minima[15]. The distribution of the main ore-forming components (zinc, lead and copper) in a horizontal section is illustrated on plans of three horizons representing the upper, middle and deep parts of the field.

5.3. Issues of the genesis of the field

The dissertation on the characteristics of the composition of ores, geological conditions of occurrence and connections with igneous rocks analyzes in detail the family of pyrite deposits, including their classical types, distinctive and similar features. According to the characteristics of the ore composition, geological conditions of occurrence and connection with igneous rocks, the dissertation analyzes in detail the family of sulfide fields (VMS, SEDEX, MVT), including their classical types (Kuroko, Altai, Cypriot, Bessi and Ural), distinctive and similar peculiarities. It is noted that the sulfide fields of the Rudniy Altai, Southern Urals and Lesser Caucasus in the mobile

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[15] Саттар-заде, Н.А. , Имамвердиев, Н.А. Геохимические особенности и зональность залежи Филизчайского колчеданно-полиметаллического месторождения (Южный склон Большого Кавказа) // Северо-Кавказский регион: Известия высших учебных заведений, – 2022. № 4-2, – с. 60-76.

zones of the Hercynian and Alpine ages have many common peculiarities. The ores were formed under conditions of an active volcanic process, the derivatives of which were ore-hosting volcanogenic formations, sulfide ores, explosive breccias and post-ore dikes.

The Filizchay field is very different from the abovementioned types of sulfide fields. There is no direct connection with volcanism at this field. In contrast, the host rocks here are finely rhythmic flyschoids with series of sandstones, shales and silty clay. According to the geological structure, the reserves of valuable components (Zn+Pb+Ag) of the Filizchay field can be classified as SEDEX type of fields[16].

To confirm this concept, the dissertation examines in detail the origin issues of sulfide objects of the Greater Caucasus, including the Filizchay field.

Summarizing the views on the origin of sulfide-polymetallic fields on the southern slope of the Greater Caucasus, we note that most researchers support their exhalation-sedimentary genesis, which was then subjected to hydrothermal-metasomatic and metamorphogenic processes.

This situation is typical for SEDEX type of fields. Unfortunately, this type is not mentioned in the existing literature on the genesis of the Filizchay field. But, according to the latest publications of Western researchers, the Filizchay field refers precisely to this type[17,18].

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[16] Imamverdiyev, N.A., Sattar-zade, N.A. Filizchay pyrite-polymetallic deposit (the southern slope of the Greater Caucasus) - as a typical representative of the SEDEX type pyrite deposits // – Dnipro, Ukraine: Journal of Geology, Geography and Geoecology, – 2022, v. 31, No. 4, – p. 643-652.

[17] Emsbo, Poul, Seal, R.R., Sedimentary exhalative (Sedex) zinc-lead-silver deposit model / R.R. Emsbo Poul Seal, G.N. Breit, S.F.Diehl, [and &] // U.S. Geological Survey Scientific Investigations Report, – 2010. № 5070, – 57 p.

[18] Goodfellow, W.D., Lydon, J.W. Sedimentary exhalative (SEDEX) deposits. In: Goodfellow, W.D. (Ed.) Mineral deposits of Canada: a synthesis of major deposit types, district metallogeny, the evolution of geological provinces, and exploration methods // – Ottawa: Geological Association of Canada Special Publication 5, – 2007. – p. 163–183.

5.4. The mechanism of ore deposit formation

According to N.M. Zairi[19], syngenetic pyrites from the host rocks are characterized by a wide dispersion of the isotopic composition δS^{34} - 60% sulfur, which indicates a biogenic nature.

δS^{34} in all textural varieties of ores varies in a narrow range (from +1.0‰ to 6.0‰), which are isotope-normal, homogeneous, high-temperature, and are associated with a deep hydrothermal source.

So, the isotope composition of sulfur of the main minerals (pyrite, galena, sphalerite, pyrrhotite, chalcopyrite) selected from various types of ores of the Filizchay field allowed N.M. Zairi[21,20] to come to the conclusion that the deposit was formed from several portions of incoming hydrothermal solutions, which we can agree with. Moreover, each portion of the solutions was different in the isotopic composition of sulfur, with a general tendency to increase the content of the S^{34} isotope from the earliest sulfide stage (δS^{34} =+3‰) to the final process of chalcopyrite ore formation (δS^{34} =+6‰).

So, the Filizchay field is combined in its formation method and is formed due to components carried out by hydrothermal flows associated with underwater alteration of basalts (palagonitization). The formation temperatures of primary sulfide-polymetallic ores are relatively low. They are determined by the surprisingly constant difference in δS^{34} between pyrite and sphalerite coexisting in the same sample. Fluctuations of this difference are 1.0-3.0%, on average 2.0%[21,22]. On the one hand, such constancy indicates the formation of sphalerite and pyrite from a single solution, and on the other hand, a

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[19] Заири, Н.М. Закономерности вариаций изотопного состава серы сульфидов и некоторые вопросы формирования колчеданных залежей Балакяно-Закатальского рудного района (Южный склон Большого Кавказа): / автореф. дисс. на соискание геол.-минер. наук / – Москва, 1972. – 23 с.

[20] Заири, Н.М. Изотопно-геохимические модели формирования месторождений золото-углеродистой формации: / автореф. дисс. докт. геол.-минер. наук / – М., 1992. – 46 с.

[21] Гриненко, В.А. Изотопы серы / В.А.Гриненко, Л.Н. Гриненко - Москва: Наука, – 1974. – 275 с.

[22] Гриненко, В.А., Заири, Н.М., Шадлун, Т.Н. Полигенная природа сульфидов в стратиформных месторождениях // – М.: Геология рудных месторождений, –1974. №1, – с. 66-75.

relatively low temperature of their formation (from 200° to 100°C) according to different measurements[23,24,25].

Copper-pyrrhotite ores were formed under different conditions. The similar isotopic composition of sulfur in their sulfides, the same spectrum and amount of impurities as in sulfides of sulfide-polymetallic ores, as well as numerous remains of early pyrites in impregnated ores, indicate that the substance of copper-pyrrhotite ores is not introduced from the outside, but arises in the process of transformation of earlier impregnated ores. The presence of magnetite, biotite and actinolite in them indicates the high temperature of their formation. According to the Fe content in pyrrhotites (mostly 47.2, less often 47.0%), the temperature of its formation is 350-400°C[21,26].

So, considering the formation mechanism of the Filizchay field, the following can be noted:

The relationship of natural types of ores composed of various mineral associations with the stages of folded and disjunctive dislocations allows to divide the process of deposit formation into the following three stages of ore formation: 1. deposits of massive hydrothermal-sediment based pyrite ores; 2. formation of hydrothermal-metasomatic ores of pyrite-copper-polymetallic composition; 3. deposition of hydro-thermal-metamorphogenic ores of copper-pyrrhotite composition. Available data indicate a favorable environment for the formation of sedimentary pyrite ores with a significant role of C_{org} and sulfate reducing bacteria. At the same time, hydrothermal-sedimentary processes played the main role in the accumulation of the bulk of sulfide masses. The significant role of the hydrothermal-

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[23] Труфанов, В.Н. Термобарогеохимические условия формирования рудных месторождений Большого Кавказа: / автореферат дисс. докт. геол.-мин. наук / Смирнов, С.С. – Тбилиси, 1983. - 48 с.

[24] Ohmoto, H., Rye, R. Isotopes of sulfur and carbon // Geochemistry of hydrothermal ore deposits, – 1979. v.2, – p.509-567.

[25] Vikentyev, I.V. Metamorphism of volcanogenic massive sulphide deposits in the Urals / I.V.Vikentyev, E.V.Belogub, K.A.Novoselov [et al.] // Ore Geology Reviews, – 2017. v. 85, – p. 30-63.

[26] Ингерсон, Е. Методы и проблемы геологической термометрии. Проблемы рудных месторождений / Е. Ингерсон. – М.: ИЛ, –1958. – с. 309-374.

sedimentary process is also shown by data of sulfur isotope of pyrites[21,22]. Evidence of hydrothermal-sedimentary ore deposition is also the fact that an outpouring of spilites and basalts occurred in the neighboring northern block (in a narrow trough-shaped depression) by the period of accumulation of sediments of the ore-bearing horizon. These post-volcanic exhalations (as primary sources) can be associated with the introduction of iron sulfides into the more southern basin with stagnant waters. The presence of these processes is evidenced by the widespread development of argillaceous shales and series of terrigenous flysch of ore rhythmites ("ore flysch") in the underlying ore deposit, as well as veinlet ores of essentially pyrite composition, which underwent intense dynamometamorphism due to the development of cleavage fracture of flow. Apparently, sulfide ores of the syndepositional depressions accumulated in clayey sediments, which are deposited under stagnant conditions.

In our opinion, this circumstance predetermined the polygenic genesis of the ores of the Filizchay field[27].

CONCLUSIONS

1. The number of sulfide impregnations, concretions and nodules (mainly pyrite composition) increases naturally from top to bottom – from the Toarcian to the Pliensbachian, reaching a maximum in the third series of the Pliensbachian shales (Filizchay series), which hosts the stratiform sulfide deposit of the field. On the contrary, metamorphism increases in the opposite direction from the Pliensbachian to the Toarcian, which is explained by the coverage of the terrigenous strata of the Toarcian by the Kohnamedan shear zone;

2. The beginning of the formation of modern structures of the Kasdag-Filizchay ore cluster is associated with the growth during the Lower Jurassic of the Kasdag and Karabchay longitudinal syndepositional uplifts, which are separated by a narrow uncompensated trough, where outpourings of initial basalts and ore exhalations oc-

[27] Sattar-zade, N.A., Imamverdiyev, N.A. Origin of the Filizchay ore field (the southern slope of the Greater Caucasus) // – Dnipro, Ukraine: Journal of Geology, Geography and Geo-ecology, – 2023. 32(4), – p. 839-848.

curred, creating stratiform ore bodies of these fields, corresponding in time to the Pliensbachian and Toarcian centuries;

3. It has been established that there is a decrease in the contents of zinc, lead, cadmium, indium, thallium, silver, gold, bismuth, antimony, arsenic in the main deposit of the studied deposit from the western flank to the eastern flank and an increase in the concentrations of copper, cobalt, mercury, nickel and selenium. Along the dip of the ore deposit, geochemical zoning is expressed by a decrease in the concentrations of zinc, lead, cadmium, indium, bismuth, antimony, arsenic and an increase in the contents of copper, cobalt, nickel and manganese.

4. A clearly expressed zoning in distribution has been established in the field of textural and mineralogical types of ores and in the distribution of the main ore components, as well as accompanying elements according to thickness, updip and course in the ore deposit. The latter is expressed in the values of zoning indicators, indicator ratios of elements, as well as changes in the concentration levels of accompanying elements in sulfides.

5. Pre-ore hydrothermal alterations, represented by chloritization and carbonatization, are intensely occurred in the footwall of the deposit and develop non-simultaneously. Sericitized rocks are located zonally along ore conduit. Carbonatization is overlayed on crushed chloritized rocks in the zones of these ore conduits and spreads higher, occupying the Kohnamedan reverse-thrust zone. The mineralization is closely related to carbonated rocks. These alterations are occurred in the hanging wall of the ore deposit to a much weaker extent, where the processes of redeposition of diagenetic pyrite in the pre-ore period with the formation of acculumations of cubic crystals and framboidal spheres overlayed on regionally developed near-fault schistosity are widespread.

6. According to the geological structure, reserves of valuable components Zn+Pb+Ag of the Filizchay field can be classified as SEDEX type of fields, for which the main industrially valuable minerals are sphalerite and galena, and pyrite, which always present in the ores, can be of secondary importance or play a dominant role as in massive sulfide bodies.

7. It has been established that the field developed over a long period of time, starting from the period of sedimentation and up to the formation of ores of the copper-pyrrhotite stage. After the completion of the formation of pyrite mineralization, which has gone through the phase of regressive metamorphism, copper-pyrrhotite ores are formed, the deposition of which is preceded by brecciation of pyrite-polymetallic ores and their progressive metamorphism occurs with the formation of skarnoids with a sharp increase in temperature.

As you can be seen, the formation of pyrite-polymetallic and copper-pyrrhotite ores occurs under different physicochemical conditions. The formation of pyrite-polymetallic ores occurs under conditions of moderate and low temperatures (240-100°C) under regressive temperature conditions. At the same time, copper-pyrrhotite ores are characterized by high formation temperatures (350-400°C). The lower age limit of pyrite mineralization is determined by the presence of hydrothermal-sedimentary ores of the Upper Pliensbachian. The upper age limit is established by the presence of pebbles of hydrothermally altered rocks and sulfide ores in the conglomerates underlying the lower Upper Jurassic sediments.

PRACTICAL RECOMMENDATIONS

1. According to the intensity of occurrence of zinc, lead and silver mineralization two parts can be distinguished in the ore deposit: the western one is richer, where almost all the maxima are concentrated, and the eastern one is poorer, where most of the minima occur. According to this, in-mine exploration of the eastern flank of the deposit should be recommended, where the continuation of the ore body under the surface can be expected, judging by the intense veinlet mineralization traced 1 km east of the mine, and the inclination of the ore body in the same direction.

2. To date, the explored length of the ore body along strike is 1200 m. The few wells drilled on the eastern and western flanks of the field either do not intercept ore or produce noncommercial capacity or vein-type mineralization. However, the prospects for both flanks of the field remain unclear. The most promising is the western flank of the field, despite the fact that the wells drilled here revealed

only veinlet mineralization, and the ore-hosting thrust fault, which is traced in the exposed left side of the Karabchay River, does not contain mineralization at all. These results may indicate not a complete extinction of mineralization in the eastern direction, but a temporary interruption due to the development of several transverse flexural folds in the ore-bearing strata in this area. The abovementioned ideas determine the primary importance of structural factors in the localization of mineralization during its search. Apparently, prospecting work should be directed to areas of intense isoclinal folding, where fault structures of the thrust type, which is favorable for mineralization, can be expected. Occurrence of chloritization and carbonatization can serve as direct search indicators.

3. Geological and mineralogical data indicate a gradual wedging out of mineralization on the western flank of the field. Nevertheless, the possibility of its occurrence in the west of the traced transverse structures, where the continuation of the ore-bearing thrust is observed, cannot be excluded. Therefore, further detailed geological exploration work is recommended (drilling wells with depth of 400-500 m).

4. A very important task is the assessment of the deep horizons of an already known deposit, for which reserves are currently being calculated. According to the data of drilled wells, this ore body has been traced along a dip of about 900-950 m. For further exploration of deep horizons, it is necessary to drill about 15-20 wells with a depth of 800 to 1500 m through a network that ensures an increase in reserves in category C_1.

List of main publications on the topic of the dissertation

Scientific papers:

1. Novruzov, N.A., **Sattar-zade, N.A.** Features of chemical composition of pyrite ores of the Filizchay deposit // – Baku: Baku State University News, Natural Science Series, - 2022. No. 4, - p. 81-91. (in Russian)

2. Novruzov, N.A., **Sattar-zade, N.A.** About the distribution of impyrity elements in the products of enrichment of ores of the

Filizchay deposit // – Baku: Baku State University News, Natural Science Series, – 2018. № 3, – с. 73-76. (in Russian)

3. **Sattar-zade, N.A.** About geochemical features of ore components of the Filizchay deposit // – Baku: Baku State University News, Natural Science Series, – 2019. №2, – s. 59-65. (in Azerbaijani)

4. **Sattar-zade, N.A.** Geochemical model of ore components in the ore deposit of Filizchay field // – Baku: «Young Researcher», – 2019. Volume VI, № 2, – p. 121-126. (in Russian)

5. Novruzov, N.A., Sattar-zade, N.A. The main mineralogical-geochemical features of the Filizchay deposit ores (Azerbaijan) // – Moscow: «Domestic Geology», – 2019. №2, – p. 50-54. DOI: 10.24411/0869-7175-2019-10025 (in Russian)

6. Novruzov, N.A., **Sattar-zade, N.A.** Characteristics of mineralogical and geochemical features of Filizchay stratiform pyritic field (Great Cacasus, Azerbaijan) // – Vladikavkaz: News of Vladikavkaz Scientific Center of the Russian Academy of Sciences, – 2022. 31 (4) – p. 69-79. DOI: 10.46698/VNC.2022.99.83.001 (in Russian)

7. **Sattar-zade, N.A.,** Imamverdiyev, N.A. Geochemical features and zoning of the Filizchay pyrite-polimetallic deposit (Southern slope of the Greater Caucasus) // North Caucasus region: News of higher educational institutions, – 2022. №4-2, – p. 60-76. DOI: 10.18522/1026-2237-2022-4-2-60-76. (in Russian)

8. Imamverdiyev, N.A., **Sattar-zade, N.A.** Filizchay pyrite-polymetallic deposit (the southern slope of the Greater Caucasus) - as a typical representative of the SEDEX type pyrite deposits // – Dnipro, Ukraine: Journal of Geology, Geography and Geoecology, – 2022. v. 31, No. 4, – p. 643-652. DOI: 10.15421/1122560.

9. Imamverdiyev, N.A., **Sattar-zade, N.A.** Geochemical peculiarities of accompanying elements Filizchay pyrite-polymetallic deposit (southern slope of the Greater Caucasus) // – Baku: Scientific Petroleum, – 2023. №1, – p. 12-19. (in Russian)

10. **Sattar-zade, N.A.,** Imamverdiyev, N.A. The peculiarities of the main ore-forming components distribution in the Filizchay field of the southern slope of the Greater Caucasus // – Kyiv: Visnyk of Taras Shevchenko National University of Kyiv: Geology, – 2023. 2 (101), – p. *43-50.* DOI: http://doi.org/10.17721/1728-2713.101.06

11. **Sattar-zade, N.A.,** Imamverdiyev, N.A. Origin of the Filizchay ore field (the southern slope of the Greater Caucasus) // – Dnipro, Ukraine: Journal of Geology, Geography and Geoecology, – 2023. 32(4), – p. 839-848. DOİ:10.15421/112374

Conference materials:

12. Novruzov, N.A., Muradkhanova G.A., **Sattar-zade, N.A.** On the typomorphic significance of impurities of rare and noble metals in pyrite deposits of the Eastern Caucasus // In the collection: "Geology, minerageny and prospects for the development of mineral resources of the Republic of Kazakhstan", Geological Sciences Institute K.I. Satpayev name's, – Almaty: – November 26-27, – 2015, – p. 327-331. (in Russian)

13. Novruzov, N.A., **Sattar-zade, N.A.** Features of the distribution of the main components of ores in the three-dimensional space of the Filizchay deposit (Greater Caucasus) // In the collection: "Problems of geology and expansion of the mineral resource base of Eurasian countries." Geological Sciences Institute K.I Satpayeva name's, – Almaty: – November 28-29, – 2019, – p. 195-200. (in Russian)

Abstracts:

14. **Sattar-zade, N.A.** About the correlations of gold and silver pyrite-polymetallic ore deposit Filizchay // 1st International Scientific Conference of young scientists and specialists «The role of multidisciplinary approach in solution of actual problems of fundamental and applied sciences (earth, technical and chemical)», – Baku: – October 15-16, – 2014, – p. 56-57. (in Russian)

15. Novruzov, N.A., **Sattar-zade, N.A.** On the composition of ore-forming minerals of the Filizchay deposit // abstracts of Republican scientific conference dedicated to the 80th anniversary of M.Nagiev Institute of Catalysis and inorganic chemistry, – Baku: – November 15-16, – 2016, – p. 72-73. (in Russian)

16. **Sattar-zade, N.A.** Textural-structural features of the Filizchay deposit // Materials of the Republican scientific conference dedicated to the 95th anniversary of the birth of Heydar Aliyev on «Actual problems of Geology», – Baku: – May 17-18, – 2018, – p. 42-44.

(in Russian)
17. Novruzov, N.A., **Sattar-zade, N.A.** Nabiyev F.N. On the geochemical spectrum of pyrite deposits of the Southern slope of the Greater Caucasus // Materials of the Republican scientific conference dedicated to the 96th anniversary of the birth of Heydar Aliyev on «Actual problems of Geology», – Bakı: – May 15-16, – 2019, – p. 16-17. (in Russian)
18. **Sattar-zade, N.A.** Features of the mineralogical and geochemical zoning of the ore deposit of the Filizchay deposit // Materials of the Republican scientific conference dedicated to the 99th anniversary of the birth of Heydar Aliyev on «Geology: problems, prospects», – Baku: – May 05-06, – 2022, – p. 66-69. (in Russian)
19. **Sattar-zade, N.A.** The main features of the distribution of the main ore-forming elements in the ores of the Filizchay deposit // Materials of the Republican scientific conference dedicated to the 100th anniversary of the birth of Heydar Aliyev on «Subsoil study and forecasting of mineral resources», – Baku: – May 1-2, – 2023, – p. 29-31. (in Russian)
20. **Sattar-zade, N.A.** Geochemical model of the main ore-bearing elements of the Filizchay deposit // Materials of the Republican scientific conference Dedicated to the 85th anniversary of Academician Vasif Baba-zadeh on «Geology: unity of theory and practice» – Baku: – December 19-20, – 2023, p. 41-42. (in Azerbaijani)

The defense will be held “___” ______ 2024 at ____ am at the meeting of the one-time Dissertation council BED 2.21 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the Baku State University of ministry of Science and Education

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