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Geological and genetic peculiarities of the formation of porphyry copper mineralization in the Goshgarchay porphyry-epithermal system (Lesser Caucasus, Azerbaijan)

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ABSTRACT

Problem statement. The third defended point. Substantiation of long-term and multi-stage formation of endogenous ore deposits and occurrences of geological and physico-chemical conditions of mineralization, ore-metasomatic and geochemical zoning in porphyry-epithermal systems.
Formulation of the purpose. Investigation of the geological and genetic characteristic of the formation of cooper-porphyry mineralization in the Goshgarchay porphyry-epithermal system based on geological and physical-chemical criteria.
Research methods. Rock samples were studied by inductively coupled plasma mass spectroscopy (ICP-MS) (Turkey, Izmir). Analytical studies were performed at the USGS Analytical Laboratory of the US Geological Survey (USGS, Denver). Using certified inhouse standars. Isotope analyzes were performed at the Stable Isotope Laboratory at the University of Arizona (Thermo Quest Finnigan Delta Plus XL). Fluid inclusion studies were carried out in the Laboratory of Istanbul University.
The main material. The basis of the factual material was a collection of samples (about 150 pieces) taken inside and around the stockwork with vein- impregnated mineralization and on its flank to a depth of more than 500 m from the surface. The samples were used to make petrographic thin sections and plates polished on both sides for the study of fluid inclusions, and the rest of these samples were clustered and dispersed on sieves.
Conclusions. The characteristic elements of the intrusions are Cu, Pb, Zn, Ag, Mo. Fluid inclusions in minerals associated with the ore, including Cu sulfates and quartz show that the ore-forming fluid may have a mineralization of 2-5 wt.% NaCl eq., although there may be a marked increase in mineralization with depth to 20-30 wt.% NaCl eq. below the ore zone. Each type of mineralization corresponds to quite a certain range of physicochemical parameters and chemical composition of the ore-forming fluid. Sulfides, which complete the ore process of the quartz-sphalerite-chalcopyrite stage, are characterized by a marked enrichment in the heavy sulfur isotope δS34 with a rather narrow range of δS34 variation from +0.1‰ to +0.7‰. Porphyry copper ores were formed in a post-magmatic hydrothermal environment at a depth of about 0.5-1.0 km at a temperature range of 365-200°C. Based on mineralogical, geochemical, fluid inclusion and sulfur isotope data, the Goshgarchay porphyry copper field represents a late stage of peripheral magmatic and hydrothermal mineralization, likely underlain by a latent porphyry field. The formation of the Goshgarchay porphyry copper deposit began with the occurrence of primary quartz veins at a depth of 2.5-3 km at a temperature of 400-250°C. Porphyry copper ores were formed in a post-magmatic hydrothermal environment at a depth of about 0.5-1.0 km at a temperature range of 365-200°C. The complexity of the objects shows the high potential of porphyry copper areas and selected areas in the rank of potential ore fields.

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Introduction

Porphyry copper fields are among the major sources of Cu, Mo, as well as Au, Ag, Sn with associated Re, W, In, Pt, Pd and Se. From 50 to 60% of world copper production falls to their share and more than 95% of world Mo production. The patterns of placement and conditions of formation of porphyry copper fields have been studied by many researchers. First of all, numerous studies on porphyry copper fields are aimed at revealing the peculiarities of their formation in different

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geodynamic settings, creating descriptive and genetic models as a basis for effective prediction, prospecting and assessing areas with economically important mineral fields [9, 26].

Porphyry copper fields of the Lesser Caucasu s are most intensively occurred in the Lok-Karabakh and Miskhan-Zangezur zones, which differ significantly in the geodynamic regime of formation and metallogenic zonation.

Formation of the Lok-Karabakh zone deposits occurred in island-arc conditions in connection with volcano-plutonic complexes, the Miskhan-Zangezur zone deposits in connection with granitoid complexes of the stage of tectonic-magmatic activation of the Iran median massif.

Accordingly, these fields in the Lesser Caucasus are characterized by double occurrences. It occurred in a narrow time interval in the Lok-Karabakh island arc (late Jurassic-early Cretaceous), and in the upper Eocene-Miocene in the Miskhan-Zangezur. Porphyry copper fields are observed in Murovdag, Gadabay, Mehmana, copper- and molybdenum-porphyry fields in Ordubad and Dalidag ore districts.

The Murovdag ore district is one of the most promising ore districts of the Lesser Caucasus folded mountain structure and is characterized by the occurrence of a number of fields and ore occurrences that are promising for copper, molybdenum, gold, lead, zinc and other minerals. There are also several fields and ore occurrences of the porphyry copper type, in which copper ore resources can be classified as large fields. The most studied is the Goshgarchay porphyry copper field, where exploration work was carried out, which allowed to identify it as very promising.

Factual materials and research methods

The basis of the factual material was a collection of samples (about 150 pieces) taken inside and around the stockwork with vein-impregnated mineralization and on its flank to a depth of more than 500 m from the surface. The collection includes samples collected from gabbroids, quartz diorites, quartz veins with galena-sphalerite-chalcopyrite mineralization. The samples were used to make petrographic thin sections and plates polished on both sides for the study of fluid inclusions, and the rest of these samples were clustered and dispersed on sieves. Atomic absorption spectrometry on a Perkin Elmer instrument allowed to quantify elements such as Cu, Mo, Cr, Ni, Co, Pb, Zn, Sr, As, Bi. Rock samples were studied by inductively coupled plasma mass spectroscopy (ICP-MS) (Turkey, Izmir). Analytical studies were performed at the USGS Analytical Laboratory of the US Geological Survey (USGS, Denver). Using certified inhouse standars. Isotope analyzes were performed at the Stable Isotope Laboratory at the University of Arizona (Thermo Quest Finnigan Delta Plus XL). Fluid inclusion studies were carried out in the Laboratory of Istanbul University

The results of spectral, atomic absorption and chemical analyzes were used when solving the issues of determining the main ore components and its genetic and geochemical properties in the Goshgarchay porphyry-epithermal system. The number of testing points within the porphyry-epithermal system was up to 1000. Their distribution was equal within the area. Rooty exposures were tested by natural outcrops and exploratory mountain excavations (trenches, pits, wells). All testing points were accompanied by geological-petrographic descriptions.

Geological setting

The formation of the secondary folding arc of the Lesser Caucasus, the compaction towards the Anatolian and Iranian plates, the longitudinal and transverse diagonal dislocations, the formation of systems, the transverse uplift zones of the Caucasus are related to the giant rupture fractures-transverse faults that control the occurrence of its orogenic effusive magmatism. The Lesser Caucasus is the main part of the Tethys orogenic belt, which stretches from the Black Sea to the Caspian Sea. This ribbon-like belt, extending to Asia, connects the Western and Central metallogenic belts of Tethys [23, 30]. The Lesser Caucasus corresponds to the collision zones of the microcontinents marked by the subduction of the oceanic crust of the Lesser Caucasus limb of the Mesotethys, covering the edges of the Eurasian plate in the north and the Iranian plate in the south [9, 23] (Fig. 1).

According to the concept of the formation of the Lesser Caucasian mature island arc on the subduction zone lying to the north, from beginning the Middle Paleozoic and including the Middle Jurassic, researchers believe that since the Late Jurassic, the subduction front shifted to the north, and then sharply changed its direction to the south-southwest [9]. The Lok-Karabakh zone is located parallel to the Kura depression, and is bounded by large thrust and upthrust-dislocations (Murovdag, Karabakh) that surround the ophiolite zone to the southwest and separate it from the Goycha-Hakara zone. This zone is intermittently characterized as an island arc, which is distinguished by calc-alkaline magmatism as a result of subduction of the Neotethys from the Jurassic to the Cretaceous. It is divided into different segments by transverse faults characterized by strong volcanism in Bajocian-Bathonian and Kimmeridgian. The model of geodynamic development of the region, which was proposed by a number of researchers [9], allows to explain sufficiently the petrological seriality and petrochemical polarity in the development of

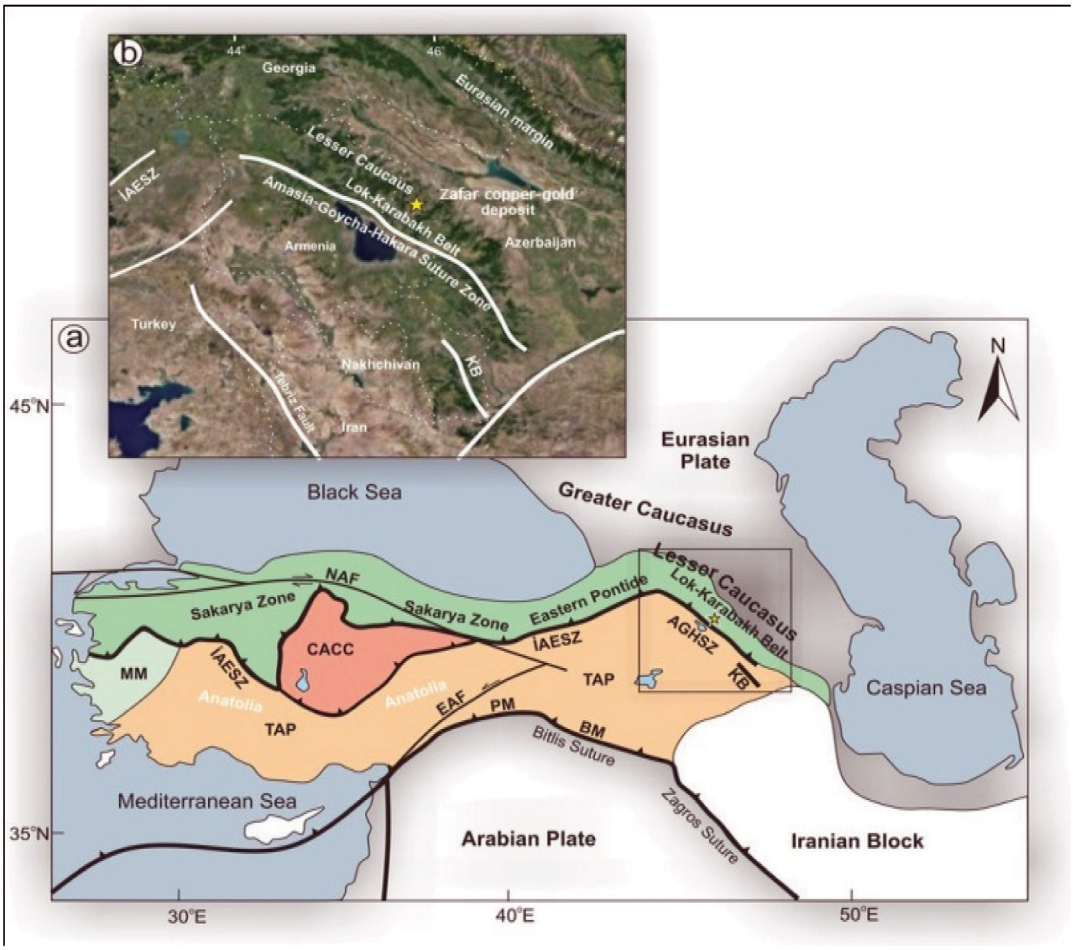

Fig. 1. Simplified tectonic map of the Caucasus area, with main blocks and suture zones

magmatism, the observed metallogenic zoning – Late Kimmeridgian and Alpine tectono-magmatic cycles and the formation of metallogenic epochs in the Lesser Caucasus. Zonally developed copper-pyrite and polymetallic, porphyry copper, skarn-magnetite, gold-polymetallic, copper-molybdenum-porphyry, antimony-mercury-arsenic and other ore deposits and occurrences were formed within the region [11].

The principles of segregation and study of the ore-magmatic system of the region are currently considered the superior and more informed direction in the theory of endogenous ore formation with optimal criteria for the search and prediction of endogenous ore deposits.

The main goal for the purpose of metallogenic research and distinguishing the ore-magmatic system is to study the regularity of the formation and location of mineral deposits and the evolution of geological processes and their spatial and temporal relationship, and the main element is the processes of magmatism and mineralization.

The analysis of materials on non-ferrous and noble metal systems in the Lok-Karabakh mature island arc shows that the ore-magmatic system develops on a single principle with sour rocks of Late Jurassic-Early Cretaceous magmatism and has an asymmetric zonal structure. They are highly metallic, promising for noble and non-ferrous metals, and are located in certain areas of island arc volcanism, forming a general zonation.

The Murovdag anticline subzone extends from west to east along the watershed of the Shahdag and Murovdag ranges, covering the Shahdag, Gamish and Murovdag highlands. Most researchers consider this structure as an integral part of the Lok-Karabakh fold zone. According to E.Sh.Shikhalibeyli [27], the second-order Murovdag anticlinorium is located after the Gamish-Toraghaychay thrust and is connected to the first-order Goyche-Hakara synclinorium, and this thrust reflects the deep fault zone and is separated from the eastern Shahdag range by the depth-specific Karabakh fault. The geological structure of anticlinorium is composed of Middle Jurassic volcanogenic formations [9, 27].

Large transversal depth faults within the anticlinorium are represented by the Goygol-Khoshbulag faults in the west, and the Murovdag-Zod faults in the eastern flank. Faults are characterized by the older NW (280-300°), near meridional (330-10°) and meridional, and relatively young near latitudinal (80-100°) and latitudinal directions [10].

Intrusives of the Murovdag group were divided into Goshgardag and Gizilarkhaj groups by R.N.Abdullayev [1] according to their geological position and spatial location. Intrusives of the Goshgardag group are located on the eastern and western slopes of Goshgardag Mountain, at the junction of the Balaja and Boyuk Qashgachay rivers. Outcrops of the Ojagdag intrusive are represented by transversely layered bodies, as well as small stock-like bodies, and they are represented petrographically by quartz diorite, gabbro-diorite, a small amount of diorite, gabbro and banatites [9].

Intrusive massifs were opened at a shallow depth by erosion processes, and only the crust of the massif participates on the upper surface. The contact surface of the intrusive is rough and dips at an angle of 55-65° towards the host rocks. This factor shows that intrusives can be attributed to solid bodies expanding at depth. T.Ab.Hasanov [14] discovered stock-shaped and dyke-shaped small outcrops of ultramafic rocks (hyperbasites) among the Early Bajocian volcanites at the junction of Boyuk and Balaja Gashgachay rivers.

The chemical and normative mineral composition of the rocks of these massifs with the most important petrochemical characteristics are given in Table 1.

The rocks in the classification diagram (Na_2O+K_2O)-SiO_2 occupy the field of rocks of normal alkalinity, which allows them to be classified as a normal petrochemical series (Fig. 2). The described classification diagrams of the rock are mainly concentrated in gabbroid fields. The diagram shows that they are compactly arranged. Other petrographic rock types or differentiates are located in the fields of quartz diorites, and according to the normative mineralogical composition here, the content of albites increases significantly, in accordance with this, the content of basic plagioclases decreases significantly [9].

According to new petro-geochemical data, it was determined by V.M.Babazadeh et al. (2008) that ultramafic volcanic rocks – picrites, picrobasalts and picrodolerites occur in this region, and their age corresponds to the Kimmeridgian Age of volcanism. Also, picrobazalts are also found in the form of thin subvolcanic bodies among Kimmeridgian volcanics within the Elbeydash syncline (Abdullayev, and others 1988).

Here, Kimmeridgian vulcanites and picrobasalts are subalkaline and are associated with trachyandesite and trachydasite. According to M.A. Mustafayev, the amount of alkali in these rocks increases to 7.40-9.0%. According to their composition (MgO – 15-20%; K_2O – 0.9-2.5%; Ni – 210 g/t; Cr – 36-400 g/t), these rocks correspond to picrite and picrobasalt [9].

As can be seen from the petrochemical analysis, the Late Jurassic (Kimmeridgian) - Early Cretaceous (Neocom) multiphase intrusives are composed of gabbroid and quartz diorite phases. The latter are associated with monzodiorites, monoquartz diorites and syenites. Each of these phases is distinguished by its own mineralization.

The intrusives of Murovdag complex are located between the calc-alkaline trend and the alkaline trend in the AFM diagram. The calc-alkaline trend corresponds to the direction of alkaline area, and the tholeitic trend corresponds to the direction of ferruginous area. As it can be seen, the evolution of magma took place in a fairly wide variation of alkalinity and iron content. Picrite and picrobasalts are low in titanium (TiO_2 - 0.40-0.57%) and potassium (K_2O-0.06-0.42%) according to their petrochemical properties. Besides, high amounts of iron oxide (FeO-10.15-16.10%) and low amounts of Ca, Mn and Al are observed in all analyses [9].

Bajocian basalt-rhyolite, Bathonian andesite-dacite-rhyolite, and Late Jurassic-Early Cretaceous basalt-andesite-dacite formation are developed within Murovdag anticlinorium. Bajocian volcanics of both complexes belong to sodium (Na_2O/K_2O>4) and potassium-sodium (Na_2O/K_2O=0.4-4.0) series [1, 9].

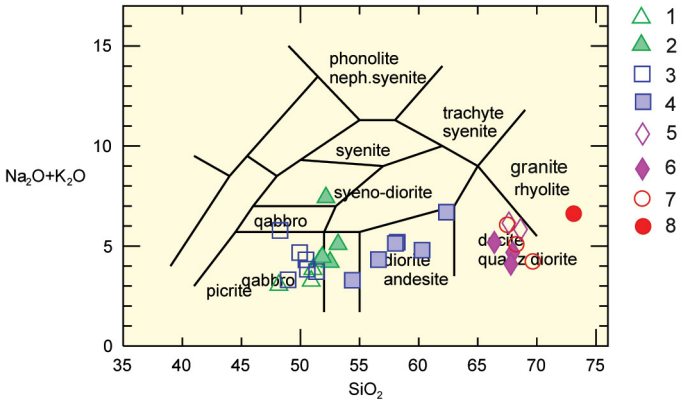

Fig. 2. Position of rocks of igneous complexes on the classification diagram (Na_2O+K_2O)-SiO_2 of the Murovdag anticlinorium: 1 - gabbro-norites, 2 - gabbroids, 3 - gabbro, 4 - quartz diorites, 5 - granodiorites, 6 - dacites, 7 - rhyodacites, 8 - rhyolites

The determining peculiarities of rare earth elements in the metasomatites and host rocks of the Goshgarchay ore-magmatic system were reviewed and it was determined that all rocks, including metasomatic rocks are characterized by a slight advantage of light lanthanoids over heavy lanthanoids. The distribution of rare-earth elements in host rocks and metasomatites of the ore district is listed in table 2. All docks, including metasomatites, ore characterized by slight LREE predominance over HREE. The ratio of La/Yb is 1.4-4.6. A significant advantage of light lanthanides over heavy ones is observed only in diorites, La/Yb=13.4. The ratio of Ce/Ce* is 0.81-1.03 in

Table 1

Chemical composition of rocks of igneous complexes of Murovdag anticlinorium

	1	2	3	4	5	6	7	8
SiO2	48.16	50.93	51.06	51.64	53.19	52.52	52.17	51.84
TiO2	0.53	0.2	0.47	1.04	0.38	1.48	0.46	1.66
Al2O3	19.63	17.79	19.14	16.87	16.48	17.87	21.88	17.45
Fe2O3	10.27	3.9	3.46	3.77	5.76	2.85	3.16	4.47
FeO	3.06	5.6	5.02	4.44	5.09	5.07	4.87	4.84
MnO	0.14	0.13	0.14	0.09	0.08	0.03	0.0	0.13
MgO	3.42	6.04	5.8	5.42	4.22	3.93	3.43	5.02
CaO	12.13	10.01	9.24	10.79	9.63	9.48	5.43	8.04
Na2O	2.27	2.56	3.44	3.63	4.54	3.43	4.53	3.74
K2O	0.79	0.74	0.44	0.64	0.57	0.76	2.87	0.73
P2O5	0.0	0.0	0.043	0.0	0.0	0.0	0.0	0.0
I	0.44	2.08	1.07	2.14	0.62	2.37	1.66	2.03
Σ	100.84	99.98	99.32	100.47	100.56	99.79	100.66	99.95

	9	10	11	12	13	14	15	16	17	18	19	20
SiO2	51.35	50.56	50.45	49.91	48.96	48.27	54.38	58.18	56.6	58.03	60.28	62.33
TiO2	0.25	0.63	0.31	0.51	0.28	0.41	0.66	0.66	0.47	0.12	0.43	0.23
Al2O3	16.55	12.36	18.15	12.98	16.68	21.78	14.37	18.24	16.51	15.01	15.63	13.83
Fe2O3	7.18	10.52	5.07	7.52	9.18	5.38	6.77	2.23	2.5	5.66	3.37	4.42
FeO	6.23	7.42	4.63	8.88	4.37	3.62	5.06	2.63	4.95	4.08	3.73	2.73
MnO	0.12	0.14	0.06	0.14	0.12	0.07	0.04	0.11	0.14	0.0	0.06	0.0
MgO	2.82	3.97	5.42	3.36	5.06	4.02	5.03	3.67	4.7	2.31	2.81	3.12
CaO	10.33	9.64	7.13	10.53	10.66	6.13	6.95	7.13	7.1	6.92	5.35	8.65
Na2O	3.36	3.13	3.43	4.08	2.73	3.88	2.28	3.96	3.2	3.32	3.46	6.22
K2O	0.35	0.73	0.88	0.61	0.58	1.87	1.0	1.23	1.12	1.82	1.33	0.48
P2O5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.09	0.0	0.0	0.0
I	2.22	1.72	4.02	2.06	1.29	4.26	3.2	1.32	2.2	3.04	2.32	0.86
Σ	100.76	100.82	99.55	100.58	99.91	99.69	99.74	99.36	99.58	100.31	98.77	102.87

	21	22	23	24	25	26	27	28	29
SiO2	68.61	67.64	67.95	67.82	66.42	69.66	68.25	67.47	73.12
TiO2	0.21	0.56	0.25	0.26	0.27	0.37	0.37	0.37	0.37
Al2O3	16.34	15.36	15.12	16.83	16.98	14.51	14.63	14.91	13.16
Fe2O3	1.96	2.03	2.28	2.26	2.23	1.73	1.83	1.68	2.17
FeO	2.54	2.56	1.47	1.98	1.75	1.56	1.28	1.86	0.98
MnO	0.12	0.12	0.07	0.02	0.09	0.07	0.06	0.05	0.06
MgO	0.0	1.06	1.77	1.78	2.43	1.73	1.87	2.68	1.66
CaO	4.0	3.54	5.16	3.62	4.27	5.12	4.83	4.23	0.82
Na2O	3.66	3.67	3.28	2.63	3.46	2.96	3.46	3.36	6.02
K2O	2.17	2.48	1.37	1.47	1.74	1.25	1.63	2.68	0.61
P2O5	0.0	0.0	0.06	0.08	0.06	0.06	0.07	0.07	0.07
I	0.56	0.76	0.98	1.03	0.95	0.72	0.97	0.88	0.68
Σ	100.17	99.78	99.76	99.78	100.65	99.74	99.25	100.24	99.72

Note: 1-4 – gabbro-norites, 5-8 – gabbroids, 9-14 – gabbro, 15-20 – quartz diorites, 21-25 – dacites, 26-28 rhyodacites, 29-rhyolites

metasomatites [16]. Absence of Ce anomaly in metasomatites may show the dominance of magmatogenic fluids in the composition of fluids that formed metasomatites and ore mineralization .The determining trends of rare earth elements in metasomatites reflect the determining characteristics of these elements in primary rocks (gabbroids, diorites and andesites) subjected to metasomatic alterations. However, the maximum value of the sum of rare earth elements is observed for diorites (91 g/t), and the minimum for gabbro (6.5 g/t). Diorites enriched in light lanthanides occur with increasing ratio of Ce/Yb. In contrast to other rocks, the ratio for these rocks is 25.7, which shows the magmatogenic origin of the fluids [15] (Fig.3).

Analysis of obtained data shows that the metasomatites and host magmatic rocks in the studied deposits have similar REE distribution patterns, which may indicate that similar magmatic rocks were protoliths for the metasomatites. This also follows from the systematic distribution of insompatible elements. In the La-Nb and Sm-NB diagrams, the metasomatites and host rocks define a common trend (Fig.4).

Analysis of the data shows that the host rocks and metasomatites have close determination parameters of rare earth elements and both types of rocks have uniform fluid nature. By characterizing the determination of rare earth elements in the igneous and metasomatic rocks of the Goshgarchay ore-magmatic system, the following conclusions can be come: 1) metasomatites and host rocks are characterized by the predominance of light rare earth elements over heavy elements, rare earth elements have a uniform genesis; 2) rare earth elements show different mobility during the formation of ore metasomatites: light rare earth elements (La to Sm) show minimal mobility, and heavy rare earth elements show maximum mobility; 3) the fact that metasomatites and host rocks have similar determination parameters

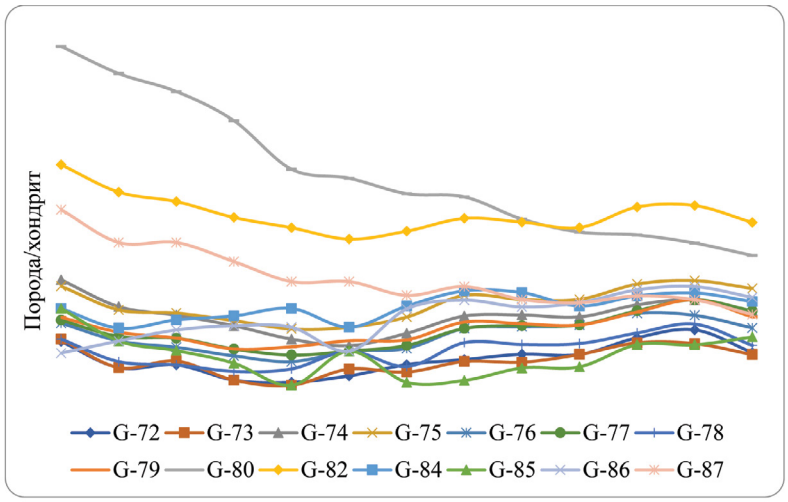

Fig. 3. Chondrite-normalized REE distribution patterns for the magmatic and merasomatic rocks of the Murovdag ore district. Normalizing valuues are from (Sun, McDonough, 1989). For sample number, see table 2

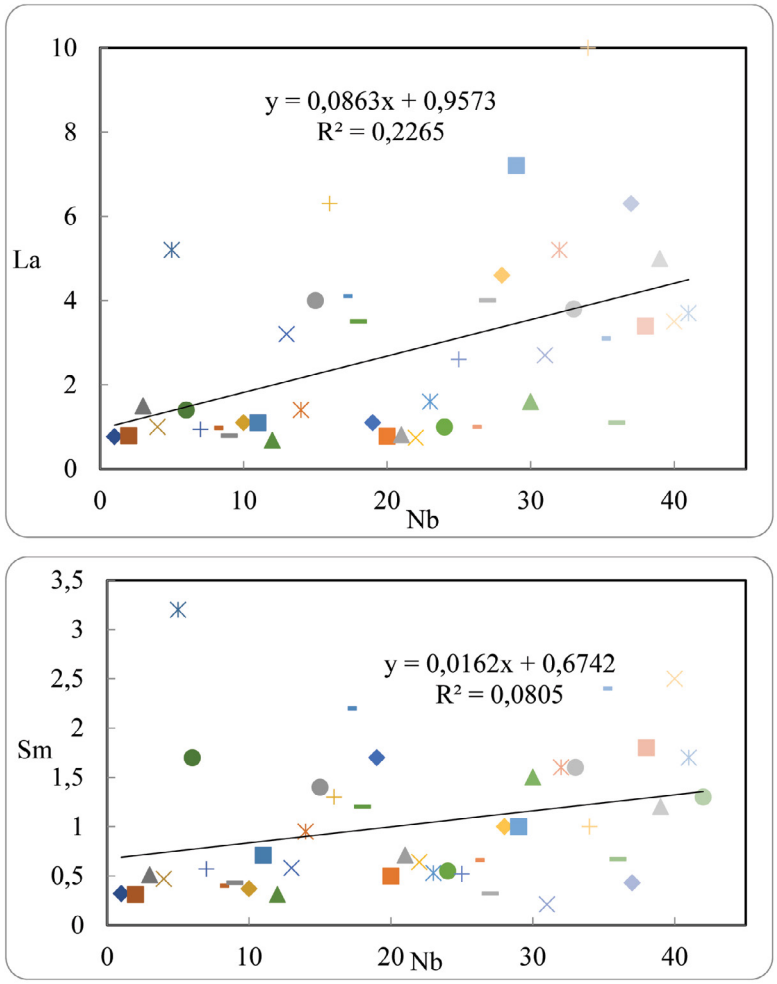

Fig.4. The La-Nb and Sm-Nb diagrams for the magmatic and metasomatic rocks of the Murovdag ore district. Intrusive rocks (gabbro, gabbro-dolerites, diorites, quartz diorites);volcanic rocks (basalts, andesitis, bazalts-andesites); metasomatic rocks (scondary quartzites, ore secondary).

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Table 2

The contents of rare – earth elements in the maqmatic and metasomatic roeks of the Murovdag ore district

Compo-nent	Gabbro				Diorite	Basalt	Andesite	Secondary quartzite	Ore secondary quartzite				Copper-porphy-ry ore
	G-72	G-73	G-74	G-79	G-80	G-82	G-75	G-76	G-78	G-84	G-86	G-87	G-85
La	0,76	0,78	1,80	1,00	18,6	5,20	1,40	0,93	0,77	1,10	0,85	3,20	1,10
Ce	1,51	1,50	2,90	2,20	36,00	10,0	2,81	2,01	1,62	2,31	2,01	5,81	2,01
Pr	0,23	0,26	0,42	0,33	4,60	1,41	0,40	0,28	0,23	0,38	0,350	0,91	0,27
Nd	1,00	1,00	1,80	1,40	16,50	5,81	1,91	1,31	1,11	2,01	1,81	3,60	1,20
Sm	0,33	0,32	0,52	0,46	3,20	1,72	0,56	0,41	0,36	0,72	0,55	0,96	0,32
Eu	0,14	0,13	0,19	0,18	1,12	0,56	0,23	0,16	0,16	0,23	0,15	0,35	0,16
Gd	0,53	0,47	0,74	0,67	3,32	2,22	0,86	0,63	0,53	0,97	0,95	1,10	0,44
Tb	0,10	0,097	0,15	0,16	0,57	0,45	0,21	0,13	0,13	0,22	0,15	0,21	0,090
Dy	0.71	0,65	1,12	1,00	3,12	3,01	1,31	0,96	0,81	1,41	1,21	1,30	0,63
Ho	0,15	0,15	0,23	0,23	0,61	0,62	0,28	0,23	0,17	0,26	0,25	0,26	0,13
Er	0,55	0,54	0,80	0,73	1,71	2,31	1,01	0,74	0,58	0,87	0,93	0,86	0,53
Tm	0,093	0,082	0,14	0,14	0,24	0,35	0,15	0,12	0,11	0,13	0,15	0,14	0,07
Yb	0,491	0,480	0,76	0,74	1,42	2,01	0,97	0,63	0,52	0,86	0,85	0,73	0,57
∑REE	6,594	6,459	11,57	9,24	91,01	35,67	12,10	8,54	7,10	11,47	10,21	19,43	7,53
La/Yb	1,572	1,646	1,947	1,387	13,356	2,60	1,427	1,467	1,491	1,293	0,763	4,323	1,895
Lan/Ybn	1,126	1,181	1,396	0,995	9,582	1,863	1,023	1,052	1/068	0,927	0,547	3,102	1,561
Eu/Eu*	0,968	1,105	0,902	1,025	1,026	0,901	0,952	1,041	1,195	0,805	0,695	1,071	1,421
Ce/Ce*	0,855	0,844	0,887	0,935	0,985	0,892	0,882	0,928	0,862	0,808	1,027	0,855	0,865
∑(REE)n	35,518	34,581	56,537	49,476	343,65	172,10	64,395	45,571	38,803	61,694	56,569	88,65	60,215
Ce/Yb	3,060	3,126	3,765	3,056	25,713	5,01	2,856	3,124	3,017	2,706	2,246	7,836	3,447
Eu/Sm	0,405	0,450	0,353	0,403	0,344	0,334	0,384	0,424	0,458	0,307	0,292	0,377	0,547

Eu/ Eu* = Eu/((Sm+(Gd)/2); Ce/Ce* = (Ce_N/ ($2La_N$ + Sm_N + Sm_N)/3)

indicates that analogous igneous rocks are the substrate for metasomatites [20].

Murovdag ore region is characterized by the prospect of porphyry copper, copper-pyrite, copper-polymetallic and other types of ore deposits and occurrences. Two ore-magmatic systems are separated within the ore region: Goshgarchay and Gizilarkhaj. The first of these includes the Goshgarchay and Goshgardagh porphyry copper, as well as the Chanakhji and Zivlan copper- pyrite deposits and occurrences. The second includes the Gizilarxhaj, Kecheldag, Jamillibulag, Erik-Manuc and Elbeydash porphyry copper and copper-polymetallic deposits and occurrences. We tried mainly to investigate the geological-genetic characteristics of the first ore-magmatic system.

Porphyry copper mineralization covering Goshgarchay, Goshgardag, Gizilarkhaj and other deposits and occurrences in the Murovdag ore region is spatially and genetically associated with the granitoid intrusive of the same name. The intrusives that make up the ore-magmatic system, the Goshgarchay complex that forms the effusive-pyroclastic complex and creates a contact-thermal relationship with them, consists of granitoid intrusives (Goshgardag, Ojagdag, Balaja Goshgardag) and their dyke systems.

Fracture structures with different directions that create the block structure of the ore-magmatic system play an important role in the spatial determination of porphyry copper and copper-polymetallic mineralization in the ore region [3].

Goshgarchay porphyry copper deposit

The deposit is considered the most promising deposit of the ore-magmatic system of the same name and is located on the southwestern flank of the Murovdag anticlinorium, adapted to the endo- and exocontact zone of the gabbro-diorite-garanodiorite formation intrusive belt.

The closest and Caucasus-oriented faults in the region are considered to be direct ore-bearing structures, and the northwest- oriented faults that cross the Goshgarchay fault from the dependent side are considered to be ore-locating structures. This is explained by the following factors: 1) localization of ore zones at the moment of dependence of fault; 2) ore zone and faults falling in the same direction at a steeper angle; 3) localization of ore zones in small fracture systems and locally significant faults; 4) adaptation of intensively hydrothermally altered rocks and impregnated sulfide mineralization to major faults of subvolcanic masses and dykes [3, 20].

Ore-metasomatic zonation. The zonation of minerals and chemical elements in the ore masses of hydrothermal deposits is directly related to the zonation of wallrock metasomatites. From this point of view, porphyry copper deposits, which clearly show the horizontal and vertical zonation of various formations of ore- forming elements and metasomatites, are considered typical [22].

During the formation of the Goshgarchay massif, the segregation of metal-bearing fluids varied, which led to the formation of a wide propylitization zone related to the initial phase, and then to the formation of potassic, quartz-sericite, and quartz metasomatites and argillization related to the acidic late phase. Most of the formation of industrially important porphyry copper mineralization occurred as a continuation of the occurrence of the early generation of porphyries [2; 3].The late phase of the porphyry is accompanied by intense silicification, which allows to note the possibility of the formation of a “quartz core” in the central part of the deposit.

Three metasomatic zones are separated in the shape of an ellipse around the quartz-diorite porphyry intrusive stock in the structure of the metasomatic column within the Goshgarchay ore- metasomatic system [3, 20]: 1) *the inner zone* was represented by intensely secondary quartzites covering the endocontact and apical part of the porphyry intrusive. According to the mineral composition, this zone corresponds to the quartzsericite facies of the secondary quartzites, and its mineralization is usually weak. A gradual increase in the amount of sulfides is observed with depth, and the amount of Cu increases from 0.01% to 0.15%; 2) *the middle zone* separates as a quartz-sericite-chlorite facies of secondary quartzites. The mineral composition of metasomatites is represented by quartz, chlorite, sericite, epidote, calcite and pyrite. The development of mineralization is particularly characteristic of the quartz-sericite-chlorite facies; 3) *the outer zone* of the metasomatic column was represented by the propylite facies of secondary quartzites. Here, propylitization has a regional distribution. New mineral assemblages represented by chlorite, epidote, albite, sericite, actinolite, and pyrite are widely developed and reflect the regional character of propylitic alteration in the host rocks.

The following main features are observed in the zoning of metasomatites in the porphyry copper deposits of the Goshgarchay ore-magmatic system: 1) positional connection with granitoid porphyry intrusive; 2) replacement of the biotite-kalifeldspath-quartz-sericite-propyllite metasomatite zone; 3) the vertical zoning order of elements is represented by Mo→ Cu→ Co → Ni → Cr → Ag→ Pb → Zn; 4) impregnated -veinlet type of mineralization [3, 14, 28].

A complex geological model of the porphyry system began to be formed as a result of development of numerous geological, petrological and metasomatic indicators. The most perfect of them belongs to R.N. Sillitoe [45]. Besides other types of deposits, the position of porphyry copper deposits is shown in this model. According to this

Table 3

Results of chemical analyses on the main ore caused elements

№	Cu	Mo	Pb	Zn	Sb	As	Ni	Co	Ti	V	Cr	Bi	Ba	Sr
G-72	105.0	0.91	11.11	83.6	0.58	1.8	2.20	0.62	667.0	127.0	1260.0	0.13	50.20	39.8
G-73	248.0	0.82	5.51	1120.0	0.41	1.3	20.7	21.0	689.0	120.0	1340.0	0.07	170.0	42.3
G-74	149.0	0.76	3.67	130.0	0.44	2.0	534.0	84.8	891.0	151.0	1530.0	0.08	57.01	35.5
G-75	88.40	2.21	51.7	173.0	0.96	2.0	321.0	59.3	1230.0	202.0	1520.0	0.14	106.01	69.6
G-76	104.0	0.46	3.63	77.21	0.22	4.2	519.0	85.7	886.0	161.0	1780.0	0.07	59.1	29.8
G-77	66.20	0.68	3.87	124.0	0.20	<1.0	539.0	88.6	949.0	156.0	2210.0	0.07	93.51	30.5
G-78	334.0	1.30	68.2	636.0	0.87	4.5	597.1	95.3	770.0	159.0	2260.0	0.10	582.0	41.2
G-79	116.0	0.66	3.07	68.7	0.25	2.3	492.1	83.6	990.0	196.0	2360.0	0.07	120.0	33.6
G-80	214.0	2.10	13.0	90.0	1.11	5.5	17.8	17.3	6750.0	102.0	261.0	0.15	864.0	699.0
G-82	49.5	1.0	7.92	60.2	0.23	4.8	26.7	20.3	2520.0	323.0	203.0	0.07	48.81	50.0
G-84	15000.0	4.5	6.72	106.0	1.0	5.8	34.8	9.50	1300.0	180.0	719.0	0.87	456.0	240.0
G-85	10900.0	4.51	9.50	49.61	2.2	12.5	34.7	8.40	819.0	123.0	738.0	0.43	95.7	249.0
G-86	20300.0	4.21	6.94	79.31	1.20	7.6	46.3	13.20	1090.0	158.0	251.0	0.34	353.0	196.0
G-87	1350.0	7.20	6.76	35.32	0.53	1.4	15.0	10.0	1160.0	92.3	421.0	0.07	112.0	290.0

Note: G –72-gabbro, G – 73-gabbro, G – 74-gabbro, G –79-gabbro, G – 80-diorite, G – 82 – basalt, G –75-andesite, G –76-andesite, G –77-andesite, G-78-secondary quartzite, G – 84-ore secondary quartzite, G – 85-porphyry copper ore, G – 86-ore secondary quartzite, G – 87-ore secondary quartzite. Rock samples were analyzed by inductively coupled plasma mass spectroscopy (ICP-MS). Analytical studies were carried out in the analytical laboratory of the United States Geological Survey (USGS) (Denver).

model, it can be stated that the main factors of metasomatic alterations in the Goshgarchay ore-magmatic system are small porphyry intrusives of the surrounding ledge, stock and dyke type, the composition of primary rocks, breccia and ore masses, ore-metasomatic zoning, mineralogical composition of ore-bearing metasomatites, etc. [30].

According to the ore-metasomatic characteristics of the porphyry copper deposits of the Goshgarchay ore-magmatic system, the following can be stated: 1) intrusive complexes associated with porphyry copper mineralization belong to the Late Jurassic-Early Cretaceous gabbro-diorite-granodiorite formation according to their geological and petrological characteristics; 2) the segregation of metal-bearing fluids was repeated many times and first led to the formation of a large propylite zone associated with the early phase and then, the formation of potassic, quartz-sericite and quartz metasomatites and argillization associated with the acidic late phase; 3) Metasomatic formations of porphyry copper deposits were represented by the successive occurrence of kalifeldspath, greisen, propylite, secondary quartzite and argillaceous formation; 4) the main volume of industrially important porphyry copper mineralization is controlled by porphyry stocks and breccia masses, and sometimes they carry the ground mass of the ore material [19].

Geochemical peculiarities of ore-forming systems. The study of the geochemical peculiarities of the porphyry copper systems of the Murovdag ore district was based on the results of chemical analysis (Table 3) of the drill-hole cores,

Table 4

Results of factor analysis of geochemical data using the method of main components

Minerals	Factors		
	F 1	F2	F3
Cu	-0,49628	0,2845950	-0,7401
Mo	-0,2032	0,113154	-0,84753
Pb	0,976722	0,02410	-0,13387
Zn	0,400451	0,033847	0,6858260
Sb	1,0606580	0,05587	-0,00528
As	1,2639560	0,1219790	-0,15024
Ni	1,3594420	0,3115810	-0,07492
Co	1,1946370	0,139580	0,4975770
Ti	-0,77458	-2,7810	-0,879241
V	-0,75297	-1,01646	2,8523180
Cr	-1,49068	1,745757	0,5305890
Bi	-0,94605	0,882603	-0,60154
Ba	-0,95204	0,335892	0,055852
Sr	-0,64013	-0,25150	-1,1892

Note: Bold font - significant values of factor loadings

at a depth of 280m on average. Geochemical data on boreholes were processed in the "STATISTIKA" program using the factor analysis method of main components [6; 7]. As a result of the conducted studies, three factors were obtained, reflecting the correlation relationship between fourteen ore elements (Table 3).

According to the weights, the elements are grouped into factors or geochemical associations,

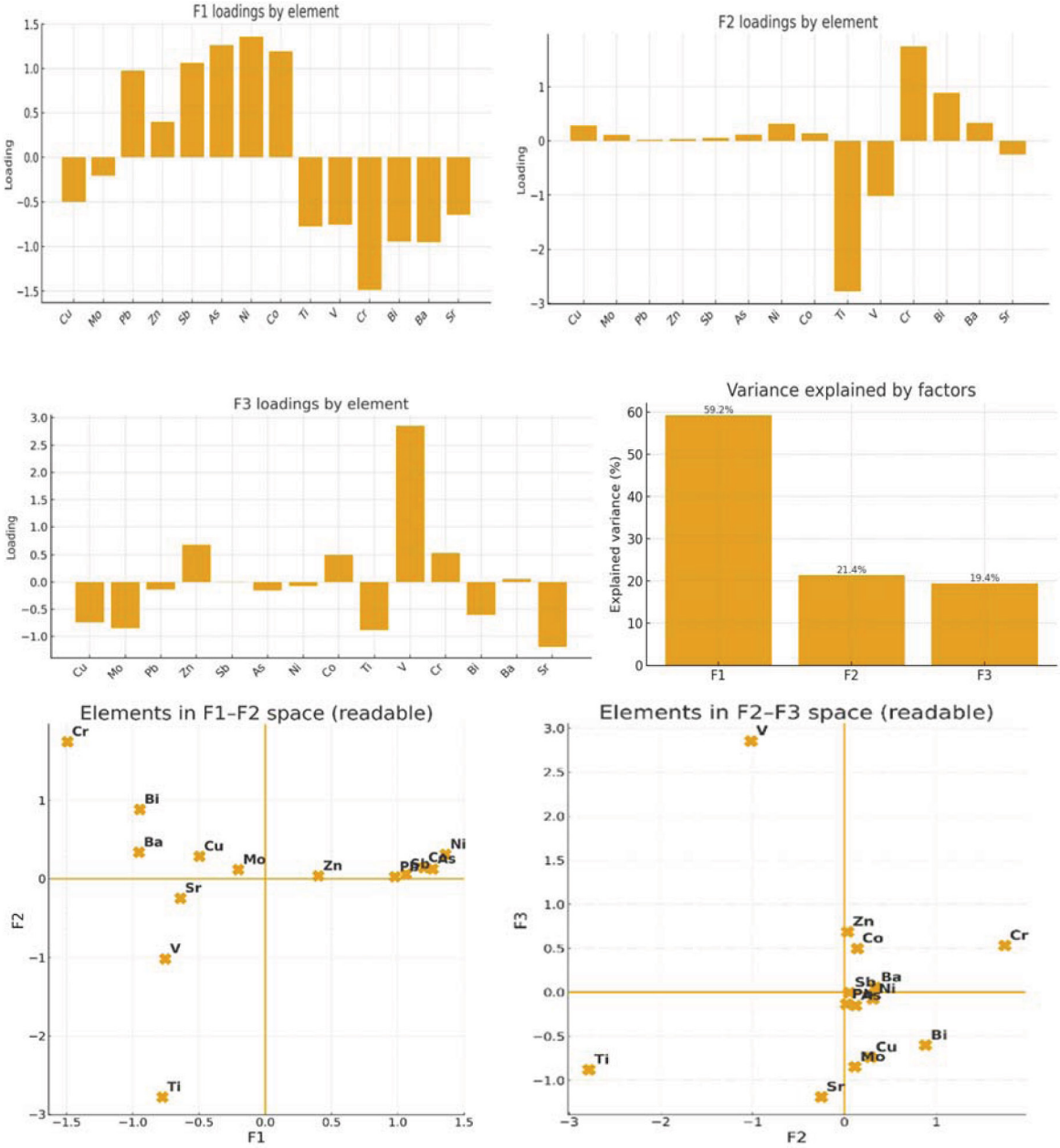

Fig. 5. Dependence graphs of F1, F2 and F3based on the results of factor analysis

which can be compared with mineral parageneses of the main stages of ore deposition [24]. The relationship between geochemical and mineral associations is confirmed by the correlation coefficients between the factor analysis of elements and the sulfide content according to drill-hole core testing data (Table 4, 5)

The values of the factor F1 correlate with the amount of chalcopyrite, bornite and pyrite, which gives grounds to link the geochemical association Cu (Mo, Pb, Sb) with the earliest chalcopyrite-bornite-pyrite mineralization of the porphyry stage of the ore-bearing structure formation.The values of factor F2 corresponding to the Mo (Cu, Pb, Co) association are statistically related to the content of chalcopyrite and molybdenite, which form the main mineral paragenesis of copper-molybdenum-porphyry mineralization. The dependence graphs of F1 and F2 based on the results of factor analysis are shown in Figure 5.

It can be concluded from the materials presented above that the elements are grouped in factors or geochemical associations comparable to the mineral paragenesis of the main ore deposition stage.

The following are considered element-indicators for various factors: 1 – Zn, Cu, Co and Ni – for the constituent factor of host rocks; 2 – Cu, Mo, Co and Ni – for geochemical specialization and primary magma type factors; 3 – Mo -– for the depth factor; 4 – Pb, Mo, Zn and Cu for ore-bearing factor [19, 20].

According to the information by V.Baba-zadeh et al. [3], and M.Mansurov [20], impregnated and impregnated-veinlet type stockwork ore masses have developed in the Goshgarchay porphyry copper deposit. Vein-type ore masses have limited

Table 5

Correlation between sulfide content and factor values based on drill-hole core testing

Minerals	Factors		
	F 1	F2	F3
Chalcopyrite	**0,949830**	**0,1232260**	0,088396
Bornite	**0,9590180**	0,042406	0,129708
Sphalerite	-0,30862	-0,84416	0,003184
Galena	0,057913	0,007865	0,994675
Pyrite	**0,9030980**	0,29172	-0,07574
Molybdenite	-0,61713	**0,5558440**	0,042268
Eigenvalues	3,116916	1,123696	1,021546
Factor loadings	0,519485	0,187283	0,170257

development, are represented by quartz and carbonate veins smeared with pyrite, chalcopyrite and molybdenite minerals, located in shear and hydrothermal alteration zones.

The stockwork-shaped ore masses cover the central part of the deposit and are adapted to the apical and outer part of the porphyry intrusive, more precisely, to its endo- and exocontact zone. Enriched areas are gradually merged and form single ore mass with a complex morphology-stockworks. According to the information by V.M.Babazadeh et al. the existence of two ore horizons, which were enriched with copper mineralization in the deposit and inclined towards the north (15-30°), was determined. The upper ore horizon has a considerable thickness and comes to the surface, while the lower ore horizon lies at a depth of 80-150 m below the surface [3].

The mineral composition of the Goshgarchay deposit is relatively simple and the following ore minerals have been found: pyrite, chalcopyrite, sphalerite, arsenopyrite, melnicovite-pyrite, marcasite-pyrite, marcasite, cobalt-pyrite, enargite, galena, chalcosine, covelline, malachite, azurite, limonite, etc.

According to a number of researchers [3, 20], the formation of the Goshgarchay porphyry copper deposit took place in two stages: hydrothermal- metasomatic ores were deposited in the first stage, and polymetallic ores were deposited in the second stage. According to the composition of copper minerals in the deposit, the following types of ores are distinguished: 1) pyrite-chalcopyrite and chalcopyrite-pyrite; 2) pyrite-bornite-chalcopyrite; 3) dull ores (pyrite)-chalcopyrite; 4) chalcocine-chalcopyrite; 5) native copper. The more common types are chalcopyrite-pyrite and pyritebornite-chalcopyrite ores.

One of the main factors in the formation and location of porphyry copper deposits is their relationships with certain magmatic complexes. From this point of view, the Murovdag anticlinorium reflects the intrusive-volcanic association characterized by andesite volcanism and represented by the gabbro-diorite-granodiorite formation of granitoid intrusive magmatism [3].

The geological-genetic model of the porphyry copper deposits of the Goshgarchay ore-magmatic system is based on geological factors such as the geological characteristics of the host rocks and fault structures, the morphology and occurrence characteristics of intrusive complexes, the mineralized phases of intrusives (porphyry, granitoid), metasomatic alterations and their formational diversity, the morphology and boundaries of ore masses, and thermobarochemical conditions of the mineralization process, stages of mineral formation and mineral associations (intermediate zone-pyrite+chalcopyrite; inner zone and core-pyrite+chalcopyrite+molybdenite), successive concentric zonal alterations, ore-metasomatic zoning, segregation of sulphide mineralization, eruptive breccias and features of erosion section [19, 21].

According to the analysis of existing geological data (structural, magmatic, geophysical, geochemical, etc.) and the results of multi-year studies on the Goshgarchay ore-magmatic system, one of the main features for the building of the geological- genetic model of porphyry copper deposits is the direct connection of the metasomatic alteration zonation of the host rocks with rich ore fields. More obvious examples are potassic, quartz-sericite secondary alterations,

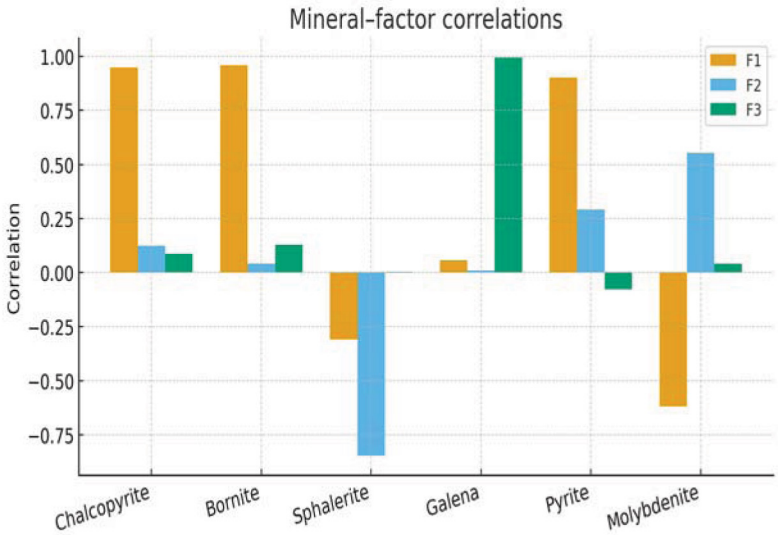

Fig. 6. Mineral–factor correlations

extended argillization and propylitization. Usually, hypogene expanded argillite alteration is formed relatively late in the formation process of the porphyry system [24, 28].

The developed model provides ideas not only about the lateral location of the metasomatic zone and sulphide mineralization in the ore-bearing intrusive, but also about the vertical determination of the

intrusive and mineral association [29], and touching on the proportions of metasomatic zones (from the center to the edges and from the bottom to the top: kalifeldspathization, biotitization, sericitization, propylitization, argillisitization, and silicifivation), it was also stated that most ore- bearing porphyry stocks were formed at a depth of 0.6-4.0 km from the surface.

Formation conditions

Studies of fluid inclusion. Recently, considerable attention has been paid to studies of the influence peculiarities of magmatic systems on ore-forming processes. Fluid inclusion analysis is increasingly used to solve these problems, allowing direct information on the physicochemical parameters of magmatic processes to be obtained. In the case of porphyry copper fields, the study of inclusions in quartz impregnations has provided a significant amount of information on ore-magmatic systems [4, 6, 26].

The use of the thermobaric geochemistry method provides for the establishment of the sequence of fluid inclusion capture in minerals of igneous rocks of ore-magmatic systems and in different mineral associations of fields, reconstruction of such parameters as temperature, salinity, gas content and metal content of fluids responsible for mineralization based on fluid inclusions, and establishing the nature of metal-bearing solutions [12, 31].

Fluid inclusions in ore-associated minerals, including Cu sulfates and quartz, show that the ore-forming fluid may have a mineralization of 2-5 wt% NaCl eq, although there may be a marked increase in mineralization with depth to 20-30 wt% NaCl eq below the ore zone [12]. This spatial separation of the low-mineralized hydrotherms, which are associated with the ores of highly sulphidized fields over the more mineralized hydrotherms in the subsurface of the system, differs from the higher mineralization of the hydrotherms that are located in deeper porphyry copper fields, where hypermineralized brines coexist with low-mineralized steam. This difference may be due to the high density of the brine, which cannot easily rise to shallow depths [5, 31].

The physical and chemical conditions of the formation of fields in the studied area can be judged by gas-fluid inclusions. We have applied the methods of homogenization and decrepitation of inclusions in quartz, galena, sphalerite and chalcopyrite in all successive stages of minerogenesis, which allows to trace the nature of alterations in the temperature regime of solutions in space and time. Fifteen samples from veins and veinlets of fields and ore occurrences of the Murovdag ore district, representing different types of mineral associations, were studied. Three generations of fluid inclusions were distinguished in quartz grains among the studied fluid inclusions according to the known criteria (Redder, 1987): I – primary, located within quartz grains with resistive fractures; II – primary-secondary, not extending beyond the boundaries of quartz grains; III – secondary, associated with resistive fractures. Fluid inclusions, which are uniformly distributed in the volume of the host mineral or confined to growth zones, are classified as primary. Inclusions confined to fractures crossing the host mineral were considered secondary. Primary-secondary fluid inclusions are confined to fractures that do not reach the outer boundaries of crystals and grains, and they are similar to primary inclusions in terms of phase filling [21, 24].

Four quartz-containing rock samples M-3,M-4, M-6 and M-10 were used for the investigation of fluid inclusions. Fluid inclusions in all samples were selected as primary and secondary according to their origin, and transparency and fluid inclusions were determined that allowed to observe the phase changes during microthermometric measurements for measurement. Primary inclusions are two-phase inclusions which are fluid and gas (type SG) at room temperature.

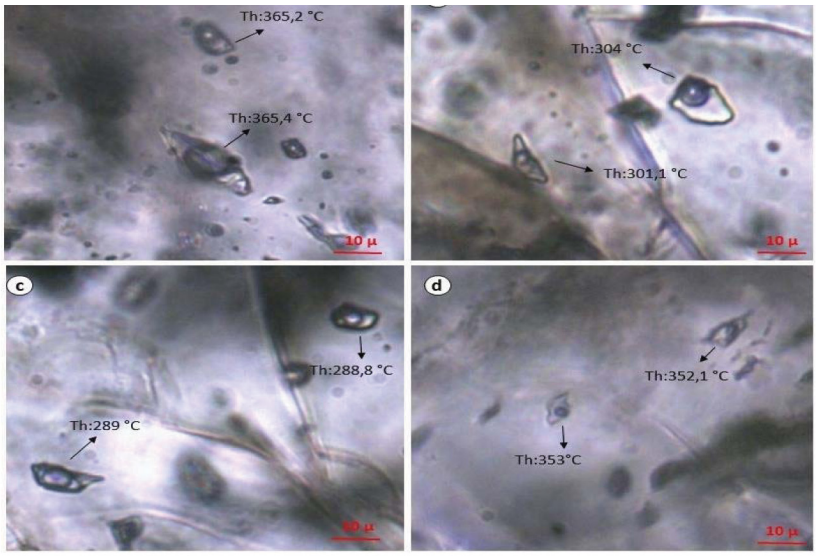

Fig. 7. View of PS-type, primary fluid inclusion associations found in quartz minerals (a, b, c, d)

The fluid phase is larger in volume than the gas phase and dominates in fluid-gas inclusions in quartz mineral. All measured primary fluid-gas type inclusions were homogenized in the gas phase. No measurements were made on secondary inclusions developing along the fractures (Fig. 7).

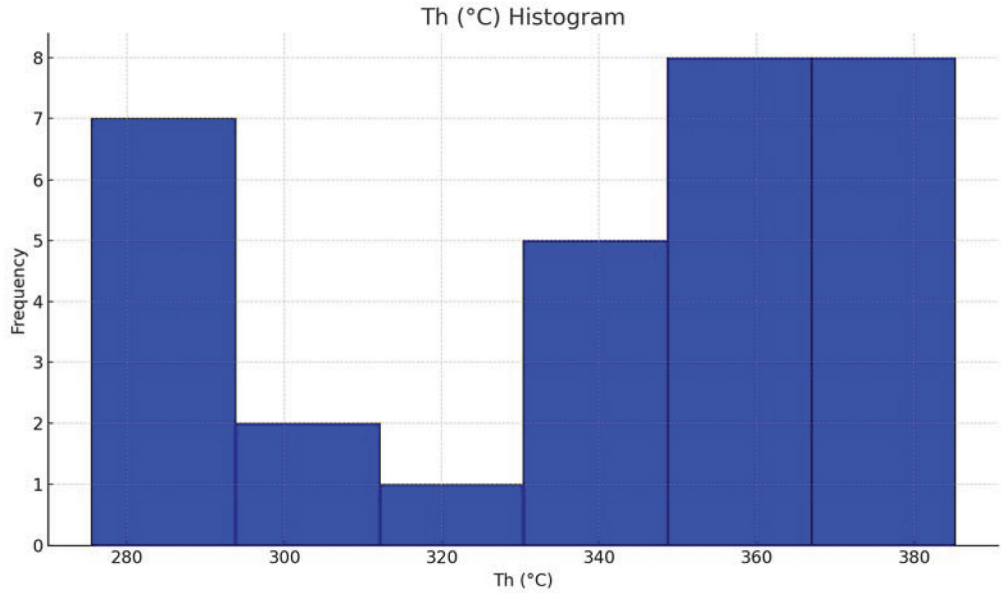

Fig. 8. Frequency histogram of homogenization temperature (Th) obtained on quartz minerals

Size of fluid inclusions found in the studied quartz samples range from 5 to 30 mμ and are typically 15 microns in size. The final melting temperature (Tm °C) and homogenization temperature (Th°C) of fluid inclusions were measured by microthermometric measurements on the studied quartz samples. It was found that Tm is between 1.5-4.8°C in the measurements performed on fluid-gas type inclusions. The homogenization temperatures (Th, °C) of the fluid-gas type inclusions range from 253.3-380°C in microthermometric measurements, and the salinity corresponding to Tm ranges from 2.6% to 7.6% NaCl ([8, 20,21].

The distribution of obtained homogenization temperature (Th) values is reflected in the Th frequency histogram (Fig. 8). The value of homogenization (Th) varies between 250-300°C (on average 278°C Th) among the first group of inclusions, and has an average salinity of 5.2% NaCl-eq. The temperatures of the inclusions in the second group are higher – 350-380°C (on average Th 366°C), and the average salinity varies in 5% NaCl eq. The value of homogenization temperature (Th) obtained from quartz minerals was determined to be 313°C on average [8, 20].

According to the obtained microthermometric data, the initial average salinity of the fluid inclusions in the quartz mineral was 5% NaCl and the temperature was 366°C, and the temperature of the fluid inclusions reached 278 °C on average, and the salinity was 5.2% NaCl on average in the later stages of mineralization (Fig. 9).

To identify the source of ore-forming solutions by the stages of minerogenesis of the Murovdag ore district, data on the isotopic composition of sulfur, sulfides and the gas phase of ore-bearing quartz-pyrite-chalcopyrite and quartz-chalcopyrite hydrotherms were used. A directed fractionation of sulfur isotopes towards enrichment of sulfides with a light isotope from the early productive stage of ore deposition to the late one was established, as a consequence of a natural increase in the oxidation potential of the hydrothermal system. Sulfides, completing the ore process of the quartz-sphalerite-chalcopyrite stage, are characterized by a marked enrichment in the heavy sulfur isotope δS^{34} with a rather narrow range of variation of δS^{34} from +0.1‰ to +0.7‰. A similar value of $\delta^{34}S$ = +10.0‰ was also shown by pyrrhotite from the halo of disseminated sulfide mineralization on the flank of the stockwork. The obtained sulfur isotope data of sulfides (+0.1‰ to +0.7‰) are significantly heavier than the range of values ($\delta^{34}S$ = 0±35‰) attributed to magmatic sulfur [13, 21, 25]. Heavy isotope-enriched sulfur could have been formed by hydrolysis of sulfides contained in the host sedimentary rocks [23]. In this case, there are no characteristic differences in the ratios of sulfur isotopes in pyrite from impregnation in wallrock altered rocks, from veinlets in host rocks and pyrite from the most enriched parts of mineralized zones [20]. So, it is assumed that there was a single source of sulfur in pyrites, which were formed under similar conditions, and the absence of sulfates in direct association with sulfides, relatively homogeneous isotopic composition of pyrite, and finally, the absence of directional separation of isotope during the ore-forming process indicate the homogenization of heavy sulfur under certain high-temperature conditions [21, 25, 26].

Ore-forming hydrothermal solutions, according to the study of fluids at 30 wt.% NaCl eq. Ore components were transported by these solutions in the form of complex ions containing sodium and potassium chlorides, and less frequently sulfates and carbonates. Mineralization occurred in the range of 350-200°C [28].

Since meteoric waters can play a significant role in the formation of porphyry fields, the occurrence of anhydrite can also be associated with the enrichment

of the lower parts of hydrothermal systems with hypergene sulfate ion in accordance with the known hydrochemical zonality of confined groundwater. The relative role of juvenile and surface waters can apparently vary widely, which is reflected in the peculiarities of the geological structure, megasomatic and ore zoning of separate fields [28].

The formation of Goshgarchay field occurred in a narrow temperature range from homogeneous fluids of essentially Na-chloride composition with moderate and low salinity. It is a typical hydrothermal field. The relatively low temperature and pressure of ore-forming fluids at this field, in comparison with other fields in the Murovdag region, may be due to the fact that only one of the four stages of porphyry copper mineralization, which usually occur in other large fields in the region, takes place here.

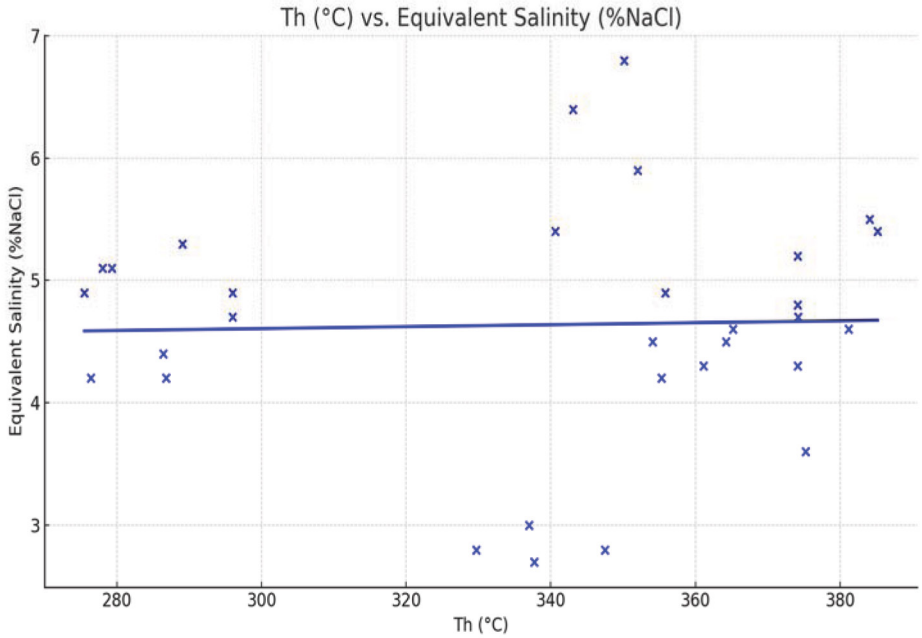

Fig. 9. Equivalent salinity diagram between homogenization temperature and NaCl % obtained on quartz minerals

So, the available data show a magmatic and partially surface origin of the substance of porphyry copper ores and solutions from which they were formed.

In most cases, the porphyry copper ore fields of the studied ore district are characterized by an insignificant level of erosion truncation, which can be judged by the analysis of facies and thicknesses of sedimentary and sedimentary-volcanogenic rocks and their paleotectonic reconstructions, by the facies of the depth of igneous rocks, by the occurrence of low-temperature contact minerals (epidote, zoisite, albite, chlorite, etc.). All this show that only the upper parts of the intrusive massifs and the spatially associated porphyry copper fields have been exposed. The ranges of values of this indicator allow to create a model of the horizontal and vertical section of the Goshgarchay porphyry copper field (Fig. 10, 11). The field is characterized by the upper ore level of

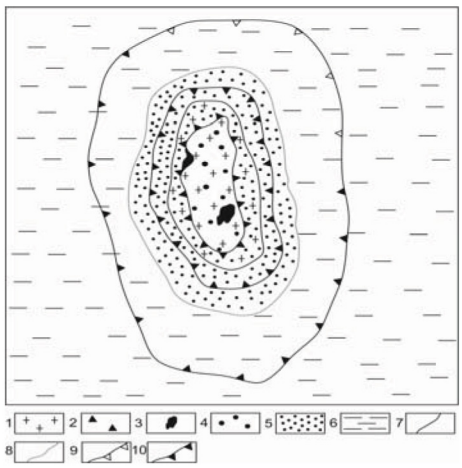

Fig. 10. Model of Goshgarchay porphyry copper deposit in vertical section: 1 - granodiorites; 2 - explosive breccias; 3 - quartz core zone; 4 - presumed kalifeldspathization zone; 5 - silicification, sericitization and chloritization zone; 6 - propylitized rocks; 7 - ore-bearing porphyry intrusive; 8 - intrusive pyritization halos; 9 - industrially significant mineralization boundary; 10 - section line

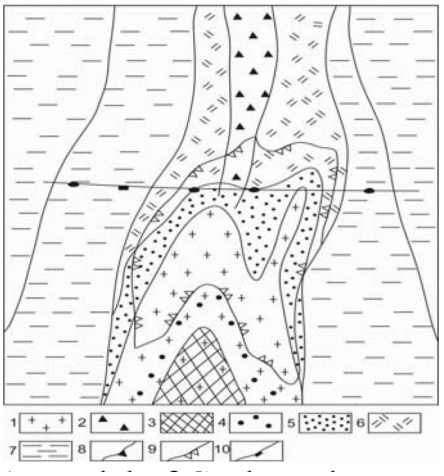

Fig. 11. Model of Goshgarchay porphyry copper mineralization in horizontal section: 1 - ore porphyry intrusive; 2 - breccia pipe; 3 - quartz core; 4 - presumed kalifeldspathization zone; 5 - silicification, sericitization and chloritization zone; 6 - argillization zone; 7 - propylitized rocks of intrusive ledge; 8 - border of intrusive pyritization halos; 9 - border of industrial mineralization; 10 - state of the erosion section

the section, epithermal mineralization is preserved most completely here, and a significant volume of porphyry copper ores is predicted at depth.

The main components of the models are the host frame (phaneric intrusions), small porphyry bodies of stock and dike types (as a rule, localized in the zones of development of ore-controlling structures and spatially closely related to mineralization), breccia bodies, ore bodies and ore-metasomatic zoning [28]. The model takes into account known ideas about the nature of the relationship between mineralization, small porphyry intrusions and locally widespread ore-bearing hydrothermalites [3, 18].

Conclusions

1. The Murovdag ore district is a promising area for porphyry copper, as well as gold and polymetallic ores.

2. Intrusive complexes with porphyry copper mineralization belong to the Late Jurassic-Early Cretaceous gabbro-diorite-granodiorite formation by geological and petrological peculiarities. The characteristic elements of the intrusions are Cu, Pb, Zn, Ag, Mo.

3. The generalized column of metasomatic zoning on the scale of the ore district and field is expressed in the successive change of the following zones: quartz → potassium feldspar → quartz-sericite → argillite → propyllite.

4. Fluid inclusions in minerals associated with the ore, including Cu sulfates and quartz show that the ore-forming fluid may have a mineralization of 2-5 wt.% NaCl eq., although there may be a marked increase in mineralization with depth to 20-30 wt.% NaCl eq. below the ore zone.

5. Hydrothermal ore deposition within the Murovdag ore district occurred in a wide temperature range (350-200°C). Each type of mineralization corresponds to quite a certain range of physicochemical parameters and chemical composition of the ore-forming fluid.

6. Sulfides, which complete the ore process of the quartz-sphalerite-chalcopyrite stage, are characterized by a marked enrichment in the heavy sulfur isotope δS^{34} with a rather narrow range of δS^{34} variation from +0.1‰ to +0.7‰. The obtained sulfur isotope data of sulfides (+0.1‰ to +0.7‰) are significantly heavier than the range of values ($\delta 34S = 0 \pm 35$‰) attributed to magmatic sulfur.

7. Based on mineralogical, geochemical, fluid inclusion and sulfur isotope data, the Goshgarchay porphyry copper field represents a late stage of peripheral magmatic and hydrothermal mineralization, likely underlain by a latent porphyry field.

8. The formation of the Goshgarchay porphyry copper deposit began with the occurrence of primary quartz veins at a depth of 2.5-3 km at a temperature of 400-250°C. Porphyry copper ores were formed in a post-magmatic hydrothermal environment at a depth of about 0.5-1.0 km at a temperature range of 365-200°C.

9. The complexity of the objects shows the high potential of porphyry copper areas and selected areas in the rank of potential ore fields.

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Геолого-генетичні особливості формування мідно-порфірового зруденіння в Гошгарчайській порфіро-епітермальній системі (Малий Кавказ, Азербайджан)

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АНОТАЦІЯ

Проведено обґрунтування тривалого та багатоетапного формування родовищ ендогенних руд та проявів геологічних та фізико-хімічних умов зруденіння, рудно-метасоматичної та геохімічної зональності в порфіро-епітермальних системах. Досліджено геолого-генетичної характеристики формування мідно-порфірової мінералізації Гошгарчайської порфіро-епітермальної системи за геологічними та фізико-хімічними критеріями. Зразки гірських порід досліджували методом мас-спектроскопії з індуктивно пов'язаною плазмою (ICP-MS) (Туреччина, Ізмір). Аналітичні дослідження проводились в Аналітичній лабораторії Геологічної служби США (USGS, Denver). Ізотопний аналіз проводився в лабораторії стабільних ізотопів Університету Арізони (Thermo Quest Finnigan Delta Plus XL). Дослідження рідинних включень проводилися в лабораторії Стамбульського університету. Основою фактичного матеріалу була колекція проб (близько 150 шт.), відібраних всередині та навколо штокверка з жильно-вкрапленим зруденінням та на його фланзі до глибини понад 500 м від поверхні. Зразки були використані для виготовлення петрографічних тонких зрізів і пластин, відполірованих з обох сторін для дослідження рідинних включень, а решта цих зразків була згрупована та розсіяна на ситах. Характерними елементами інтрузій є Cu, Pb, Zn, Ag, Mo. Флюїдні включення в мінералах, пов'язаних з рудою, включаючи сульфати Cu та кварц, показують, що рудоутворюючий флюїд може мати мінералізацію 2-5 мас.% екв. NaCl, хоча може спостерігатися помітне збільшення мінералізації з глибиною до 20-30 мас.% екв. NaCl. нижче рудної зони. Кожному типу зруденіння відповідає цілком певний діапазон фізико-хімічних показників і хімічного складу рудоутворюючої рідини. Сульфіди, що завершують рудний процес кварц-сфалерит-халькопіритової стадії, характеризуються помітним збагаченням важким ізотопом сірки δS34 з досить вузьким діапазоном зміни δS34 від +0,1‰ до +0,7‰. Мідно-порфірові руди утворилися в постмагматичному гідротермальному середовищі на глибині близько 0,5-1,0 км в діапазоні температур 365-200°C. Виходячи з мінералогічних, геохімічних даних, флюїдних включень і ізотопів сірки, Гошгарчайське порфірове родовище міді представляє пізню стадію периферійної магматичної та гідротермальної мінералізації, яка, ймовірно, лежить в основі прихованого порфірового поля. Формування Гошгарчайського мідно-порфірового родовища почалося із залягання первинних кварцових жил на глибині 2,5-3 км при температурі 400-250°C. Мідно-порфірові руди утворилися в постмагматичному гідротермальному середовищі на глибині близько 0,5-1,0 км в діапазоні температур 365-200°C. Складність об'єктів свідчить про високий потенціал міднопорфірових ділянок і окремих ділянок у ранзі потенційних рудних родовищ.

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Ключові слова:

Гошгарчайська порфірово-епітермальна, геохімічна, генетична характеристика, рідкісноземельні елементи, гідротермально-метасоматичні зміни, середовище еволюції, генетичні особливості, мідно-порфірове зруденіння, пропілітова зміна.