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[1]**Umarbekova Z.T.,**
PhD, ORCID ID: 0000-0001-7890-1851,
e-mail: zama7777@mail.ru
[1]**Gadeev R.,**
Researcher, ORCID ID: 0000-0002-9428-8142,
e-mail: gadeev_ravil@mail.ru
[1,2]**Togizov K.**
PhD, ORCID ID: 0000-0002-4830-405X,
e-mail: k.togizov@satbayev.university
[1]**Mashrapova M.A.,**
PhD, ORCID ID: 0000-0002-6009-9730,
e-mail: moldir_m_m@mail.ru
[1,2]***Miniskul Sh.D.,**
Researcher, ORCID ID: 0000-0001-8878-2008,
*e-mail: shat_230393@mail.ru
[1]**Amanbaev R.A.,**
Junior Researcher, ORCID ID: 0000-0002-7798-1076,
e-mail: rustemamanbaev_85@mail.ru

[1]K.I. Satpayev Institute of Geological Sciences, Almaty, Kazakhstan
[2]Satbayev University, Almaty, Kazakhstan

PHASE FORMS OF GOLD AND THEIR INFLUENCE ON RECOVERY IN THE OXIDATION ZONE OF THE ARKHARLY GOLD-SILVER DEPOSIT (KAZAKHSTAN)

Abstract

The aim of this study is to determine the phase forms of gold in the oxidation zone of the Arkharly deposit and to assess their influence on the efficiency of gold and silver recovery. The main research methods included mineralogical analysis, electron microprobe studies, and technological testing. The study identified and characterized silver halides, established their genetic relationship with gold, and substantiated the role of supergene processes in the redistribution of gold. The Arkharly gold-silver deposit (Kazakhstan) is characterized by a complex composition of ores and a variety of gold occurrence forms, which significantly affect processing efficiency. This paper examines the phase forms of gold in the oxidation zone and their impact on technological recovery indicators. Based on mineralogical, electron microprobe, and technological studies, it was found that gold occurs in various forms: native gold of different fineness, electrum, as well as finely dispersed particles associated with silver minerals. Particular attention is given to silver halides, widely developed in the oxidation zone and forming complex intergrowths with native silver and gold. Textural and structural features of mineral aggregates indicate the redistribution of gold under supergene conditions. The formation of gold-bearing phases is associated with chloride and, presumably, colloidal migration of matter, leading to the formation of zonal structures and inclusions of high-fineness gold. Technological test results showed low efficiency of gravity concentration due to the fine-dispersed nature of gold, and high efficiency of cyanidation and sorption leaching (gold recovery up to 93.5%). A direct relationship between the phase forms of gold and recovery indicators has been established. The obtained results expand the understanding of gold behavior in the oxidation zone and can be used in developing effective technologies for processing complex gold-silver ores.

Keywords: Arkharly deposit, gold, oxidation zone, silver halides, phase forms of gold, supergene processes, cyanidation, sorption leaching.

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Introduction

Epithermal gold–silver deposits are characterized by a significant diversity of ore forms [1–3]. This diversity exerts a decisive influence on their technological properties and the efficiency of ore processing. One of the key challenges in the development of such deposits is the presence of finely dispersed and refractory gold associated with various minerals and products of supergene alteration.

A special role in the redistribution of gold is played by processes occurring within the oxidation zone [4, 5]. Under these conditions, primary mineral associations are transformed, secondary minerals are formed, and noble metals undergo migration and reprecipitation. In a number of cases, supergene processes lead to the formation of high-fineness gold, the development of secondary enrichment zones, and the emergence of complex phase forms of the metal that differ significantly from hypogene ones.

Despite the considerable number of studies devoted to the mineralogy of gold–silver deposits, issues related to the role of silver halide compounds [6] remain insufficiently investigated. This is particularly true for deposits where complex mineral associations involving silver chlorides, bromides, and iodides are formed within the oxidation zone and may serve as indicators of specific geochemical conditions.

The Arkharly deposit, located in Southern Dzhungaria, represents a typical example of gold–silver epithermal mineralization [7], characterized by widespread quartz veins, low sulfide content, and complex mineral zonation. Unlike many other deposits in Kazakhstan, it is distinguished by elevated contents of lead and zinc, an almost complete absence of arsenic, and the widespread occurrence of adularia, amethyst, and hematite within the ores.

In the oxidation zone of the deposit, diverse supergene mineral associations are formed, accompanied by the redistribution of gold and silver [8]. The morphology and composition of gold vary significantly, indicating complex mechanisms of its transport and deposition. In particular, chloride and colloidal forms of migration may play an important role, leading to the formation of zonal structures and finely dispersed gold inclusions within silver minerals.

At the same time, the influence of gold phase forms on technological processing indicators, including gravity concentration and cyanidation, remains insufficiently studied. Practical experience shows that finely dispersed and structurally bound gold significantly reduces the efficiency of conventional extraction methods and requires a deeper understanding of its mineralogical nature.

This paper examines the characteristics of gold phase forms in the oxidation zone of the Arkharly deposit, their genetic relationship with silver halides, and the influence of the identified mineralogical features on the efficiency of technological processes for gold and silver recovery.

Geological Setting

The Arkharly deposit is located in Southern Dzhungaria and is confined to the Saryozek synclinorium, within the southern limb of the Arkharly anticline. The geological structure of the area is defined by the development of volcanogenic-sedimentary and effusive-pyroclastic complexes of Permian and Triassic age, represented by rocks of andesite–basalt, trachyandesite–trachybasalt, and trachyrhyolite formations. The geological structure of the deposit is shown in Figure 1.

The volcanic sequences are intruded by numerous intrusive bodies of Permian and Triassic age, including sills of basaltic and andesitic porphyrites, trachyrhyolite porphyries, as well as dikes of diorites, lamprophyres, and felsite porphyries [9].

Intrusive rocks within the study area belong to the Katutau and South Dzhungarian complexes. The former is represented by gabbro-diorites and granite porphyries, while the latter, within the described area, includes gabbro, diorites, and granosyenites.

A more detailed formational and petrochemical characterization of the South Dzhungarian complex is provided in [10].

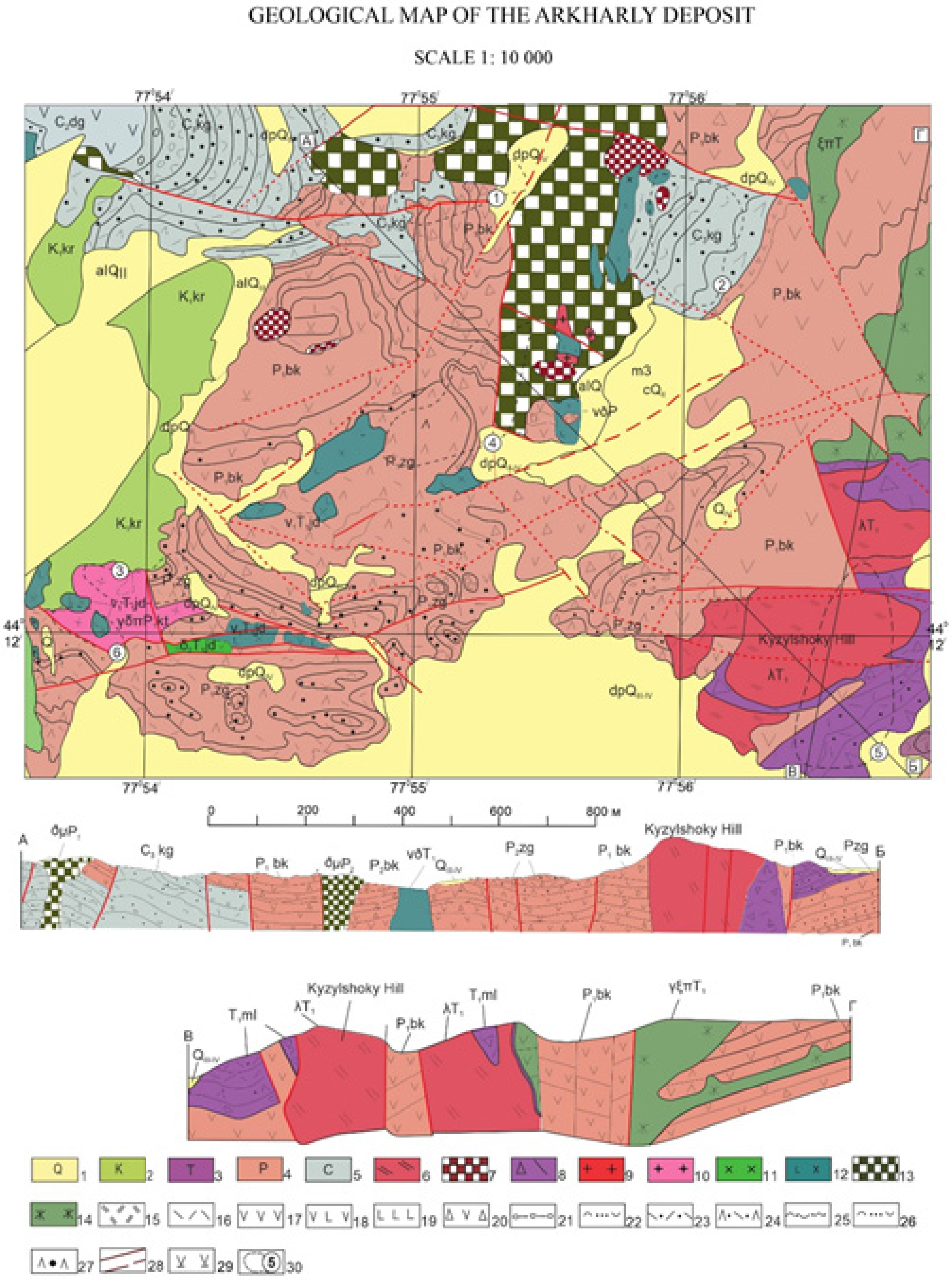

Figure 1 – Geological map of the Arkharly Au–Ag deposit showing lithological units, fault systems, and ore zones. Modified using data from Zhautikov T.M., Skrinnik L.I., as well as the authors' own observations. 1 – Quaternary deposits; 2 – Cretaceous deposits; 3 – Triassic deposits; 4 – Permian deposits; 5 – Carboniferous deposits; 6 – Kyzylshoky necks (λT1); 7 – subvolcanic trachyandesite bodies (T); 8 – vent and near-vent breccias of Kyzylshoky; 9 – granite porphyries (Pkt); 10 – granodiorite porphyries (γδπP1kt); 11 – diorites (δ2T1jd); 12 – gabbro-diabases (ν1T1jd); 13 – subvolcanic trachyandesite bodies (δμP); 14 – syenodiorite and granodiorite porphyries (ξπT); 15 – trachyrhyolite lavas; 16 – rhyolites; 17 – andesites; 18 – andesite-basalts; 19 – basalts; 20 – andesitic clastolavas; 21 – sandstones, conglomerates; 22 – tuffaceous sandstones; 23 – rhyolitic tuffs; 24 – rhyodacitic tuffs; 25 – thin interbedding of sandstones and tuffaceous sandstones; 26 – tuffaceous sandstones with tuffite interlayers; 27 – dacitic tuffs; 28 – faults: (a) exposed; (b) concealed beneath Quaternary deposits; 29 – pyroxene–plagioclase andesite-basalts; 30 – ore sites: 1 – Northern, 2 – Northeastern, 3 – Eastern, 4 – Eastern II, 5 – Kyzylshoky, 6 – Central.

The formation of the ore field is associated with the development of a dome-shaped volcano-plutonic structure controlling the localization of gold–silver mineralization.

Ore bodies are represented by a system of quartz veins, the total number of which reaches several hundred. The veins are up to 150–200 m long, 0.5 to 12 m thick, and dip at angles of 40–70°. The vertical extent of mineralization exceeds 600 m. Within the ore field, several economically significant ore zones are distinguished.

It should also be noted that breccia-type ores (explosive and eruptive breccia bodies) containing gold are present at the deposit. Their formation is associated with hydrothermal eruptions [11].

Metasomatic alterations of the host rocks are characterized by well-developed zonation. Zones of secondary quartzites (alunite-, kaolinite-, and sericite-bearing) and propylites of various compositions (chlorite–sericite–carbonate and chlorite–epidote–albite) are distinguished. Economically significant mineralization is predominantly localized within the sericite–chlorite–carbonate propylite zone.

Near-ore alterations include an outer propylitic zone and an inner zone of intense carbonatization, sericitization, and silicification. A characteristic feature of the deposit is the development of adularization associated with productive stages of ore formation [12].

Mineral zonation of the ore field is expressed by a transition from deep-seated pyrite–quartz assemblages to productive adularia–quartz and galena–sphalerite–quartz associations, followed by late chalcedony and carbonate assemblages, reflecting the evolution of the hydrothermal system.

Supergene processes are well developed in the oxidation zone and represent the final stage of deposit transformation [13]. At this stage, primary minerals are altered, iron oxides and hydroxides are formed, and secondary minerals develop. Under these conditions, gold is redistributed and secondary forms are formed, which is important for understanding the genesis of mineralization and evaluating the technological properties of ores.

Field observations confirm these patterns and allow for a more detailed characterization of the host rocks and hydrothermal alterations. Volcanic rocks of intermediate to felsic composition are developed, in which quartz veinlets and veins of varying thickness are widespread. Quartz veins often exhibit a crustiform-banded structure, reflecting the rhythmic precipitation of silica from pulsating hydrothermal fluids. Pronounced zonation of hydrothermal alteration is observed along the veins, typical of low-sulfidation deposits. From the quartz vein outward, there is a gradual transition to clay-altered rocks involving kaolinite and sericite.

Within the oxidation zones, quartz veins acquire a brownish-red coloration due to limonitization, forming halos of intense supergene alteration. In areas more distant from the veins, propylitization of andesites is observed, expressed by a greenish coloration of the rocks and the development of chlorite and epidote.

Field observations reflecting structural and metasomatic features are presented in Figure 2.

Figure 2 – Field relationships of quartz veins
and hydrothermal alteration zones at the Arkharly deposit

Materials and methods

The object of the study was oxidized gold–silver ores from the Arkharly deposit, sampled from various ore zones and stratigraphic levels. Representative ore samples, as well as technological samples prepared by quartering composite material collected from mine workings and industrial dumps, were used for mineralogical, geochemical, and technological investigations.

Mineralogical studies were carried out using optical microscopy (thin and polished sections), which made it possible to determine the morphological features of minerals, the nature of their intergrowths, and the textural and structural characteristics of the ores. Particular attention was paid to the occurrence forms of gold and silver and their relationships with secondary minerals in the oxidation zone.

The chemical composition of minerals was determined using electron microprobe analysis, which provided quantitative data on major element contents and revealed compositional zoning within individual grains. Analyses were conducted at multiple points within single mineral grains, allowing assessment of compositional variations, including changes in gold fineness within a single grain.

Additionally, X-ray diffraction (XRD) analysis was employed to refine the mineral composition of selected samples. The results enabled identification of mineral phases and confirmed the presence of silver halides.

Technological studies included tests on gravity concentration, cyanidation, and sorption leaching of gold and silver. Prior to experimentation, the ore material was crushed and ground to a specified particle size (85–90% passing −0.074 mm). Gravity concentration was performed using a shaking table, allowing evaluation of free gold recovery.

Cyanidation processes were carried out under laboratory conditions with controlled concentrations of sodium cyanide and lime, as well as controlled leaching duration. To investigate process kinetics, a series of experiments was conducted with varying contact times and degrees of ore grinding.

Sorption leaching was performed using an anion-exchange resin, enabling evaluation of gold and silver recovery from the pulp. During the experiments, pulp parameters such as density, reagent concentration, and process duration were carefully monitored.

Analytical determination of gold and silver contents in the initial samples, processing products, and solutions was carried out using fire assay and chemical methods. The obtained data were used to calculate metal recovery and evaluate the efficiency of different processing flowsheets.

Results

Mineralogical Characteristics of the Ores

The ores of the Arkharly deposit are predominantly composed of quartz (up to 50–95%), with the presence of adularia, amethyst, chalcedony, chlorite, sericite, and carbonates. The sulfide content does not exceed 3%, which allows the ores to be classified as low-sulfide type.

The principal ore minerals include sphalerite, galena, pyrite, hematite, and native gold. Secondary minerals are represented by chalcopyrite, arsenopyrite, bornite, pyrrhotite, acanthite, and other phases. A distinctive feature of the deposit is the widespread occurrence of adularia, amethyst, and hematite.

Several paragenetic associations have been identified, among which the adularia–quartz and galena–sphalerite–quartz associations are productive [14]. These associations form the main gold–silver ores and determine their technological properties. The main mineral associations are summarized in Table 1.

Table 1 – Main mineral associations of the Arkharly deposit (modified after [14])

Association	Main minerals	Genetic type
Pyrite–quartz	Pyrite, quartz	Pre-ore
Adularia–quartz	Adularia, quartz, Au	Ore (productive)
Galena–sphalerite–quartz	Galena, sphalerite, Au, Ag	Ore (productive)
Chalcopyrite–quartz	Chalcopyrite	Post-ore
Chalcedony	Chalcedony	Late stage

Textural Characteristics of the Arkharly Deposit Ores

The ores of the Arkharly deposit are characterized by a wide variety of textural and structural types, reflecting the complex conditions of their formation. Breccia-like textures are the most widespread, represented by fragments of host rocks cemented by quartz, chalcedony, or carbonate material.

Colloform and colloform-banded (agate-like) textures are also widely developed and are often combined with rhythmic banding. This indicates a pulsating supply of hydrothermal fluids and periodic precipitation of silica.

Veinlet and stockwork textures are ubiquitous and reflect multiple stages of fracturing followed by infilling with quartz and chalcedony. In some cases, lens-shaped and nest-like siliceous bodies with internal zoning are observed.

Massive and disseminated textures are also present and are typical of relatively weakly altered ore zones. In certain samples, cataclastic structures are identified, indicating a significant role of tectonic processes in the formation of the ore body.

Overall, the predominance of breccia-like, banded, and colloform textures, as well as their combination with veinlet structures, indicates a complex interaction of hydrothermal, tectonic, and supergene processes during ore formation.

Representative ore textures are shown in Figure 3, while Table 2 demonstrates the relationship between gold and silver contents and ore type and texture.

Figure 3– Representative ore samples from the Arkharly deposit showing brecciated, banded and crustiform quartz textures.

Table 2 – Main ore types and their characteristics

Ore type	Texture	Au (g/t)	Ag (g/t)
Adularia–quartz	Banded	up to 280	up to 156
Amethyst–quartz	Disseminated	0.1–40	up to 125
Chalcedony	Colloform	<0.4	up to 20
Pyrite–quartz	Massive	<0.5	up to 5

Phase Forms of Gold

Gold in the ores of the deposit is represented by various morphological and genetic types. At least two generations of gold have been identified, differing in fineness and formation conditions.

Early-stage gold is characterized by relatively low fineness (approximately 596–635) and is associated with pyrite, chalcopyrite, and sphalerite. Later-stage gold exhibits higher fineness (up to 735–772) and is related to a galena–sphalerite association.

The morphology of gold particles shows considerable diversity, including dendritic, platy, irregular, and spongy forms [15]. Gold commonly occurs as monomineralic inclusions in quartz or as complex intergrowths with other minerals.

A characteristic feature is the presence of compositional zoning within individual grains, indicating multiple stages of mineral formation.

Supergene Alteration and Silver Halides

In the oxidation zone of the deposit, a wide development of secondary minerals has been identified, including hematite, goethite, jarosite, malachite, and azurite. A significant result of the study is the identification of silver halides forming complex intergrowths with native silver and gold [16]. The association of gold with silver halides is shown in Figure 4.

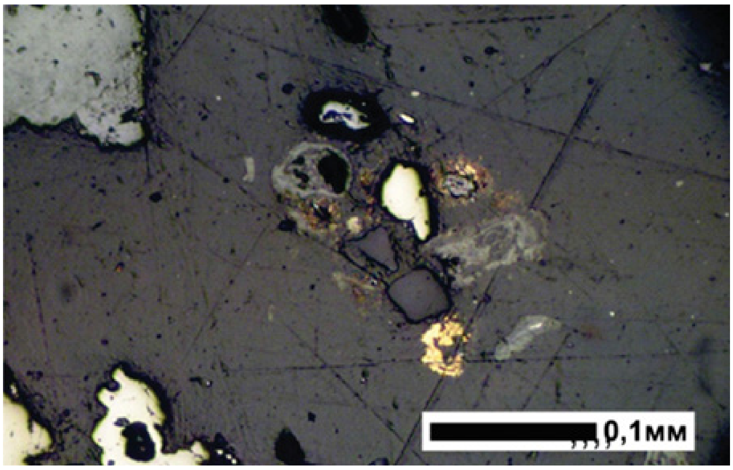

Figure 4 – Native gold associated with silver halides (grey) and pyrite in polished section.

Silver halides are represented by various phases (chlorides, bromides, and iodides) forming concentrically zoned structures. The most common are grains with a native silver core and halide rims containing microinclusions of gold [17].

Figure 5 shows chalcopyrite with a covellite rim and associated silver halides.

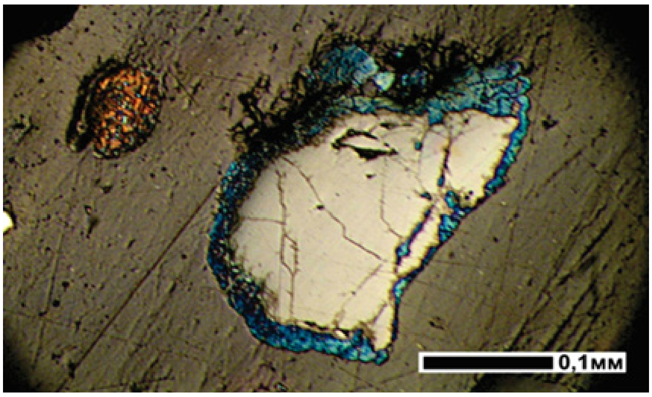

Figure 5 – Chalcopyrite with covellite rim
and associated silver halides in polished section

Complex intergrowths of electrum, native silver, and high-fineness gold are also observed (Figure 6). In some cases, gold inclusions are identified within silver and halide phases, indicating their co-formation.

Figure 6 – BSE image showing intergrowth of electrum (1)
and native silver (2) with inclusions of high-grade gold

Gold in the oxidation zone is characterized by significant variations in fineness (from ~67 to 98%), including within a single grain, which indicates its redistribution under supergene conditions.

Textural and Structural Characteristics of the Ores

The ores are characterized by the widespread development of colloform, banded, brecciated, and veinlet textures. Rhythmic zonal structures are frequently observed, indicating periodic precipitation of material.

Colloform and zonal textures are particularly typical of siliceous formations and are associated with finely dispersed gold. Breccia textures indicate the role of tectonic processes and repeated reopening of ore bodies.

The observed textural features point to a significant role of colloidal and hydrothermal–supergene processes in ore formation.

Technological Properties of the Ores

The results of technological tests show that the ores are characterized by low efficiency of gravity concentration. Gold recovery into gravity concentrates does not exceed ~18%, which is related to the predominance of finely dispersed and, in particular, structurally bound gold [18,19].

Therefore, the application of technologies ensuring more complete gold recovery is required. The average chemical composition of the deposit ore is presented in Table 3, while a comparison of different recovery methods is shown in Table 4.The average chemical composition of the ore is shown in Table 3.

Table 3 – Average chemical composition of ore

Component	Content
Au	8.17 g/t
Ag	78.73 g/t
Cu	0.012 %
Zn	0.02 %
Fe	1.91 %

Table 4 – Comparison of different methods for gold and silver recovery

Method	Au recovery (%)	Ag recovery (%)
Gravity concentration	18.5	15.3
Cyanidation	91.0	66.7
Sorption leaching	93.6	80.1
Combined scheme	92.1	74.8

Cyanidation provides gold recovery at the level of approximately 91%; however, a more efficient method is sorption leaching, which achieves recoveries of up to 93.5% for gold and up to 80% for silver.

It has been established that the optimal grinding size is about 85% passing −0.074 mm, while further increases in fineness do not lead to a significant improvement in recovery.

A combined processing flowsheet, including gravity concentration followed by sorption leaching, ensures a total gold recovery of approximately 92%.

Discussion

The obtained results indicate that the formation and redistribution of gold in the oxidation zone of the Arkharly deposit are controlled by a combination of supergene processes, including dissolution, migration, and subsequent precipitation of noble metals under varying physicochemical conditions.

One of the key factors is the involvement of chloride-bearing solutions formed as a result of sulfide oxidation and interaction with host rocks [6–20]. The presence and widespread development of silver halides in the oxidation zone indicate a significant role of halide migration, primarily for silver, and indirectly support the possibility of gold transport in the form of complex species.

The identified textural and structural features, such as concentrically zoned aggregates, inclusions of gold in silver and halides, as well as the occurrence of high-fineness gold as fine inclusions, indicate a staged character of supergene mineral formation. This suggests that gold precipitation occurred in multiple stages associated with changes in redox conditions and fluid chemistry.

Significant variations in gold fineness, including changes within a single grain, indicate processes of metal redistribution and recrystallization. High-fineness gold formed in the oxidation zone is likely the result of silver leaching from primary alloys and subsequent gold enrichment. Gold fineness reaching up to 98% in the oxidation zone confirms the leaching of silver from primary alloys and supports the supergene nature of gold redistribution [4].

Colloidal processes appear to play an important role in the formation of gold-bearing phases. The widespread development of colloform textures and the spongy morphology of gold grains indicate precipitation from gel-like media. Such conditions favor the formation of finely dispersed gold and its association with secondary minerals.

The established mineralogical features are directly reflected in the technological properties of the ores. The low efficiency of gravity concentration is explained by the fact that a significant portion of gold occurs in finely dispersed forms or as intergrowths with other minerals, which hinders its recovery by gravity methods.

At the same time, the high efficiency of cyanidation and sorption leaching is associated with the accessibility of gold for dissolution despite its dispersed state [21, 22]. This indicates that gold is not entirely locked within resistant mineral phases but occurs in forms amenable to chemical extraction.

Thus, the identified relationship between gold phase forms and technological recovery parameters confirms that mineralogical composition is a key factor controlling ore processing efficiency. Accounting for these features enables the rational selection of processing flowsheets and improves gold and silver recovery.

Conclusion

It has been established that the ores of the Arkharly deposit are characterized by a complex mineralogical composition and a wide variety of gold phase forms, represented by native gold of varying fineness, electrum, and finely dispersed occurrences.

In the oxidation zone of the deposit, a widespread development of silver halides has been identified, forming complex intergrowths with native silver and gold, indicating specific geochemical conditions of supergene mineral formation.

Gold redistribution in the oxidation zone is associated with migration in chloride-bearing and, likely, colloidal solutions, followed by precipitation as high-fineness gold and finely dispersed inclusions.

A staged character of gold formation has been established, expressed in zonal grain structures, variations in fineness, and morphological diversity of gold particles, reflecting changes in physicochemical conditions during mineral formation.

It has been shown that the textural and structural features of the ores (colloform, zonal, and brecciated textures) indicate a significant role of colloidal and supergene processes in the formation of gold–silver mineralization.

Low efficiency of gravity concentration is due to the finely dispersed nature of gold and its occurrence in intergrowths, whereas cyanidation and sorption leaching provide high recovery levels (up to 93.5% for gold).

It has been demonstrated that gold phase forms are a controlling factor in ore processing, and consideration of mineralogical features allows for the justification of an optimal gold and silver recovery flowsheet.

The obtained results have both theoretical and practical significance. On one hand, they refine the understanding of mechanisms of supergene gold redistribution and the role of silver halides in these processes. On the other hand, they can be applied to the development and optimization of processing technologies for similar oxidized gold–silver ores.

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[1]Умарбекова З.Т.,
PhD, ORCID ID: 0000-0001-7890-1851,
e-mail: zama7777@mail.ru
[1]Гадеев Р.,
ғылыми қызметкер, ORCID ID: 0000-0002-9428-8142,
e-mail: gadeev_ravil@mail.ru
[1,2]Тогизов К.,
PhD, ORCID ID: 0000-0002-4830-405X,
e-mail: k.togizov@satbayev.university
[1]Машрапова М.А.,
PhD, ORCID ID: 0000-0002-6009-9730
e-mail: moldir_m_m@mail.ru
[1,2]*Минискул Ш.Д.,
ғылыми қызметкер, ORCID ID: 0000-0001-8878-2008
*e-mail: shat_230393@mail.ru
[1]Аманбаев Р.А.,
кіші ғылыми қызметкер, ORCID: 0000-0002-7798-1076,
e-mail: rustemamanbaev_85@mail.ru

[1]Қ.И. Сәтбаев атындағы Геологиялық ғылымдар институты, Алматы қ., Қазақстан
[2]Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті,
Алматы қ., Қазақстан

АРХАРЛЫ АЛТЫН-КҮМІС КЕН ОРНЫНЫҢ ТОТЫҒУ АЙМАҒЫНДАҒЫ АЛТЫННЫҢ ФАЗАЛЫҚ ТҮРЛЕРІ ЖӘНЕ ОЛАРДЫҢ АЛЫНУ ТИІМДІЛІГІНЕ ӘСЕРІ (ҚАЗАҚСТАН)

Аңдатпа

Осы зерттеудің мақсаты – Архарлы кен орнының тотығу аймағындағы алтынның фазалық түрлерін анықтау және олардың алтын мен күмісті алу тиімділігіне әсерін бағалау. Негізгі зерттеу әдістері ретінде минералогиялық талдау, электрондық-зондтық зерттеулер және технологиялық сынақтар қолданылды. Жүргізілген зерттеулер нәтижесінде күмістің галогенидтері анықталып, олардың алтынмен генетикалық байланысы көрсетілді, сондай-ақ алтынның қайта таралуындағы гипергендік процестердің рөлі негізделді. Архарлы алтын-күміс кен орны (Қазақстан) кендердің күрделі құрамымен және алтынның әртүрлі кездесуімен сипатталады, бұл олардың өңдеу тиімділігіне айтарлықтай әсер етеді. Жұмыста тотығу аймағындағы алтынның фазалық түрлері және олардың технологиялық көрсеткіштерге әсері қарастырылған. Минералогиялық, электрондық-зондтық және технологиялық зерттеулер негізінде алтынның әртүрлі түрде кездесетіні анықталды: әртүрлі сынамалы табиғи алтын, электрум, сондай-ақ күміс минералдарымен байланысқан ұсақ дисперсті бөлшектер. Ерекше назар тотығу аймағында кең таралған және табиғи күміс пен алтынмен күрделі бірігулер түзетін күміс галогенидтеріне аударылды. Минералдық агрегаттардың текстуралық-құрылымдық ерекшеліктері гипергендік жағдайларда алтынның қайта таралуын көрсетеді. Алтынды фазалардың қалыптасуы заттың хлоридтік және, мүмкін, коллоидтық миграциясымен байланысты, бұл зоналық құрылымдардың және жоғары сынамалы алтын қосындыларының түзілуіне әкеледі. Технологиялық сынақтардың нәтижелері алтынның ұсақ дисперсті сипатына байланысты гравитациялық байытудың төмен тиімділігін және циандау мен сорбциялық шаймалаудың жоғары тиімділігін көрсетті (алтынды алу 93,5%-ға дейін). Алтынның фазалық түрлері мен оны алу көрсеткіштері арасында тікелей байланыс анықталды. Алынған нәтижелер тотығу аймағындағы алтынның мінез-құлқын тереңірек түсінуге мүмкіндік береді және күрделі алтын-күміс кендерін өңдеудің тиімді технологияларын әзірлеуде қолданылуы мүмкін.

Түйін сөздер: Архарлы кен орны, алтын, тотығу аймағы, күміс галогенидтері, алтынның фазалық түрлері, гипергендік процестер, циандау, сорбциялық шаймалау.

[1]Умарбекова З.Т.,
PhD, ORCID ID: 0000-0001-7890-1851,
e-mail: zama7777@mail.ru
[1]Гадеев Р.,
научный сотрудник, ORCID ID: 0000-0002-9428-8142,
e-mail: gadeev_ravil@mail.ru
[1,2]Тогизов К.,
PhD, ORCID ID: 0000-0002-4830-405X,
e-mail: k.togizov@satbayev.university
[1]Машрапова М.А.,
PhD, ORCID ID: 0000-0002-6009-9730,
e-mail: moldir_m_m@mail.ru
[1,2]*Минискул Ш.Д.,
научный сотрудник, ORCID ID: 0000-0001-8878-2008,
*e-mail: shat_230393@mail.ru
[1]Аманбаев Р.А.,
младший научный сотрудник, ORCID ID: 0000-0002-7798-1076,
rustemamanbaev_85@mail.ru

[1]Институт геологических наук им К.И. Сатпаева, г. Алматы, Казахстан
[2]Казахский национальный исследовательский технический университет им. К.И. Сатпаева,
г. Алматы, Казахстан

ФАЗОВЫЕ ФОРМЫ ЗОЛОТА И ИХ ВЛИЯНИЕ НА ИЗВЛЕКАЕМОСТЬ В ЗОНЕ ОКИСЛЕНИЯ НА ЗОЛОТО-СЕРЕБРЯННОМ МЕСТОРОЖДЕНИИ АРХАРЛЫ (КАЗАХСТАН)

Аннотация

Целью настоящего исследования является установление фазовых форм золота в зоне окисления месторождения Архарлы и оценка их влияния на эффективность извлечения золота и серебра. Основным методом исследования являлись минералогический анализ, электронно-зондовые и технологические исследования. Проведенным исследованием выявлены и охарактеризованы галогениды серебра, установлена их генетическая связь с золотом и обоснована роль гипергенных процессов в перераспределении золота. Золото-серебряное месторождение Архарлы (Казахстан) характеризуется сложным вещественным составом руд и разнообразием форм нахождения золота, существенно влияющих на эффективность их переработки. В работе рассмотрены фазовые формы золота в зоне окисления и их влияние на технологические показатели извлечения. На основе минералогических, электронно-зондовых и технологических исследований установлено, что золото представлено различными формами: самородным золотом разной пробности, электрумом, а также тонкодисперсными выделениями, ассоциированными с минералами серебра. Особое внимание уделено галогенидам серебра, широко развитым в зоне окисления и образующим сложные срастания с самородным серебром и золотом. Текстурно-структурные особенности минеральных агрегатов свидетельствуют о перераспределении золота в гипергенных условиях. Формирование золотоносных фаз связано с хлоридной и, вероятно, коллоидной миграцией вещества, что приводит к образованию зональных структур и включений высокопробного золота. Результаты технологических испытаний показали низкую эффективность гравитационного обогащения, обусловленную тонкодисперсным характером золота, и высокую эффективность цианирования и сорбционного выщелачивания (извлечение золота до 93,5%). Установлена прямая зависимость между фазовыми формами золота и показателями его извлечения. Полученные результаты расширяют представления о поведении золота в зоне окисления и могут быть использованы при разработке эффективных технологий переработки сложных золото-серебряных руд.

Ключевые слова: месторождение Архарлы, золото, зона окисления, галогениды серебра, фазовые формы золота, гипергенные процессы, цианирование, сорбционное выщелачивание.