Distribution of gold and silver content in copper-pyrite ores of the Gadabay deposit

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Abstract. The gold content in copper-pyrite ores of the Gadabay deposit is considered. The purpose of the research presented in the basis of the article, was to find out the features of the gold content of copper-pyrite deposits in the Lok-Karabakh metallic zone, using the example of the Gadabay deposit, for the development of examples and the forecasting of new sites and objects. Gadabay Field is located in the axial part of the Shamkir uplift. of the Lok-Garabakh structural-formational zone of the Lesser Caucasus. The character of gold and silver distribution in the ores of the Gadabay deposit was studied by atomic-adsorption methods. It was found that in different types of ores and monomineral fractions of basic sulfide minerals (pyrite, chalcopyrite, and sphalerite), noble metals (Au, Ag) are distributed unevenly. Thus, the average content of gold and silver is 0.8 and 13.6 g/t, and in pyrite-chalcopyrite-sphalerite mineral associations, the average content of gold and silver is 2.3 and 36.2 g/t. In monomineral fractions of sulfide minerals, the highest gold content is observed in chalcopyrite, where the average content is 3.8 g/t. As a result of mineralogical studies, it was established that in the ores of this deposit, gold is in free and associated form. Native gold is located inside sulfide minerals (pyrite, chalcopyrite) and often in association with them. As a result of rational analysis, it was established that the predominant amount of gold is in the free state (44.0%) and in intergrowths with late sulfide minerals (pyrite, chalcopyrite) (45.3%). The predominant amount of native gold is found in intergrowths with basic sulfide minerals.

Key words: gold, monomineral, histograms, frequency of occurrence, ore, deposit.
Introduction

The study of the gold content of the pyrite deposits is of great practical importance, so recently, special attention has been given to the solution to this problem. This interest is connected, first of all, with the growth of their involvement in industrial development in order to create and expand the gold mining industry in Azerbaijan.

The absence of microscopically visible inclusions in Au-Cu ores indicates the presence of finely dispersed gold, evenly distributed throughout the thickness of the ore bodies.

Considering the large volume of ore mass, pyrite deposits are considered one of the most promising sources of gold production. Therefore, a comprehensive study of the above deposits is of great scientific and practical interest. The achievements of modern scientific and technological progress in the field of development and processing of ore minerals allow us to take a new approach to the assessment and development of mineral resources in the subsoil of Azerbaijan. In this regard, the most optimal and realistic direction is to re-evaluate both existing gold reserves, previously exploited, and newly discovered ones, and determine the possible value of their industrial development using progressive technological methods, taking into account the peculiarities of the distribution of gold and associated metals.

An important role in the development of the gold content of pyrite deposits in the Lok-Garabag structural-formational zone of the Lesser Caucasus was played by the works of G.H. Efendiev, I.N. Sitkovsky, N.K. Kurbanov, T.G. Gadzhiev, A.N. Musaeva, E.S. Suleymanova, V.M. Babazade, G.S. Guseinova, V.I. Gegelishvili, K.D. Tomadze, V.I. Gugushvili, A.G. Megaslashvili, S.A. Kekeliah, and many other researchers.

Taking into account the above, we studied the gold content of copper-pyrite ores in the Gadabay deposit.

Gadabay deposit is located in the axial part of the Shamkir uplift of the Lok-Garabag structural-formational zone of the Lesser Caucasus, within the ore district of the same name. It is located in the exocontact zone of a granitoid intrusion in the core of a central-type extrusive structure.

The geologic structure of the deposit involves Middle and Upper Jurassic sediments, which are represented by volcanogenic rocks of the Lower and Upper Bajocian, Bata, and Callovian. Lower Bajocian volcanics – basalts, andesibasalts, and their tuffs – are intensively orogenized in the halo of the intrusion of the same name. The upper bajos are represented by rhyolites, which overlie the sediments of the Lower Bajocian. The rhyolites are hydrothermal altered and transformed into secondary quartzites. The Bathian Stage rocks transgressively overlie the rhyolite sequence and are composed of basalts, partly andesites and their tuffs, as well as tuffobreccias. In turn, they are overlain by tuffogenic-sedimentary and carbonate sediments of the Callovian-Oxfordian stages. The carbonate sediments have a very limited development, and from the contact impact of the Gadabay intrusive, they are intensely metamorphosed and transformed into vesuvian skarns (Aliyarov et al., 2023; Baba-zadeh et al., 2018; Badhban et al., 2015; Guseinov and Abasova, 2023; Guseinov and Mamedov, 2023; Kekelia et al., 2014).

The deposit is confined to the brachyanticlinal fold (Arykhdam), inherited by a central-type volcanic structure developing on the site. The structure is complicated by synvolcanic, steeply dipping faults, which were repeatedly renewed and played the role of ore supply channels. Porous, fractured, and chemically active in relation to the sedimentation of ore matter, the upper volcanoclastic horizons of rocks of the rhyolite sequence (late Bajocian), near their contact with the covering andesitic porphyrites (Bathonian), which are attributed to a screening role (Fig.1), were favorable for the localization of sulfide mineralization (Abdullayeva et al., 2017).

The structural position of the deposit is determined by its location on the extreme southeastern dip of the Shamkir anticlinorium, at the junction with the Dashkesan synclinorium, and its confinement to the southeastern side of the brachyanticlinal uplift, which is part of the Arykhdam caldera. The most significant elements of tectonics are the Gadabay, Fedorovsky, and Western faults in northeastern and sublatitudinal northwestern directions. The 40-kilometer-long Gadabay fault is essentially the main ore-control structure that determines the position and location of deposit deposits (Babazadeh et al., 2017; Gotishvili, 1980).

Another major discontinuity is the Fedorovsky fault, which, parallel to the Gadabay fault, runs northwestward east of Misdag. The western fault is the western boundary of the field, along which the volcanogenic-sedimentary stratum is in contact with andesibasalt volcanics.

Transform faults of sublatitudinal strike are the most important elements of the structure, influencing the location of vent facies of acid volcanics and cuprous deposits (Gao et al., 2022; Abdullayeva et al., 2016).

The main ore-bearing sediments are Upper Bajocian rhyodacites transformed, in most cases, into secondary quartzites (monoquartzites, quartz-kaolin-
ite, etc.), within which all known deposits of cuprous ores are located. They extend in a wide (500–700 m) strip of north-west strike and are overlapped in the west by Bath andesite-basalts, completely unaffected by metasomatic processes.

Results

A mineralogical study revealed that the bulk of hypogene minerals in the deposit ores are composed of pyrite, chalcopyrite, and sphalerite. Arsenopyrite, pyrrhotite, galena, magnetite, marcasite, and others are found in subordinate amounts. Among the hypogenic minerals, iron hydroxides, chalcosine, covellite, malachite, azurite, and cuprite are noted.

Ores from the Gadabay deposit were formed in several stages of mineralization: quartz-pyrite, pyrite-chalcopyrite-sphalerite, and quartz-carbonate. It should be emphasized that the above mineral associations contain noble metals (Au, Ag).

The study of the mineral association of gold with surrounding sulfide minerals is of great practical importance in its extraction from gold-bearing sulfide ores and is also important for the development of criteria for prospecting these deposits. As is known (Nironskiy, 1998), the dominant mineral associations of gold in all genetic types are associated with sulfides and quartz, where gold is usually xenomorphic. In sulfides (pyrite, arsenopyrite, chalcopyrite, sphalerite, etc.), gold is isolated metasomatically and sometimes fulfills fractures or crystallizes simultaneously with sulfides.

As a result of mineralogical studies of the ores of the Gadabay deposit, two main forms of gold occurrence were revealed: invisible and visible free gold.

Invisible gold is in a finely dispersed state. The main carrier of such gold is early pyrite. Getting into the weathering crust environment, it could serve as a source for «newly formed» gold, which retains information about the primary feature, which allows for the use of the obtained data for the purposes of predicting mineralization at depth and its belonging to a certain mineral type.

Free gold is usually located inside sulfide minerals, often in association with them. During the study of anschliffs (polished sections) made from primary and oxidized ores (Fig. 2), it was found that free and bound gold is associated with the surrounding sulfide minerals pyrite and chalcopyrite (Fig. 2).

As can be seen from Fig. 2, free gold is located inside chalcopyrite and pyrite (Fig. 1, a, b), probably, it was isolated simultaneously with the named minerals from ore-bearing solutions. Here it is localized syntactically with metacrystals of chalcopyrite and pyrite. Bound gold is associated with late-sulfide minerals. It is in association with pyrite and chalcopyrite (Fig. 2, c,d). Based on factual material, the author studied the nature of the distribution of noble metals (Au, Ag) in ores.
At the Gadabay deposit, oxidation zones are widely developed, containing a certain amount of gold of supergene origin, associated mainly with goethite and goethite-hydrogoethite aggregates (Fig. 3). The paragenetic relationships of gold with goethite, hydrogoethite and jarosite suggest that visible gold is mainly supergene, and hypogene gold, although it occurs, is of sharply subordinate importance compared to supergene gold.

The data obtained are confirmed by rational analysis. The predominant amount of native gold is found in intergrowths with basic sulfide minerals. The data obtained are confirmed by the results of the phase analysis.

As you can see in Table 1, in the ores of the Gadabay deposit, the predominant amount of gold is in a free state (43.0%) and in intergrowths with late sulfide minerals (pyrite, chalcopyrite) (45.3%). The gold content in iron hydroxides and sulfide minerals is low (4.8 and 6.6%, respectively), and in quartz, it is 0.3%. (Table 1).

Based on factual material, the author studied the nature of the distribution of noble metals (Au, Ag) in ores. According to atomic-absorption spectrophotometry data, it was established that gold is unevenly distributed in various types of ores and monomineral fractions of main sulfide minerals (Table 2).

As can be seen from Table 2, the gold content in the quartz-pyrite mineral association is low (on average, 0.8 g/t). Fine and finely dispersed gold precipitation is noticed. In the pyrite-chalcopyrite-sphalerite association, the concentration of gold is higher (2.3 g/t), since the main carriers of gold are chalcopyrite and, possibly, sphalerite, as evidenced by the gold content of the monomineral fractions of chalcopyrite and sphalerite, averaging 3.8 g/t and 1.6 g/t, respectively (Table 2). It is appropriate to note that in pyrite, chalcopyrite, and sphalerite ores, an increase in the average particle size of native gold is observed. This is apparently due to the redeposition and coarsening of early fine and fine gold in the quartz-pyrite association. (Baba-Zadeh et al., 2015; Nikolaeva and Yablokova, 2007).

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**Table 1.** Results of phase analysis of noble metals.

<table>
<thead>
<tr>
<th>№</th>
<th>Forms of occurrence of noble metals</th>
<th>Absolute content, g/t</th>
<th>Distribution in ore,%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Au</td>
<td>Ag</td>
</tr>
<tr>
<td>1</td>
<td>Independent with clean surface.</td>
<td>4.25</td>
<td>2.52</td>
</tr>
<tr>
<td>2</td>
<td>In joints with an open surface.</td>
<td>4.48</td>
<td>3.32</td>
</tr>
<tr>
<td>3</td>
<td>Contained in iron hydroxides and carbonates.</td>
<td>0.47</td>
<td>18.85</td>
</tr>
<tr>
<td>4</td>
<td>Contained in sulfide minerals</td>
<td>0.65</td>
<td>5.08</td>
</tr>
<tr>
<td>5</td>
<td>Contained in quartz</td>
<td>0.03</td>
<td>0.64</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>9.88</td>
<td>30.41</td>
</tr>
</tbody>
</table>
Based on the results obtained, histograms of the distribution of gold and silver in various types of ores and monomineral fractions of sulfide minerals were constructed (Fig. 4).

Histograms of the distribution of gold and silver in quartz-pyrite ores showed that the maximum frequency of occurrence corresponds to the intervals of 0.1–1.0 g/t for gold and 10–20 g/t for silver. Ores with this content are 65% gold and 54% silver. In pyrite, chalcopyrite, and sphalerite ores, the concentration of noble metals is higher. Here, the maximum frequency of occurrence corresponds to 0.1–1.0 g/t for gold and 10–20 g/t for silver. Ores with this content are 45% gold and 50% silver, which is indirectly confirmed by the higher gold content of pyrite-chalcopyrite-sphalerite ores (Guseinov and Mamedov, 2022; Guseinov et al., 2023; Guseinov, 2015).

As a result of the obtained analyses, histograms of the distribution of gold and silver in the monomineral fractions of the main sulfide minerals – pyrite, chalcopyrite, and sphalerite – were constructed (Fig. 5).

Histograms of the distribution of gold and silver in pyrite showed that the frequencies of occurrence correspond to the intervals of 1.0–2.0 g/t for gold and 2.0–5.0 g/t for silver. Monominerals with this content are 34% gold and 40% silver. Chalcopyrite has a higher gold content. In the noted mineral, the maximum frequency of occurrence corresponds to 1.0–2.0 g/t for gold, and the minimum frequency of occurrence is noted in the range of 2.0–5.0 g/t for silver. Monominerals with this content are, respectively, 40% and 22%. In sphalerite, the distribution of noble metals (Au, Ag) showed that the frequencies of occurrence correspond to the intervals of 0.01–0.1 g/t for gold (44%), and 1.0–2.0 g/t for silver (36%).

The results obtained on mineral associations and monomineral fractions of sulfide minerals showed that the main mass is deposited close in time to chalcopyrite, possibly forms a structural impurity in the field, and then is released during the cooling of the ores as a decomposition product of the solid solution.

Thus, analyses of the distribution of gold in vari-

<table>
<thead>
<tr>
<th>Ore types</th>
<th>№ samples</th>
<th>Au content, g/t</th>
<th>Ag content, g/t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Content limit</td>
<td>Average content</td>
</tr>
<tr>
<td>Mineral associations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz-pyrite</td>
<td>1</td>
<td>0.1–6.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Pyrite-chalcopyrite-sphalerite</td>
<td>5</td>
<td>0.1–8.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Monominerals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrite</td>
<td>3</td>
<td>0.01–3.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>9</td>
<td>0.2–24.1</td>
<td>3.8</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>14</td>
<td>0.2–5.4</td>
<td>1.6</td>
</tr>
</tbody>
</table>

As a result of the obtained analyses, histograms of the distribution of gold and silver in the monomineral fractions of the main sulfide minerals – pyrite, chalcopyrite, and sphalerite – were constructed (Fig. 5).

**Table 2.** Distribution of gold and silver in various types of ores and monomineral fractions of the main sulfide minerals of the Gadabay deposit.

![Fig. 4. Histogram of the distribution of gold and silver contents in quartz-pyrite (I) and pyrite-chalcopyrite-sphalerite (II) mineral associations of the Gadabay deposit according to atomic absorption spectrometry data. The abscissa axis is grades of content, g/t; along the ordinate – the frequency of occurrence of samples of a certain content class – in % rel.](image-url)
ous types of ores and monomineral fractions of basic sulfides, as well as the relationship of native gold with other minerals, indicate heterogeneous deposition of gold from solutions. A small part of it crystallized synchronously with early sulfides, mainly pyrite, and was dispersed in them in a finely dispersed state (Imamverdiyev et al., 2017; Imamverdiyev et al., 2018).

The main factors influencing the variability of gold-silver ratios are the following: quantitative relationships between mineral associations, the depth of ore occurrence, the difference between the ore formations themselves and the surrounding ore formations, and different classes of gold and silver contents (Berman and Gorelishev, 1974; Guseinov and Abasova, 2024).

The gold-silver ratio in the Gadabay deposit was studied using samples from various facies of metasomatites and mineral associations. To study this issue, 540 samples from metasomatites and 295 samples of mineral associations were analyzed. The results of the analysis for gold and silver are shown in Table 3.

As can be seen from Tab 3, among hydrothermal-metasomatic formations, the sericite-kaolinite facies (1:4) have a higher gold-silver ratio, and the monoquartzite facies have the lowest (1:13).

A decrease in the gold-silver ratio in hydrothermal metasomatites reflects the higher migration ability of silver and the diversity of its mineral forms in ores.

In quartz-pyrite ore, the gold-silver ratio is higher (Au:Ag = 1:10), and a low gold-silver ratio is observed in pyrite-chalcopyrite-sphalerite ore (Au:Ag = 1:15). This appears to be due to sphalerite, which contains a high silver content.

1. The distribution of gold in pyrite-chalcopyrite-sphalerite mineral associations is higher (2.3). Among the monomineral fractions, the high amount of gold distribution corresponds to chalcopyrite (3.8). This indicates that chalcopyrite has a high gold content.

2. The variability of gold and silver ratios has been studied in ores and non-ores of the Gadabay deposit. The amount of gold is higher (1:4) in the metasomite of sericite-kaolin (non-ore) than in others.

Table 3. Variability of the gold-silver ratio in the Gadabay deposit.

<table>
<thead>
<tr>
<th>Type of geological formations</th>
<th>№ samples</th>
<th>Au:Ag ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metasomatite facies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz-sericite</td>
<td>6</td>
<td>1:6</td>
</tr>
<tr>
<td>Sericite-kaolin</td>
<td>8</td>
<td>1:4</td>
</tr>
<tr>
<td>Monoquartzites</td>
<td>12</td>
<td>1:13</td>
</tr>
<tr>
<td>Mineral associations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz-pyrite</td>
<td>7</td>
<td>1:10</td>
</tr>
<tr>
<td>Pyrite-chalcopyrite-sphalerite</td>
<td>15</td>
<td>1:15</td>
</tr>
</tbody>
</table>
References


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