MINERAL COMPOSITION OF ORES AND ORE-BEARING ROCKS OF THE DREVNIY SITE (UZBEKISTAN)

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ABSTRACT
The article presents the results of the mineralogical and geochemical features of ores and ore-bearing rocks of the Drevniy site in the mountains of Northern Nuratau. About 70 minerals have been identified in the composition of ores and ore-bearing rocks - rock-forming, metasomatic, ore hypogene and supergene, accessory. Quartz, plagioclase, sericite, carbonates, (for dike formations and meta-effusives) hornblende, biotite, chlorite are the main non-metallic constituents of ores and ore-bearing rocks. The group of main ore minerals includes pyrite, arsenopyrite in primary ores. Native gold, electrum and native silver were also classified as the main mineral, since they are the main valuable minerals in the composition of ores. The oxidation zone is dominated by iron hydroxides (goethite, limonite, scorodite). According to mineralogical studies, it was established that the pyrite-arsenopyrite with gold paragenetic mineral association is the main productive paragenetic mineral association at the site.

INTRODUCTION
Uzbekistan is one of the main producers of gold and is among the top ten countries in the world in terms of explored reserves of the metal. Gold reserves in Uzbekistan amount to 1,800 tons and in 2021 entered the top 10 countries in the world by production (Minerals Commodity Summaries, 2022). In the coming years, Uzbekistan plans to increase gold production, with the expansion of ore production in existing mines, as well as the involvement of new deposits in mining and with an increase in the capacity of gold processing plants. In addition, in recent years, works on the construction of new ore processing plants have been intensively carried out.

On September 10, 2021, a resolution of the Cabinet of Ministers of the Republic of Uzbekistan “On approval of the feasibility study for the investment project “Construction of a complex for the extraction and processing of gold-bearing ores at the Pistali deposit (GMZ-6)” was adopted. Hydrometallurgical plant-6 (GMZ-6) is being built on the base of the Pistali deposit in the Nurata district of the Navoi region and will be put into operation in December 2024. As a result of this, additional capacities for the extraction of 4 million tons of gold ore per year will be created at the Navoi Mining and Metallurgy Combinat.

The construction of a new hydrometallurgical plant poses new challenges for geologists, since one of the important problems of the geological industry is to ensure that the volume of explored mineral reserves is ahead of the growth in production so that gold production is always at a sufficient level. Therefore, any research aimed at expanding the mineral resource base of precious metals, especially in regions with a developed mining industry, is very relevant. These regions include Northern Nurata, where our research object, the Drevniy site, is located.

The gold deposits of Uzbekistan are confined to a single Kyzylkum-Kurama metallogenic belt, which includes the South Tien Shan orogenic belt and the Beltau-Kurama volcano-plutonic arc (Fig. 1), formed as a result of subduction of the crust of the Turkestan paleocean under the Kazakhstan-Kyrgyzz continent, its collision with the Kara-Kum Tarim continent and subsequent geological processes (Dalimov, 2002, Yakubchuk, 2002, Goldfarb, 2013). The Drevniy gold deposit is located on the northern slopes of the western end of the Northern Nuratau ridge, 3 km southeast of the Pistali deposit.

Metamorphosed terrigenous-sedimentary rocks of the Tuskazgan Formation of the Upper Proterozoic, intruded by intrusions of the Kattaich (Middle-Upper Carboniferous) and Gatchina (Late Carboniferous-Early Permian) igneous complexes, take part in the geological structure of the region. The Taskazgan Formation (PR3tts) is represented by quartz-micaceous, micaceous-quartz and carbonaceous, albite-clinozoisite-chlorite-amphibole (metabasalts) schists, metasiltstones,
metasandstones with interlayers and horizons of essentially carbonaceous and green chlorite-epidote schists, metasiliceous quartzites and dolomites. (Alimov et al., 2018)

Igneous formations are represented by intrusions of the Kattaich and Gatchi complexes and their dike counterparts. The intrusions of the Kattaich Middle-Late Carboniferous gabbro-diorite complex (К3-3к) are represented by dikes of diorite and granodiorite compositions and stock-like outcrops of quartz syenite-diorite intrusions. Dikes (lamprophyre-like diorite porphyrites, granodiorite-porphyries) form a belt up to 1400 m. wide, the strike of which is generally consistent with the orientation of the bearing rocks (NE 20-40°). The thickness of the dikes is from a few tens of cm to 20-30 m, the dip is predominantly steep, mainly to the west at angles of 60-80°, less often gently to the east at angles of 20-30°.

Intrusions of the Gatchi Late Carboniferous-Early Permian complex of two-mica granites (γ С2-3г) are represented in the eastern part of the area by the Temirkabuk massif of biotite-muscovite granites with a total area of 35 sq. km. and a series of aplite-pegmatite dikes. Dike thickness 0.1-1m, the strike is mainly northwestern and sublatitudinal.

The main plicative structure of the region is the Yambash-Ustuk brachiatricline of Hercynian origin, traced during geological surveys.

Of the discontinuities, the longitudinal structures usually associated with the formation of brachiform folds are most clearly recorded. Morphologically, these are steeply dipping faults, reverse faults. The zones of these ruptures are expressed by mylonitization, vein-veinlet silicification, ferrugination, and are sometimes healed with quartz veins.

Hydrothermal processes manifested themselves in the characterized objects in the formation of quartz-vein systems of various structural and morphological types.

Metasomatic processes in the site have a significant wide scale of biotite-chlorite-albite-sericite-quartz + chlorite-albite-sericite-quartz + albite-sericite-quartz stages, covering almost the entire section of
the Taskazgan Formation to a depth of hundreds of meters. The metasomatites of the albite-quartz-sericite stage of the metasomatic column are associated with industrially significant gold mineralization at the characterized objects (Alimov et al., 2018).

Ore deposits and zones are metasomatically altered rocks of the Lower Taskazgan subformation (shales, silty sandstones, siltstones) with disseminated gold mineralization. The morphology of ore deposits and zones is lenticular-stratal with bulges, constrictions, confluence and wedging out.

MATERIALS AND METHODS
To study the mineral composition and ore-bearing rocks, field geological work was carried out with the selection of various samples. Under laboratory conditions, they were studied by optical methods (Nikon Eclipse LV 100Pol microscope), electron microscopy (Carl Zeiss), microprobe studies (Jeol JXR8800). A rational analysis was also carried out to identify the form of finding gold and silver.

The chemical composition of ores is established by a complex of chemical and physico-chemical analytical methods of research. Including a complete silicate analysis, atomic absorption, spectral, ICP-mass spectrometric, OES-MS, etc. were carried out. The mineralogical analysis of the concentrates was carried out under a binocular, transparent sections, polished sections, artificial briquettes were made for further study under a microscope. An X-ray phase analysis was also carried out in order to establish the quantitative mineral composition of the samples.

RESULTS AND DISCUSSION
In the Drevniy site, metaterrigenous and metavolcanogenic formations of the Taskazgan Formation are the main ore-bearing rocks. Ore mineralization is accompanied by quartz veins and veinlets.

Ores and ore-bearing rocks of the Drevniy site are of aluminosilicate and silicate (vein quartz) composition. The content of silica (SiO$_2$) ranges from 62.04% to 82.25%. Alumina (Al$_2$O$_3$) in the composition of ores is up to 15.93%. The amount of alkalis (Na$_2$O+ K$_2$O) is up to 6.52%. CaO in the composition of the analyzed samples is 0.7-6.22%.

Meta-effusive massive greenish-gray rocks, fine-grained with porphyritic feldspar inclusions (Fig. 2). It can be seen microscopically that the groundmass consists of plagioclase, quartz, and thin needles of light amphibole. The grain size is 0.01-0.1 mm. Feldspars are pelitized and sericitized.

Figure 2: Metaeffusive with plagioclase porphyritic inclusions Increased 40'; Nic. X. 1-plagioclase; 2-biotite; 3-quartz.
The chemical composition of the rock (%): SiO$_2$ 63.54; Fe$_2$O$_3$(gen.) 5.17; Fe$_2$O$_3$(calc.) 5.17; FeO 3.31; TiO$_2$ 0.55; MnO 0.07; Al$_2$O$_3$ 13.6; CaO 13.6; MgO 2.97; Na$_2$O 2.88; K$_2$O 1.57; P$_2$O$_5$ 0.00; S$_{total}$ 0.37; SO$_3$ 0.22; S$_{sulfide}$(calc.) 0.28; PPP 1.64; ∑ 97.92; CO$_2$ 0.89; H$_2$O 0.18.

On the SiO$_2$-∑Na$_2$O+K$_2$O diagram of A.A. Marakushev, rocks fall into the area of development of andesite-dacites (A.A. Marakushev).

Also, lamprophyre dikes are widespread rocks at the site. The structure is nematogranoblastic, porphyritic. The texture is massive, interspersed. The bulk of the rock is fine-grained plagioclasite. The shape of the grains is xenomorphic, elongated prismatic.

Quartz is veingranoblastic, macrocrystalline. The texture is massive, interspersed. Contains rock fragments. Sometimes in quartz there is a thin rash of carbonaceous matter (<0.005 mm). Ore mineralization in quartz is represented in intergranular spaces by inclusions, accumulations of sulfides (pyrite, etc.). The gold content is 0.36-4.38 g/t and averages 2.37 g/t.

Mineral composition of ores

The mineral complex of ores and ore-bearing metasomatites of the Drevniy site is very significant. About 70 minerals have been identified in the ores and ore-bearing metasomatites of the Drevniy site. Minerals are divided into groups - the main (widespread), minerals of medium abundance and accessory - rare.

Quartz, plagioclase, sericite, carbonates, (for dike formations and meta-effusives) hornblende, biotite, chlorite are the main non-metallic minerals in the studied samples of ores and ore-bearing rocks. The group of main ore minerals includes pyrite, arsenopyrite in primary ores. Native gold, electrum and native silver were also classified as the main mineral, since they are the main valuable minerals in the composition of ores. The oxidation zone is dominated by iron hydroxides (goethite, limonite, scorodite).

The group of minor minerals (locally distributed in individual samples and in small amounts) includes pyrrhotite, marcasite, galena, sphalerite, chalcopyrite, bornite, alabandine, native copper, native arsenic, freibergite, stephanite, krennerite, acanthite, miargyrite, yalpaite, hessite, polybasite, wittikhinite, stromeyerite, andorite, tetrahedrite, molybdenite, pyrolusite, native iron, CrFe alloy.

Cerargyrite, bromyrite, covellite, chalcocite, povellite, copper green, hematite, psilomelane from secondary minerals of copper, silver, iron and manganese are found in the oxidation zone.

Accessory minerals include zircon, monazite, apatite, ilmenite, rutile, magnetite, scheelite, wolframite, barite, celestite, gypsum, etc. (Table 1).

### Table 1. The mineral composition of the metarocks of the Drevniy site

<table>
<thead>
<tr>
<th>Spread</th>
<th>Rock-forming and metasomatic nonmetallic</th>
<th>Ore basic (Au, Ag) and associated</th>
<th>Hypogenic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widespread (major)</td>
<td>Quartz, plagioclase, sericite, biotite, chlorite, hornblende, carbonate</td>
<td>Pyrite, arsenopyrite, native gold, electrum, native silver</td>
<td>Goethite, jarosite, limonite, scorodite, clay minerals,</td>
</tr>
<tr>
<td>Distributed locally</td>
<td>Potassium feldspar, actinolite, epidote, graphite, carbonaceous matter</td>
<td>Pyrrhotite, marcasite, galena, sphalerite, chalcopyrite, bornite, alabandine, native copper, freibergite, stephanite, krennerite, acanthite, miargyrite, yalpaite, hessite, polybasite, wittikhinite, stromeyerite, andorite, molybdenite, fahlore, pyrolusite</td>
<td>Cerargyrite, bromyrite, covellite, chalcocite, copper green, powellite, hematite, psilomelane</td>
</tr>
<tr>
<td>Accessory (elastic)</td>
<td>Zircon, monazite, apatite</td>
<td>Ilmenite, rutile, magnetite, wolframite, scheelite</td>
<td>barite, celestite, gypsum, lead oxide</td>
</tr>
</tbody>
</table>
Ore minerals are revealed in the form of individual inclusions, veinlets, nesting, and massive accumulations. Ore minerals are often arranged according to the schistosity of the rocks. The structure is thinly-, small-, hypidiomorphic-granular, allotromorphic-granular (Fig. 3).

The content of ore minerals in polished sections ranges from single grains to 10-15% in individual polished sections. Polished sections are dominated by the content of ore minerals 1-3%. Below is a description of the main minerals separately.

*Native gold* is the main valuable mineral ore. Native gold is found in polished sections in the form of microsegregations in quartz and along cracks. Often, native gold is associated with pyrite and arsenopyrite, in the zone of their oxidation by decomposition products. The size of gold particles is 0.00n-1.0 mm. In heavy fractions, they are observed as free grains in intergrowths with quartz, iron hydroxides, and sulfides (Fig. 4).

The composition of native gold according to the results of local X-ray spectral analysis on a Jeol 8800R microprobe varies: from 68.76 to 80.34% gold; silver content from 17.78% to 31.16%. Small amounts of iron and copper impurities are observed (Table 2).

**Table 2.** The chemical composition of native gold according to the results of local X-ray spectral analysis on a Jeol 8800R microprobe, %

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Spectrum</th>
<th>Au</th>
<th>Ag</th>
<th>Fe</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native gold</td>
<td>1</td>
<td>68.76</td>
<td>30.69</td>
<td>0.28</td>
<td>0.01*</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>69.07</td>
<td>31.16</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>Native gold</td>
<td>1</td>
<td>79.61</td>
<td>18.76</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>78.39</td>
<td>17.78</td>
<td>3.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>79.65</td>
<td>19.11</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Gold in quartz</td>
<td>1</td>
<td>80.34</td>
<td>19.77</td>
<td>0.14*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>80.28</td>
<td>19.5</td>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Structural and textural features of ores. Photography in reflected light.
In addition, the chemical composition of native gold was established by scanning electron microscopy (Fig. 5). The chemical composition of native gold is as follows: Au - 64.44-85.83%; Ag - 35.36-14.17%. According to the chemical composition, the native gold of the Drevniy site corresponds from low-fine (600-699) to moderately high-fine, medium sample (800-899) according to the classification of N.V. Petrovskaya (1973). Some grains according to the composition corresponds to electrum: Au - 38.96-52.43%; Ag - 47.57-61.04%.

<table>
<thead>
<tr>
<th>№</th>
<th>Spectrum num.</th>
<th>Mineral</th>
<th>Composition, %</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spectrum 2202</td>
<td>Native gold</td>
<td>85.83</td>
<td>14.17</td>
</tr>
<tr>
<td>2</td>
<td>Spectrum 2203</td>
<td>Quartz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Spectrum 2204</td>
<td>Native gold</td>
<td>80.88</td>
<td>19.12</td>
</tr>
<tr>
<td>4</td>
<td>Spectrum 2205</td>
<td>Native gold</td>
<td>77.73</td>
<td>22.27</td>
</tr>
</tbody>
</table>

Figure 5. Native gold intergrown with quartz. Photography in backscattered electrons under SEM. The linear scale is indicated in the photographs.

The form in which gold and silver have been found has been established by rational analysis. 57.33% of gold is native, intergrown with other minerals: chlorides, sulfates, simple silver sulfides. Gold associated with minerals and chem. compounds of Sb and As (except arsenopyrite and compounds of pentavalent Sb), Ag sulfosalts (cyanidated after alkaline treatment) is 6.67% according to rational analysis. 9.33% gold is associated with acid-soluble minerals, iron and manganese oxides (carbonates, oxides and hydroxides) (cyanated after HCl treatment). Finely burnt gold in sulfides (pyrite and
arsenopyrite is 16%. 10.67% of gold is found in quartz, aluminosilicates, and other acid-insoluble minerals.

Of the silver minerals, native silver, acanthite, silver sulfarsalts: miargyrite (AgSbS₂), pyrargyrite (Ag₃SbS₄), stephanite (Ag₅SbS₄), yalpaite (Ag₃CuS₂), andorite (AgPbSb₃S₆), freibergite (Ag₆Cu₄Fe₂Sb₄S₁₃), also stromeyerite (AgCuS), bromyerite AgBr, kerargyrite (AgCl). Silver minerals are closely associated with each other, as well as the main minerals of ores (Fig. 6).

Pyrite is the main ore mineral of primary ores. The amount of pyrite is from single grains to the first percent (1-5%). Dissemination predominates, sometimes veinlets, often lenticular accumulations along schistosity. Grain size up to 1.5 mm. The shape is cubic, sometimes pentagon-dodecahedral, xenomorphic, aggregated clusters. Pyrite contains inclusions of pyrrhotite, chalcopyrite, silver sulfantimony, galena, and sometimes intergrowths with arsenopyrite. Along the edges of the pyrite, there is a rim of stromeyerite, native silver. Pyrite is replaced by Fe hydroxides up to pseudomorphs.

Arsenopyrite occurs quite often in primary ores. In the oxidation zone, it is replaced by iron and arsenic hydroxides. A pyrite-arsenopyrite with gold paragenetic mineral association of the early sulfide stage of mineral formation was established both in the form of free xenomorphic grains and in intergrowths with pyrite (Tsoi et al. 2021).

Goethite widespread mineral of the oxidation zone. It is usually a decomposition product of primary sulfides (pyrite). The amount is from single grains to several percent, on average according to the recalculation of chemical. analyzes the amount of the mineral is 3.8%.
CONCLUSION

Native gold and electrum from gold minerals have been established. Silver is represented by native silver, silver sulfosalts, acanthite, bromyrite, iodargyrite, etc.

Native gold is revealed in association with quartz, pyrite, and arsenopyrite, and their decomposition products in the oxidation zone. Pyrite-arsenopyrite with gold PMA is widely occurred at the site and is the main productive mineral association for gold mineralization.

The ores are low-sulfide, sulfide minerals are mainly represented by pyrite and arsenopyrite (1-5%). Pyrite is a "through" typomorphic mineral, present both in ore metasomatites and in unaltered host rocks. Arsenopyrite, as a rule, is found only in ore metasomatites and has a positive correlation with gold.

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