https://doi.org/10.33271/nvngu/2022-2/017

D. S. Kaumetova[1],
orcid.org/0000-0003-4197-4891,
I. D. Arystan[1],
orcid.org/0000-0001-5095-4935,
H. K. Absalyamov[2],
orcid.org/0000-0001-6231-0520,
K. K. Zhusupova[3],
orcid.org/0000-0001-8510-2361,
A. D. Zhukenova[2],
orcid.org/0000-0002-3053-8122,
G. S. Abisheva[2],
orcid.org/0000-0002-8030-7218

1 – Karaganda Technical University, Karaganda, the Republic of Kazakhstan, e-mail: kaumetovadinara@mail.ru
2 – Non-profit Joint Stock Company "Kokshetau University named after Sh. Ualikhanov", Kokshetau, the Republic of Kazakhstan
3 – Satbayev University, Almaty, the Republic of Kazakhstan

RESEARCH INTO HEAP LEACHING TECHNOLOGY OF GOLD-BEARING ORES AT THE VASILKOVSKY GOLD ORE DEPOSIT (KAZAKHSTAN)

Purpose. To study gold-bearing ores subjected to heap leaching technology to identify both free gold particles, as well as gold in aggregates and adhesions, which makes it possible to obtain data on the distribution of gold by its occurrence forms.

Methodolgy. Leaching process studies are conducted at the laboratory setup of the Institute of Metallurgy and Ore Beneficiation of the Ministry of Education and Science of the Republic of Kazakhstan. The gold particles are studied using an AxioScope A1 optical microscope on the polished thin section surface. The sample materials are taken from the heap leaching site of the Vasilkovsky gold ore deposit.

Findings. As a result of a microscopic test of a sample taken from the heap leaching site, ultrafine-dispersed and finely-dispersed gold particles have been found both in free form and in aggregates with waste rock and arsenical pyrite, as well as the fact of Au particles – "adhesions", accumulated on a grain of the host waste rock. The size class of detected Au particles varies from 0.35 to 9.5 μm.

Originality. For the first time, according to the samples of gold-bearing ores of the Vasilkovsky gold ore deposit, a pattern of the gold distribution according to the forms of its occurrence has been revealed.

Practical value. The data obtained as a result of the research make it possible to predict the distribution of the gold form occurrence in other areas of the deposit. This can greatly simplify the conditions for its development, as well as adjust the technological process of leaching the gold-bearing ores and the main technological parameters of the heap leaching process.

Keywords: *gold-bearing ores, heap leaching, gold, research, deposit*

Introduction. Mining of precious metals in the Republic of Kazakhstan is performed both at placer and primary deposits, which implies a fundamental transition of technologies from traditional to physical-chemical and, above all, to heap leaching. Thanks to the latter, it is possible to significantly reduce capital investments and operating costs [1]. Heap leaching is usually applied to low-grade off-balance ores or old dumps formed as a result of stockpiling off-balance ore. Gold leaching is used in mining of small deposits, processing of old dumps, as well as low-grade off-balance ores. Not all ores are suitable for heap leaching. It is most efficient to recover gold and silver from silicified and calcareous sedimentary rocks, sandy dolomites and shales, quartz and volcanic rocks.

In world practice, when processing low-concentration gold-bearing ores, in recent decades, the heap leaching of gold with alkali metal cyanide solutions has been widely used, which expands the raw material base and improves the technical-and-economic performance of both existing and new gold mining enterprises, without significant capital costs [2, 3].

Heap leaching of gold, firstly implemented in the United States, was the beginning of a new stage in mining of gold ore deposits with a relatively low content of the precious metal, since this geotechnology, in comparison with traditional approaches, does not require such costly processes as grinding and preliminary concentrating of gold-bearing mineral raw materials. A special program developed by the United States Bureau of Mines (USBM), which provided for certain government benefits, loans within reasonable taxation, has contributed to the rapid development and implementation of a new technology for heap leaching of gold from low-grade ores in the US industry [4, 5].

Heap leaching, as a highly profitable and environmentally friendly gold mining process, has become a common gold mining practice in the USA, Canada, Australia, South Africa, China, Mexico, Chile, Portugal and many other countries. This technology is being implemented very quickly and very effectively. Despite the efficiency of the heap leaching process of gold recovery from the ores of most deposits in the Zabaykalsky Krai, Primorsky Krai, Uzbekistan, Tajikistan and other regions, the industrial development of heap leaching technologies for precious metals in the USSR was held back for a number of reasons. It was only in the early 1990s that the industrial development of heap leaching technology for gold-bearing raw materials began [6, 7].

In the mining industry of the Republic of Kazakhstan, geotechnological processes, such as heap leaching, have been developed relatively recently. As a result, the advantages of these ore processing methods have not been fully revealed [8]. Technological schemes for heap leaching process are relatively simple and low-cost compared to those used in gold recovery plants.

Most of the existing heap leaching enterprises use surface mined ore, which is the most economical method when mining the large low-grade ore deposits [9]. Depending on the material composition of the ore, the leaching material should have a certain particle size in order to ensure the necessary contact with the solution, as well as dissolution. The preliminary ore preparation can be excluded (in this case, the ore mined from the subsoil is sent to the pile), or crushing and agglomeration can be used [10]. Particular attention should be paid to the geomechanical monitoring system [11], which allows not only determining displacements and deformations of structures, but also assessing the geomechanical state of the earth's surface and rocks [12].

Ores at a number of precious metal deposits of Kazakhstan have significant hardness, as well as contain both free and invisible gold in arsenical pyrite and pyrite [13]. The presence of such gold causes high demands on the operation of the ore crushing and leaching cycle, as well as on the development of new ore preparation methods [14]. At the ore preparation stage, a significant amount of fines is formed, the presence of which sharply reduces the seepage of the solution through the ore layer in the pile during leaching.

The Vasilkovsky gold ore deposit is located in the contact zone of two granite intrusions of different ages: granodiorite – granodioritic (Krykkuduk); gabbro – granodiorite – granitic (Borovsk).

The rocks of the Vasilkovsky ore field are intensively hydrothermally altered. Several mineralization stages have been revealed:

- preore – quartz – feldspar veins and veinlets;
- hydrothermal changes associated with spatial-temporal relations with ore quartz – arsenical pyrite veins (silicification, sericitization, chloritization, biotization);
- postore stage of quartz – carbonate, carbonate – fluorite, carbonate – epidote veins.

The sequence of zoning the ore stage rocks is invariable chlorite-sericite, quartz-sericite, sericite veins. The main type of ores is arsenic disseminated, vein-disseminated and vein.

The bulk of the ore bodies is represented by quartz-arsenical pyrite veinlets of various thickness and length. Usually, the quartz component in the veinlets exceeds the arsenical pyrite component. Monomineral arsenical pyrite veinlets are rare, gold is associated mainly with quartz veinlets [15, 16].

The vein-disseminated ores represent a transitional aureole. The gold content in them is very heterogeneous. The disseminated ores form the outer mineralization layer. The gold content in them is low, in the primary ores of the deposit it ranges from 0 to 26.8 g/t, on average, about 5 g/t [17].

The thickness of the oxidation zone, which spatially coincides with the ancient weathering crust, varies from 4.5 to 46.5 m. Individual segregations of oxidized sulphides occur at depths up to 80 m. Sulphides are replaced by scorodite and limonite during oxidation. With an increase in the depth of the oxidized zone, the gold content increases [18].

The following minerals are identified in the composition of ore bodies: hematite, limonite, arsenical pyrite, chalcopyrite, pyrite, marcasite, magnetic pyrite, molybdenite, bismuthine, fahl ore, chalcocite, bornite, tetradymite, silicates – quartz, sericite, chlorite, tourmaline, prehnite, feldspars, fluorite, as well as native metals – gold and bismuth [19]. The gold content in the oxidized zone reaches up to 56.8 g/t. The size of gold particles is from tenths of a micron to 250 μm. The bulk (more than 50 %) has a size of 4 to 14 μm.

In terms of size, gold is distributed uniformly throughout the deposit. Only with depth in the oxidized and sulphide zones, there is some increase in the size of particles: the largest gold particles of 40–120 μm occur at a depth of 300 m and aggregate predominantly with chalcopyrite. The size of gold particles in quartz is 2.5–8 μm; shape is round and irregular.

The gold-bearing ores of the Vasilkovsky deposit are very diverse in terms of their material composition and forms of gold occurrence, and in each specific case, a certain technology for their processing is required. The cyanide leaching technology has become the most widespread.

Heap leaching with an alkali metal cyanide solution is a promising method for involving low-grade ores, dumps and small deposits in gold recovery. This allows expanding the ore base and improving the technical-and-economic performance of gold mining enterprises, which is extremely important for the mining industry in Kazakhstan.

Methods. Gold in ores is in association with copper and iron-bearing minerals. In order to leach gold, first of all, it is necessary to open these minerals. The gold dissolution rate depends on the rate of opening the minerals with which it is associated.

In recent years, close attention has been paid to the study of the selective dissolution of gold in alkaline solutions [20, 21]. It has been revealed that Au dissolves quite easily, while Ag and Cu dissolve very slightly in such media, which is explained by the formation of hardly soluble films based on Ag_2S and $Cu_{1.92}S$ [22].

Percolation leaching is conducted using the laboratory setup of the Institute of Metallurgy and Ore Beneficiation of the Ministry of Education and Science of the Republic of Kazakhstan. The percolators are equipped with false bottoms and polyethylene vessels for collecting solutions after irrigation. Ore sub-sample of a certain size in each percolator in laboratory experiments is 20 kg.

The leaching solution is fed into the percolators from above. Passing through the ore mass, it is collected in a collection tank. Upon reaching a certain concentration of gold in the solution, the latter is fed to sorption. Solutions after sorption, completely or partially refreshed with a solvent and replenished with water to the required volume, are sent for repeated irrigation [23, 24]. Acidity is regulated using a pH-meter.

Before leaching, the ore is saturated with water for 4–20 days (80 l/t of ore). At the initial stage of the process, the influence of the solvent concentration on the process parameters is studied at a constant irrigation density and a pause in irrigation. The optimal parameters of percolation (heap) leaching of ores, such as solvent concentration, density and irrigation pause, depend on the chemical and mineralogical composition of the ore. These parameters are set experimentally. Before loading into the percolator, the ore is crushed.

The initial raw material is the ore from the Vasilkovsky deposit. The only main valuable component in the processed ore is gold, the content of which is about 2.0–2.3 g/t. In terms of mineral composition, the ore is 97 % represented by rock-forming minerals, the main of which are quartz, plagioclase and potassium feldspars. The ore mineralization is represented by sulphides – pyrite and arsenical pyrite. Their total share in samples is 3 %. In terms of material composition, the ore from the Vasilkovsky deposit belongs to the gold-quartz low-sulphide primary type of ores.

From the analysis of literary sources, it follows that metallic gold interacts with a wide range of various reagents, thus forming soluble compounds. During the experiments, the alkaline solutions of NaCN and sulfuric acid solutions (H_2SO_4 – 5 g/dm^3) containing KBr, NaCl, $FeCl_3$, $Fe_2(SO_4)_3$, $CS(NH_2)_2$, $CO(NH_2)_2$ in various concentrations are used [25]. The experiments are conducted in a thermostatted beaker at a temperature of 293 K, with a ratio of S : L = 1 : 10, the leaching time is 6 hours. The concentration of thiourea solution during percolation leaching of ore is varied from 2.5 to 40 g/dm^3. Irrigation density is 50 dm^3 per ton of ore. The process is conducted in two modes: percolation and immersion of the ore in the percolator, alternately flooding the ore for a day with sulfuric solutions of ferrous sulphate (III) and thiourea.

The gold particles are tested on an AxioScope A1optical microscope designed to work with bright field, dark field, phase contrast, as well as Differential Interference Contrast (DIC) and its alternative PlasDIC.

Results and discussion. The maximum gold recovery without an oxidizing agent is observed when using leaching solutions containing, g/dm^3: thiourea – 5.0 and urea 20.0, while when leaching separately with solutions of thiourea and urea solutions with a concentration of 20 g/dm^3, 45.5 and 36.1 % of gold has been recovered, respectively. When using potassium bromide (20 g/dm^3) as a solvent, the recovery of Au is 40.5 %.

The use of a sodium chloride solution in combination with an oxidizing agent such as ferric chloride makes it possible to obtain a maximum recovery of 28.1 % gold at a $FeCl_3$ concentration of 7.5 g/dm^3.

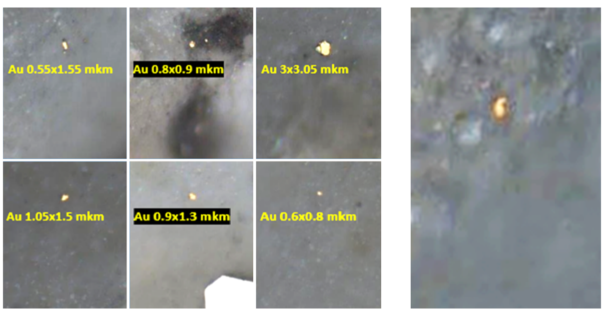
The admixture of Fe(III) as an oxidizing agent in the amount of 2.5 g/dm^3 in solutions of urea (5 g/dm^3), thiourea (5 g/dm^3) and in their mixtures significantly increases the recovery of gold, up to 80.0, 80.2, 82.6 %, respectively. With an increase in the concentration of Fe(III), the recovery of gold decreases, since the maximum concentration of $Fe_2(SO_4)_3$ in urea solutions is 0.32 %, and thiourea – 0.4 %. An increase in these concentrations of reagents during gold leaching leads to a decrease in the process efficiency.

The variety of gold grains can be characterized as ultrafine-dispersed (0.1–1.0 μm) and finely-dispersed (1.0–10.0 μm) – according to the classification by N. V. Petrovskaya “Samorodnoe zoloto” (Native gold).

The shape of gold particles is varied: elongated, monolithic, isometric, irregular oval, filiform. The contours are both smooth and uneven with jagged edges. The surface of the particles is both clean hummocky and without roughness. The only case of the so-called “flour gold” is noted, which has oxidation films on its surface (Fig.1).

As a result of microscopic test using an AxioScope A1 optical microscope, on the polished thin section surface formed from this material, 1 “adhesion” fact and 23 gold particles have been identified. They include:

- particles in free form (33.33 %) – grain size from 0.35 to 3.05 μm, that is ultrafine-dispersed, finely-dispersed gold;
- 3 particles in aggregates with arsenical pyrite (12.5 %), Au size from 0.45 to 9.5 μm;
- 12 particles in aggregates with waste rock (50.0 %). The grain size varies within Au from 0.45 to 2.6 μm;
- the only fact of accumulated gold particles, presented as if in the form of “adhesions” on the host waste rock – 4.17 %. It is not possible to determine the size of these particles due to their unnatural “smeared” shape.



a *b*

Fig. 1. Free gold particles:
a – in polystyrene; b – covered with an oxidation film

As a result of a microscopic test of a sample taken from the heap leaching site – 11, dated November 06, 2019, ultrafine-dispersed and finely-dispersed gold particles have been found both in free form (Figs. 1, *a, b*), and in aggregates with waste rock and arsenical pyrite, as well as the fact of accumulated Au particles – “adhesions” on the grain of the host waste rock (Figs. 2–4). The size of the Au particles found in the product varies from 0.35 to 9.5 μm.

The size of gold particles is one of its most important technological characteristics. Based on the behavior of gold in subsequent technological operations of ore processing, three groups are conditionally distinguished by size:

- coarse gold with a size of gold particles over 0.07 mm;
- fine gold with a particle size from 0.01 to 0.07 mm;
- finely-dispersed gold with a size of less than 0.01 mm.

During ore grinding, coarse gold is freed from its bond with rock and minerals. It is easily captured during gravity concentration, but it floats poorly and slowly dissolves in cyanide leaching processes.

Fine gold in crushed ore is partly in a free form, and partly in aggregates with other minerals. Fine free gold floats well, dissolves quickly in the cyanide leaching process, but is difficult to recover by gravity methods. The flotation activity of such gold is determined by the flotation properties of the mineral associated with it.

Finely-dispersed gold, associated in most cases with sulphide minerals, is only slightly opened during ore grinding, and the bulk of it remains in minerals. During cyanide leaching process, such gold does not dissolve, but in the processes of gravity and flotation it is recovered together with carrier minerals.

The coarsest gold grains have been found in marginal aggregate with arsenical pyrite, the parameters of which are Au 9.15 × 9.5 μm.

Based on the data obtained, 65.22 % is of the “1.0–10.0 μm” class – finely-dispersed gold, which is 30.44 % more than in the “0.1–1.0 μm” class – ultrafine-dispersed gold according to the classification by N. V. Petrovskaya “Samorodnoe zoloto” (Native gold).

From the data obtained on the distribution of gold according to the forms of its occurrence in the sample, it can be argued that 29.16 % is the so-called “virgin” gold. There is a single case of the so-called “flour gold”, which has oxidation films on its surface – 4.17 %. Au aggregates with host waste rock – 50.0 %, of which 37.5 % belongs to aggregates represented by “core inclusions”. The percentage ratio of free gold

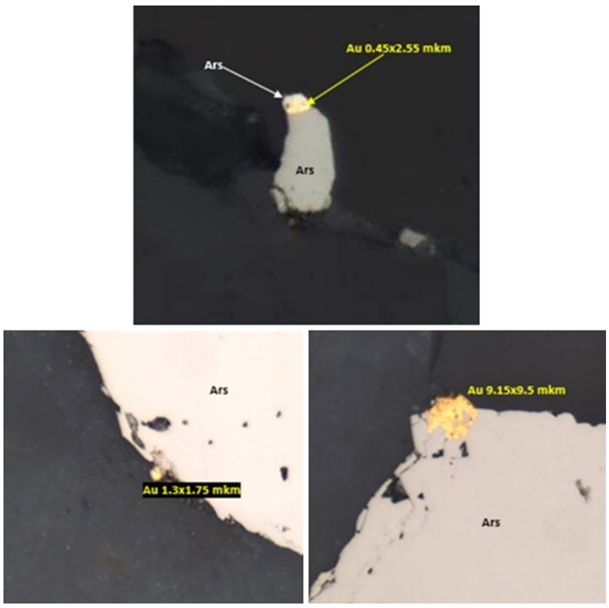


Fig. 2. Gold in aggregates with arsenical pyrite

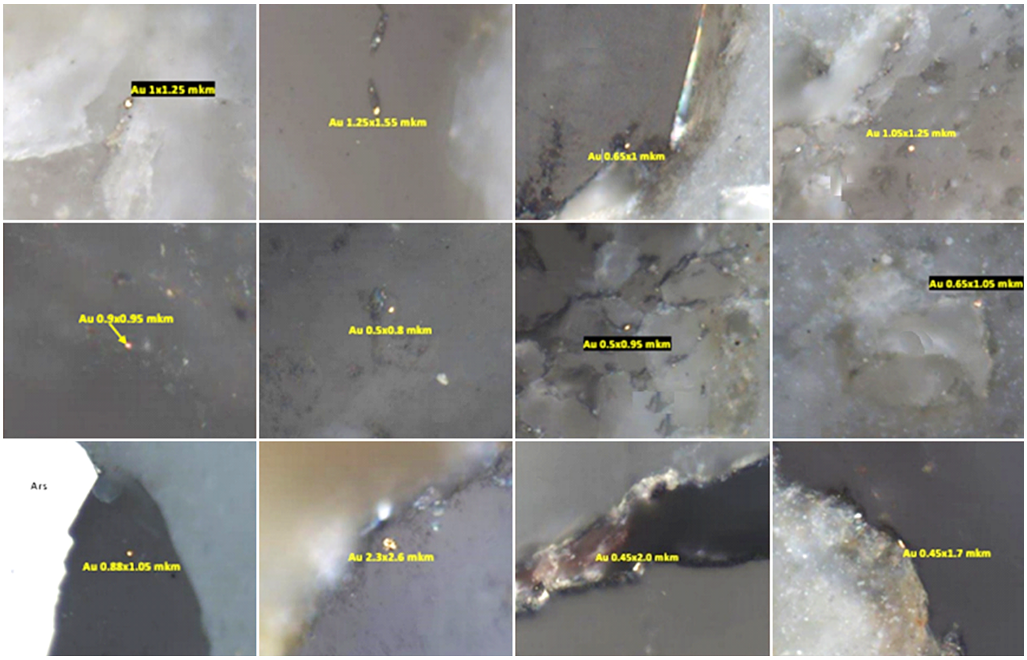


Fig. 3. Gold in aggregates with host waste rock

in relation to gold in aggregates is 33.33 : 66.67 %, respectively. The shape of gold particles is varied: elongated, monolithic, isometric, irregular oval, filiform. The contours are both smooth and uneven with jagged edges. The surface of the particles is both clean hummocky and without roughness.

In turn, corroded particles of metal scrap Fe (percentage ratio – 10.4 % of the total amount of test grains, excluding waste rock particles), as well as free particles of silver Ag – 0.7 % occur repeatedly.

Since the sample material is taken from the heap leaching site, most of the host waste rock grains of the product are yellow-ochre to vermilion red in color (Fig. 5). The reason for staining is the presence in it of a sufficiently large percentage of goethite-hydrogoethite aggregates – 13.6 %, which are oxidation zones closely associated with each other and other minerals, and the presence of an equally high content of artificial iron (metal scrap fragments) – 10.4 %.

The size of the largest metal scrap fragment – Fe from this sample, reaches 1253 μm (Fig. 6), while the maximum size of sulphide minerals, in particular arsenical pyrite, reaches

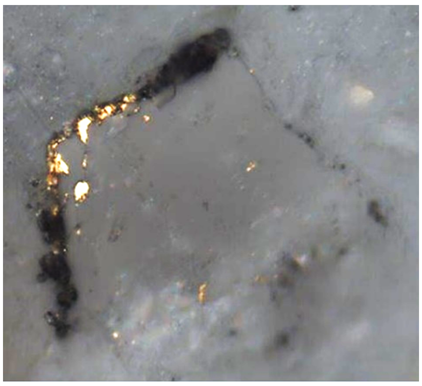


Fig. 4. Gold "adhesions" on the grain of the host waste rock

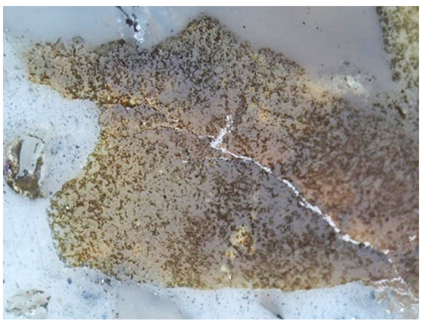


Fig. 5. Area of polished thin section (200X magnification)

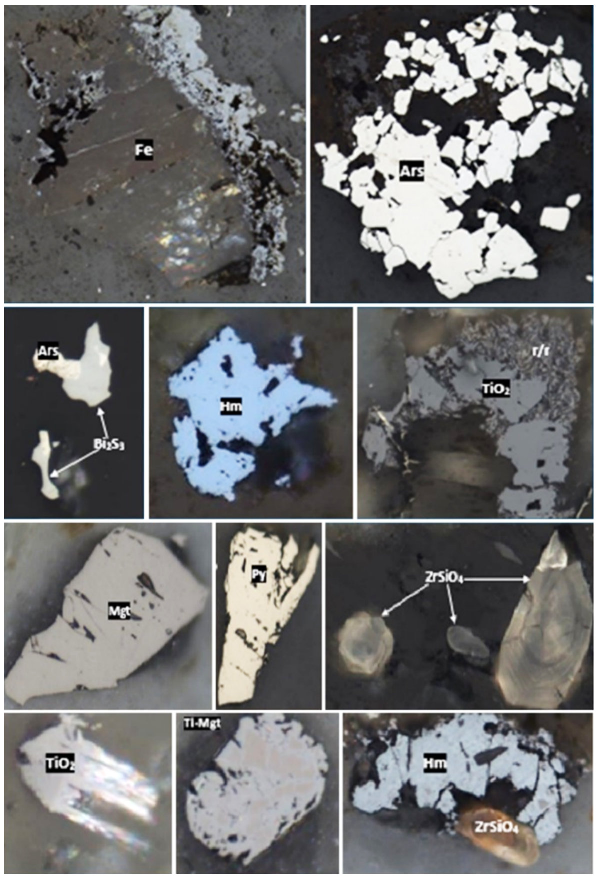


Fig. 6. Associated components in the test sample

Table

Form of gold particle occurrence in a sample from the studied heap leaching site – dated November 06, 2019

Form of gold occurrence	Free gold		Gold in aggregates with waste rock		Gold in aggregates with arsenical pyrite		Gold "adhesions" on the grain of the host waste rock	
	Au (clean surface)	Au "flour gold"	marginal aggregates Au	core inclusions Au	marginal aggregates Au	core inclusions Au	marginal aggregates Au	core inclusions Au
Quantity of particles, pcs.	7	1	3	9	2	1	1	
Percentage ratio, %	29.16	4.17	12.5	37.5	8.33	4.17	4.17	
Total quantity, pcs	8		12		3		1	
Total percentage ratio, %	33.33		50.0		12.5		4.17	
Total, %	100.0							

860 μm. Non-metallic components are represented by prevailing quartz, mica, feldspars, carbonates, chlorite and sericite.

Since the sample material is taken from the heap leaching site, most of the host waste rock grains of the product are yellow-ochre to vermilion red in color (Fig. 6). The reason for staining is the presence in it of a sufficiently large percentage of goethite-hydrogoethite aggregates – 13.6 %, which are oxidation zones closely associated with each other and other minerals, and the presence of an equally high content of artificial iron (metal scrap fragments) – 10.4 %.

Characteristics of associated components in ore are presented in the order of their occurrence:

- sulphides: arsenical pyrite – Ars (FeAsS), pyrite – Py (FeS_2), chalcopyrite – Cp ($CuFeS_2$), rarely: bismuthine – Bi_2S_3 and secondary copper sulphide (covelline and digenite) – cov/dig (CuS/Cu_9S_5);
- iron oxides and hydroxides: goethite/hydrogoethite – goe/hydrog ($HFeO_2/HFeO_2ag$), magnetite – Mgt (Fe_3O_4), hematite – Hm (αFe_2O_3), as well as rutile – TiO_2 and titanomagnetite (Ti-Mgt) in direct association with ulvospinel and leucoxene – Ti-Mgt/ulvosp/leucox.

Along with this, quite often, zircon $ZrSiO_4$ grains are identified, which are presented in the form of well-faceted arrowheaded minerals of a long-prismatic and dipyramidal habitus, both regular shape, retaining its contours, and partially destroyed shape (marginal remnants).

In turn, corroded particles of metal scrap Fe (percentage ratio – 10.4 % of the total amount of test grains, excluding waste rock particles), as well as free particles of silver Ag – 0.7 % occur repeatedly.

The form of gold particle occurrence in a sample taken from the heap leaching site – 11, dated November 06, 2019, is shown in Table, and the distribution of gold according to the forms of its occurrence in a sample taken from the heap leaching site is shown in Fig. 7.

As can be seen from the diagram, gold in aggregates with waste rock has the maximum distribution (37.5 %), free gold is 8 % less. Gold has an equal distribution (12.5 %) in aggregates with waste rock, in marginal aggregates and in aggregates with arsenic pyrite. At the same time, free flour gold and gold "adhesions" on the grain of the host waste rock have an equal distribution (4.17 %).

When calculating the ratio of Au particles to a particular size class, the fact of accumulated gold particles of "adhesion" is not included. Since it is impossible to determine the parameters of gold particles due to their unnatural "smeared" shape (the original size of Au particles has not been saved).

The gold content in the bulk gravity-flotation concentrate obtained as a result of the ore beneficiation process at the Vasilkovsky deposit is 25–40 g/t. In terms of mineral composition, the concentrate consists of 40–60 % of rock-forming minerals, mainly represented by quartz, plagioclase, mica and potassium feldspars. The ore mineralization is mainly represented by sulphides, the main of which are pyrite and arsenical

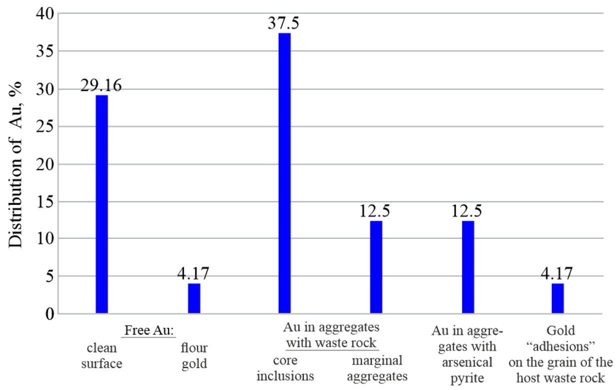


Fig. 7. Graphical gold distribution according to the forms of its occurrence in a sample from the studied heap leaching site – 11, dated November 06, 2019

pyrite. The amount of arsenical pyrite in the concentrate is 37–47 %, pyrite is up to 10 %.

Conclusions. Based on the conducted research results, it can be concluded that the ores of the Vasilkovsky deposit belong to the type of low-sulphide gold-bearing ores, and the only valuable component of which is gold. The content of gold in the ores varies within sufficient limits for their industrial development. Bismuth, as an associated element, occurs in small quantities.

A characteristic peculiarity of the ore is a very thin dissemination of sulphides in the host rocks and a close association of gold with sulphides, such as arsenical pyrite and chalcopyrite. The finest inclusions of gold are identified in rock-forming minerals, such as quartz. The bulk of gold in ores is in a bound form in aggregates and enclosed in sulphides. The presence of gold in the ore, finely disseminated and dispersed in gold sulfides, determines their stability and presents certain difficulties in the development of gold recovery technology.

Gold in aggregates with waste rock has the maximum distribution (37.5 %). From the data on the distribution of gold according to the forms of its occurrence in the sample, it has been determined that 29.16 % is the so-called "virgin" gold. There is a single case of the so-called "flour gold", which has oxidation films on its surface – 4.17 %.

Acknowledgments. We would like to express our gratitude to Academic Advisor, Candidate of Technical Sciences, Professor Arystan Ibatolla Daiyrovich for valuable advice in planning the research and recommendations on the design of this paper. The team of authors is also very grateful to the colleagues involved in organizing the experiments.

References.

1. Bitimbaev, M., & Bahmagambetova, G. (2021). Development of innovative technology for continuous heap leaching of gold. *Bulletin of the National Engineering Academy of the Republic of Kazakhstan, 80*(2), 130-135. https://doi.org/10.47533/2020.1606-146x.95.

2. Petrov, N.I., Dimitrova, K.Y., & Baskanbayeva, D.D. (2021). On the reliability of technological innovation systems. *IOP Conference Series: Materials Science and Engineering, (1031),* 012044. https://doi.org/10.1088/1757-899X/1031/1/012044.
3. Lozynskyi, V., Medianyk, V., Saik, P., Rysbekov, K., & Demydov, M. (2020). Multivariance solutions for designing new levels of coal mines. *Rudarsko Geolosko Naftni Zbornik, 35*(2), 23-32. https://doi.org/10.17794/rgn.2020.2.3.
4. Ghorbani, Y., Franzidis, J. P., & Petersen, J. (2016). Heap leaching technology-current state, innovations, and future directions: a review. *Mineral Processing and Extractive Metallurgy Review, 37*(2), 73-119. https://doi.org/10.1080/08827508.2015.1115990.
5. Marsden, J.O. (2006). Overview of gold processing techniques around the world. *Mining, Metallurgy & Exploration, 23*(3), 121-125. https://doi.org/10.1007/BF03403198.
6. Palomo-Briones, R., Ovando-Franco, M., Razo-Flores, E., Celis, L.B., Rangel-Méndez, J.R., Vences-Álvarez, E., & Briones-Gallardo, R. (2016). An overview of reclaimed wastewater reuse in gold heap leaching. *Mineral Processing and Extractive Metallurgy Review, 37*(4), 274-285. https://doi.org/10.1080/08827508.2016.1190356.
7. Petersen, J. (2016). Heap leaching as a key technology for recovery of values from low-grade ores – A brief overview. *Hydrometallurgy, 165,* 206-212. https://doi.org/10.1016/j.hydromet.2015.09.001.
8. Dyachkov, B.A., Aitbayeva, S.S., Mizernaya, M.A., Amralinova, B.B., & Bissatova, A.E. (2020). New data on non-traditional types of East Kazakhstan rare metal ore. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu,* (4), 11-16. https://doi.org/10.33271/nvngu/2020-4/011.
9. Uteshov, Y., Galiyev, D., Galiyev, S., Rysbekov, K., & Nauryzbayeva, D. (2021). Potential for increasing the efficiency of design processes for mining the solid mineral deposits based on digitalization and advanced analytics. *Mining of Mineral Deposits, 15*(2), 102-110. https://doi.org/10.33271/mining15.02.102.
10. Yelemessov, K., Krupnik, L., Bortebayev, S., Beisenov, B., Baskanbayeva, D., & Igbayeva, A. (2020). Polymer concrete and fibre concrete as efficient materials for manufacture of gear cases and pumps. *E3S Web of Conferences,* (168), 00018. https://doi.org/10.1051/e3sconf/202016800018.
11. Dyachkov, B.A., Bissatova, A.Y., Mizernaya, M.A., Zimanovskaya, N.A., Oitseva, T.A., Amralinova, B.B., ..., & Orazbekova, G.B. (2021). Specific Features of Geotectonic Development and Ore Potential in Southern Altai (Eastern Kazakhstan). *Geology of Ore Deposits, 63*(5), 383-408.
12. Begalinov, A., Almenov, T., Zhanakova, R., & Bektur, B. (2020). Analysis of the stress deformed state of rocks around the haulage roadway of the Beskempir field (Kazakhstan). *Mining of Mineral Deposits, 14*(3), 28-36. https://doi.org/10.33271/mining14.03.028.
13. Dyachkov, B.A., Amralinova, B.B., Mataybaeva, I.E., Dolgopolova, A.V., Mizerny, A.I., & Miroshnikova, A.P. (2017). Laws of formation and criteria for predicting nickel content in weathering crusts of east Kazakhstan. *Journal of the Geological Society of India, 89*(5), 605-609. https://doi.org/10.1007/s12594-017-0650-7.
14. Sarybayev, O., Nurpeisova, M., Kyrgizbayeva, G., & Toleyov, B. (2015). Rock mass assessment for man-made disaster risk management. *New Developments in Mining Engineering,* 403-409. https://doi.org/10.1201/b19901-70.
15. Yulusov, S., Surkova, T.Y., Kozlov, V.A., & Barmenshinova, M. (2018). Application of hydrolytic precipitation for separation of rare-earth and impurity. *Journal of Chemical Technology and Metallurgy, 53*(1), 27-30.
16. Dauletbakov, T.S., Mambetaliyeva, A.R., Dosmukhamedov, N.K., Zhandauletova, F.R., & Moldabaeva, G.Z. (2016). Complex Processing of Industrial Products and Lead-Copper Concentrates. *Eurasian Chemico-Technological Journal, 17*(4), 301. https://doi.org/10.18321/ectj274.
17. Telkov, Sh.A., Motovilov, I.Tu., Barmenshinova, M.B., & Abisheva, Z.S. (2021). Study of gravity-flotation concentration of lead-zinc ore at the Shalkiya deposit. *Obogashchenie Rud*, (6), 9-15.
18. Begalinov, A., Shautenov, M., Almenov, T., Bektur, B., & Zhanakova, R. (2019). Prospects for the effective use of reagents based on sulfur compounds in the technology of extracting gold from resistant types of gold ore. *Journal of Advanced Research in Dynamical and Control Systems, 11*(8), 1791-1796.
19. Umarbekova, Z.T., Zholtayev, G.Z., Amralinova, B.B., & Mataibaeva, I.E. (2020). Silver Halides in the Hypergene Zone of the Arkharly Gold Deposit as Indicators of their Formation in Dry and Hot Climate (Dzungar Alatau, Kazakhstan). *International Journal of Engineering Research and Technology, 13*(1), 181-190. https://doi.org/10.37624/ijert/13.1.2020.181-190.
20. Khairullayev, N.B., Aliev, S.B., Yusupova, S.A., Eluzakh, M., & Akhmetkanov, D.K. (2021). Studies of solution activation in geotechnological mining methods. *Ugol,* (9), 55-57. https://doi.org/10.18796/0041-5790-2021-9-55-57.
21. Nurtazina, N.D., & Syzdykova, L. (2021). Kinetics of bornite leaching in the presence of glycine. *Vestnik KazNRTU, 143*(4), 117-126. https://doi.org/10.51301/vest.su.2021.i4.15.
22. Balbekova, B.K., & Toleuova, A.R. (2019). Study of the sulfuric acid leaching process of the rare earth elements (REE) from the scheelite concentrate. *Vestnik KazNRTU,* 689-693.
23. Baskanbayeva, D.D., Krupnik, L.A., Yelemessov, K.K., Bortebayev, S.A., & Igbayeva, A.E. (2020). Justification of rational parameters for manufacturing pump housings made of fibroconcrete. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (5), 68-74. https://doi.org/10.33271/nvngu/2020-5/068.
24. Onika, S.G., Rysbekov, K.B., Aben, E.K., & Bahmagambetova, G.B. (2020). Leaching rate dependence on productive solution temperature. *Vestnik KazNRTU, 142*(6), 700-705. https://doi.org/10.51301/vest.su.2020.v142.i6.122.
25. Aben, E., Toktaruly, B., Khairullayev, N., & Yeluzakh, M. (2021). Analyzing changes in a leach solution oxygenation in the process of uranium ore borehole mining. *Mining of Mineral Deposits, 15*(3), 39-44. https://doi.org/10.33271/mining15.03.039.

Дослідження купчастого вилуговування золотовмісних руд Васильківського золоторудного родовища (Казахстан)

Д. Кауметова[1], *І. Аристан*[1], *Х. Абсалямов*[2], *К. Жусупова*[3], *А. Жукенова*[2], *Г. Абішева*[2]

1 – Карагандинський державний технічний університет, м. Караганда, Республіка Казахстан, e-mail: kaumetovadinara@mail.ru

2 – Кокшетауський університет імені Шокана Уаліханова, м. Кокшетау, Республіка Казахстан

3 – Satbayev University, м. Алмати, Республіка Казахстан

Мета. Вивчення золотовмісних руд, схильних до технології купчастого вилуговування, для виявлення як вільних частинок золота, так і золота у зростках і примазках, що дасть можливість отримати дані про розподіл золота за формами його залягання.

Методика. Дослідження вилуговування проводилися на лабораторній установці Інституту металургії та збагачення МОН РК. Дослідження частинок золота проводилися за допомогою оптичного мікроскопа AxioScope A1 на поверхні аншліфу. Матеріали проб були представлені зразками з ділянки купчастого вилуговування Васильківського золоторудного родовища.

Результати. У результаті мікроскопічного дослідження проби, відібраної з ділянки купчастого вилуговування, були виявлені ультратонкодисперсні та тонкодисперсні частинки золота як у вільній формі, так і у зростках з порожньою породою та арсенопіритом, а також факт скупчення частинок Au – «примазки» на зерні порожньої породи. Розмірність часток Au варіює в межах від 0,35 до 9,5 мкм.

Наукова новизна. Уперше виявлена закономірність розподілу золота за формами його залягання зі зразків золотовмісних руд Васильківського золоторудного родовища.

Практична значимість. Отримані в результаті дослідження дані дають можливість спрогнозувати розподіл форми золотистості на інших ділянках родовища що значно спростить умови його розробки, а також скоригувати технологічний процес вилуговування золотовмісних руд і основні технологічні параметри процесу купчастого вилуговування.

Ключові слова: *золотовмісні руди, вилуговування, золото, дослідження, родовища*

The manuscript was submitted 09.07.21.