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Assessment of Gravity Dressability of Gold Ore – GRG Test

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Abstract: Gravity methods are widely used for processing of gold ores. But many aspects of these processing techniques require improvement. In the study, methods of fire assay, gravimetric, chemical, mineralogical analyses of gold ores were used. In terms of sulfide sulfur content and degree of sulfur oxidation, the gold ore is assigned to the low-sulfide type of ore in the primary zone. Mineralogical analysis showed the ore-bearing rock is represented by phyllite. Gold in the ore occurs mainly in the form of free large and fine particles. The fine gold is closely associated with pyrite. GRG test was carried out for assessing gravity dressability of the gold ore. The total gold recovery is more than 41 %. The highest gold recoveries were achieved at the first stage at 100 % of –1.6 mm ore grain size, and at the third stage at 80 % of –0.071 mm ore grain size. This indicates that both relatively large gold and fine free gold particles are present in the ore. This is also confirmed by mineralogical analysis. The GRG test results showed that the gold ore can be effectively concentrated using centrifugal concentrators. The level of gold recovery by gravity at the multi-stage ore grinding is quite high. When developing the ore concentration process flow sheet, gravity separation in centrifugal concentrators should be included.

Keywords: gravity separation methods, GRG test, gold ore, assessment of gravity dressability of gold ore, gold ore concentration, centrifugal concentrators.

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Оценка гравитационной обогатимости золотосодержащей руды – GRG

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Аннотация: Гравитационные методы широко применяются при переработке золотосодержащих руд. Но многие аспекты этого направления обогащения требуют совершенствования. В работе использованы методы пробирно-гравиметрического, химического, минералогического анализов золотосодержащей руды. Золотосодержащая руда по содержанию сульфидной серы и степени окисления серы отнесена к убогосульфидному типу руды первичной зоны. По данным минералогического анализа, руда представлена глинисто-слюдистыми сланцами. Золото в рудах находится в виде свободных крупных и мелких зерен, преобладает золото свободное. Мелкое золото тесно ассоциируется с пиритом. Для оценки гравитационной обогатимости золотосодержащей руды проведен GRG-тест. Суммарное извлечение золота составляет более 41 %. Наиболее высокие показатели извлечения золота получены на первой стадии при крупности 100 % класса –1,6 мм и третьей стадии при крупности 80 % класса –0,071 мм. Это указывает на то, что в руде присутствуют и относительно крупные золотины, и мелкие свободные, что подтверждается минералогическим анализом. Результаты GRG-теста показали, что золотосодержащая руда эффективно обогащается на центробежных концентраторах. Уровень извлечения золота гравитацией при стадиальном измельчении руды достаточно высок. При разработке технологической схемы обогащения руды необходимо предусмотреть гравитационное обогащение на центробежных концентраторах.

Ключевые слова: гравитационные методы обогащения, GRG-тест, золотосодержащая руда, оценка гравитационной обогатимости руды, обогащение золота, центробежные концентраторы.

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Introduction

Gravity separation is separation of minerals based on difference in their density. Gravity separation methods are known and used for millennia [1, 2]. Despite widespread use of flotation beneficiation methods, as well as magnetic and electrical separation, hydrometallurgical processes, gravity separation methods do not lose their relevance, and corresponding process flow sheets and equipment are permanently being improved [3, 4]. All methods of gravity separation are implemented at relatively low capital and operating costs, being highly productive and environmentally friendly. Gravity separation has practically no alternative when processing ores of placer deposits far removed from required infrastructure [5–7].

Over the latest decades, centrifugal facilities for advanced processing of mineral raw materials are becoming more widespread. To determine the proportion of gold recoverable from ore (sands) using gravity separation, a Knelson centrifugal concentrator (Knelson) is used. This method, which has become the standard in beneficiation, provides valuable information on the gold recoverability by gravity, as well as the ability to compare the dressability of different ores. In such studies, not only the proportion of gravity recoverable gold is determined, but also its actual particle size [8–14].

Gravity separation of gold ores may result in gold losses at the grinding stage, as large particles of gold become overground and "stick" onto walls of the mill. For the first time, to reduce the losses at the grinding stage, a special GRG test (Gravity recoverable gold test) was developed by Andre Laplante, professor at the McGill University of Canada. Later the technique was improved by Knelson [15–22].

According to this technique, the amount of gold recovered in the GRG test characterizes the ore dressability by gravity methods. The GRG test design is based on the fact that stepwise ore grinding of allows the extraction of precious metals in the course of their liberation without overgrinding and abrasion of large metal particles. The GRG test consists of three successive stages of the liberation of minerals and three stages of beneficiation. With stepwise grinding, the content of gravity recoverable gold [17–19, 23, 24] is determined as accurately as possible.

The study is aimed at assessing gravitational dressability of gold ore using GRG test.

Research Subject and Methods

The research subject is gold ore of one of Kazakhstani deposits, located in Kostanay Region. According to the results of fire assay with gravimetric finish, the ore average gold grade is 1.60 g/t, and that of silver, 3.49 g/t.

For the analysis of other elements, chemical decomposition and determination of the content of the accompanying metals by atomic absorption method were used. For phase analysis for sulfur, chemical-gravimetric method was used. Chemical composition of the ore is presented in Table 1.

Comprehensive mineralogical analysis was carried out using X-ray diffraction (phase) analysis, as well as microscopic and optical methods. The samples were studied under the microscope in thin sections, polished sections, artificial briquettes and immersion media. Gold grains were studied using the JEOL JXA-8230 Electron Probe Microanalyzer.

Table 1

Chemical composition of gold ore

Component	Percentage, %	Component	Percentage, %
Cu	0.004	K_2O	1.58
Ni	0.001	SiO_2	67.29
Co	0.003	Al_2O_3	12.38
Zn	0.005	As	0.02
Pb	0.002	Sb	0.01
Fe	3.67	S_{tot}	0.30
CaO	1.96	$S_{sulfide}$	0.29
MgO	1.10	$S_{sulfate}$	0.01
Na_2O	2.07	Sulfur oxidation degree	3.33

Note.
Ore type:
– based on sulfur oxidation degree – primary;
– based on sulfide sulfur content – low-sulfide.

Comprehensive mineralogical analysis was carried out using X-ray diffraction (phase) analysis, as well as microscopic and optical methods. The samples were studied under the microscope in thin sections, polished sections, artificial briquettes and immersion media. Gold grains were studied using the JEOL JXA-8230 Electron Probe Microanalyzer.

X-ray diffraction analysis of averaged samples was performed using the DRON-4 diffractometer with CuKa radiation, β filter. The X-ray diffraction (XRD) pattern producing conditions were as follows: U = 35 kV; I = 20 mA; shooting θ–2θ; detector – 2 deg/min.

Semi-quantitative X-ray diffraction analysis was carried out based on the diffraction patterns of powdered samples using the method of equal subsamples and artificial mixtures. Quantitative ratios of crystalline phases were determined. The X-ray diffraction patterns were interpreted using the ICDD card-index data: PDF2 (Powder Diffraction File) powder diffraction data base and the diffraction patterns of minerals free of impurities. For the major phases, the content was estimated.

The gold ore gravity dressability was estimated by the GRG test using the Knelson centrifugal concentrator (KC-MD3) under the following conditions: centrifugal acceleration - 60G; fluidizing water consumption – 3.5 dm^3/min; solids productivity – 0.5–0.6 kg/min; excess pressure of the fluidizing water – 10–14 kPa; the solids content in the pulp fed to gravity separation is 25–30 %.

GRG test design. The GRG test was conducted using a 10-kg ore sample at the Knelson concentrator (KC-MD3). This test was carried out in three stages. At the first stage, the ore weighing 10 kg was crushed to 100% passing 1.6 mm, and the crushed ore was processed at the Knelson concentrator. Next, the tailings of the first stage were reground to 80% passing 0.3 mm and processed at the Knelson concentrator. At the 3rd stage, the tailings of the 2nd stage were re-ground to 80% passing 0.071 mm. During the process, at all the stages, samples were taken from the tailings for assays and compiling the process balance. The obtained beneficiation products (concentrates and tailings) were analyzed by fire assay-gravimetric method [18, 23].

The GRG test design is given in Fig. 1.

Research Findings and Discussion

In terms of sulfide sulfur content and degree of sulfur oxidation, the gold ore is assigned to the low-sulfide type of ore in the primary zone.

Mineralogical analysis showed the ore matrix is represented by phyllite, altered to different degrees: silicified, albitized, feldsparized, and carbonatized (Figs. 2–4).

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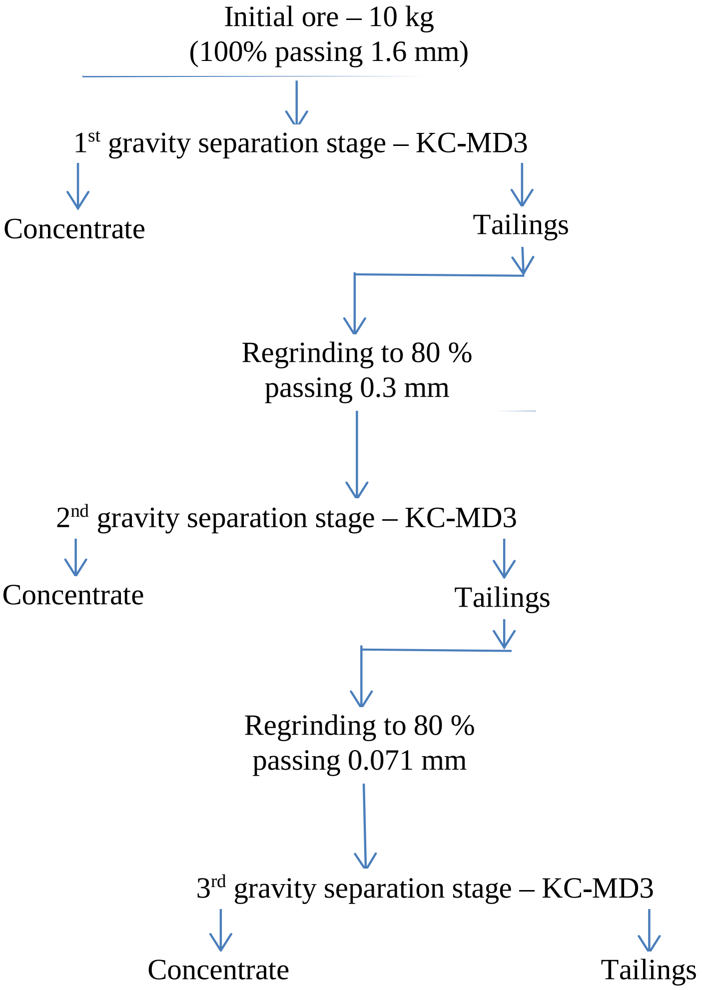

Fig. 1. GRG test design

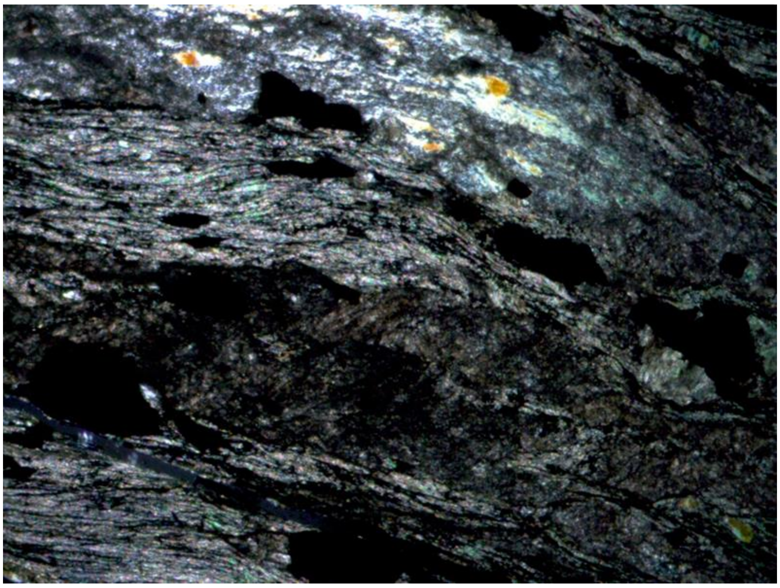

Fig. 2. Phyllite; thin section, ×40

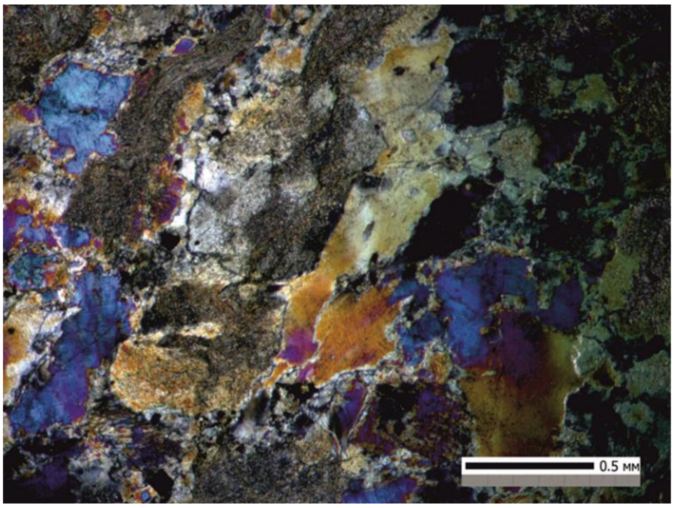

Fig. 3. Silicified, albitized and feldsparized shale; thin section, ×40

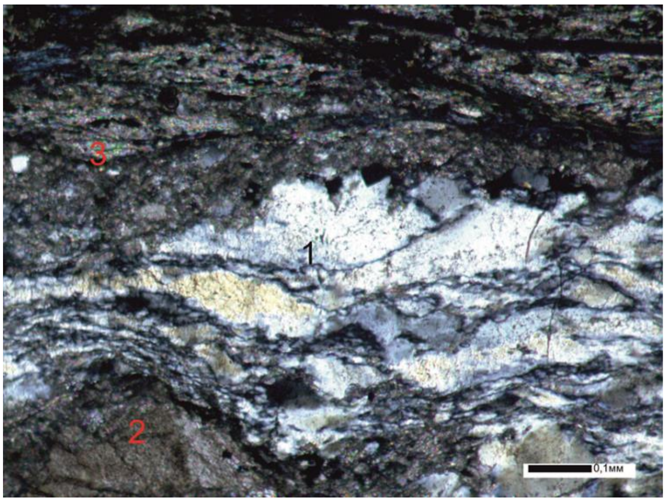

Fig. 4. Silicified and dolomitized phyllite; thin section, ×100:
1 – quartz; *2* – dolomite; *3* – muscovite

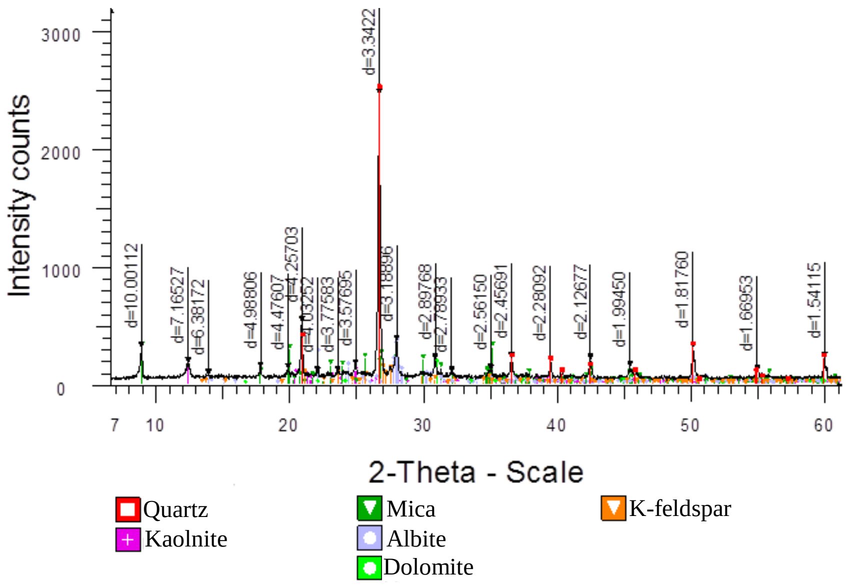

Fig. 5. X-ray diffraction pattern of averaged sample

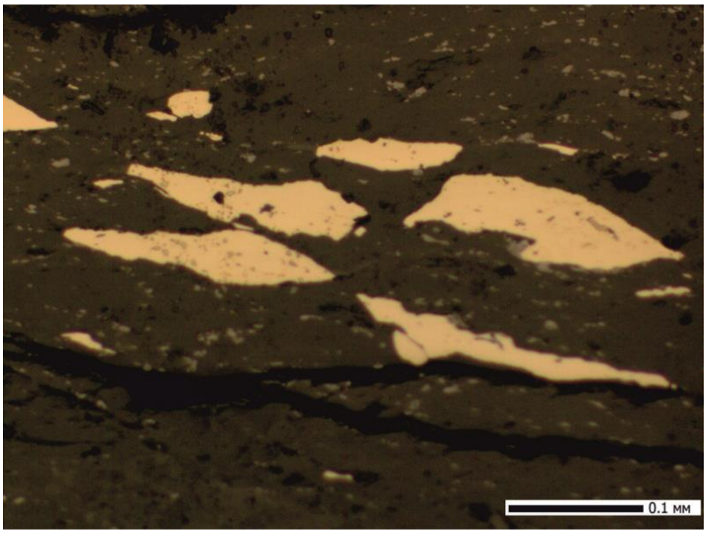

Fig. 6. Pyrite: elongated, oriented along the rock bedding; polished section, ×200

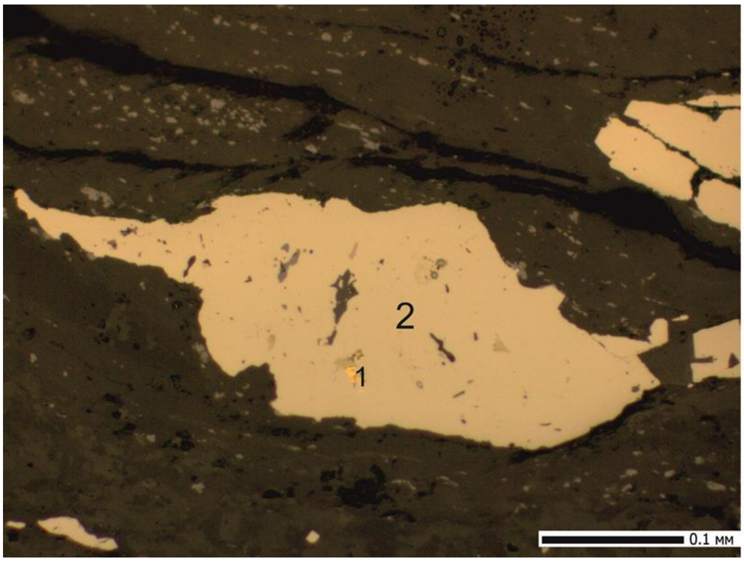

Fig. 7. Gold (1) in pyrite (2); polished section, ×200

The identification of the mineral phases based on the X-ray diffraction analysis data is shown in the X-ray diffraction pattern (Fig. 5).

Mineralogical composition of the averaged sample is as follows (%): ore minerals: pyrite – 0.5–1.0; arsenopyrite – 0.1–0.2; iron oxides and hydroxides – 6–7; chalcopyrite and lead sulfosalts - occasional small particles; rock-forming minerals: quartz – 46–47, kaolinite – 20–21, mica – 9–10, potassium feldspar – 2, albite – 9–10, dolomite – 5–6. Pyrite forms crystalline-granular aggregates in the ore mass of the averaged sample, when the aggregates contain elongated pyrite grains, oriented along the rock schistosity (Fig. 6). It should be noted that most of iron in the sample occurs in oxidized form.

Gold in the ores occurs in the form of free large and small grains. Free platy gold grains 0.06 to 0.20 mm in size prevails. Fine gold is closely associated with pyrite, forming inclusions of 0.005, 0.007, and 0.015 mm in size dispersed within pyrite (Fig. 7).

According to the fire assay, chemical, and mineralogical analyzes data, only gold is commercially valuable component in the ores.

GRG test was carried out for assessing gravity dressability of the gold ore. The GRG test results are given in Table 2.

Table 2

GRG test results

Product	Yield		Au Grade (g/t)	Au distribution, %
	g	%		
1st stage - 100% of -1.6 mm grain size				
Concentrate 1	115.9	1.16	25.57	17.53
Tailings 1	9884.1	98.84	1.41	82.47
Ore	10,000.0	100.00	1.69	100.00
2nd stage – 80% of -0.3 mm grain size				
Concentrate 2	113.8	1.15	17.60	14.48
Tailings 2	9,770.3	98.85	1.21	85.52
Feed (tailings 1)	9884.1	100.00	1.40	100.00
3rd stage – 80% of -0.071 mm grain size				
Concentrate 3	119.6	1.22	17.15	17.10
Tailings 3	9,650.8	98.78	1.03	82.90
Feed (tailings 2)	9,770.3	100.00	1.23	100.00
Total				
Concentrate 1	115.90	1.16	25.57	17.48
Concentrate 2	113.78	1.14	17.60	11.81
Concentrate 3	119.56	1.20	17.15	12.09
Concentrates, total	349.24	3.49	20.09	41.38
Tailings	9,650.76	96.51	1.03	58.62
Ore	10,000.0	100.00	1.696	100.00

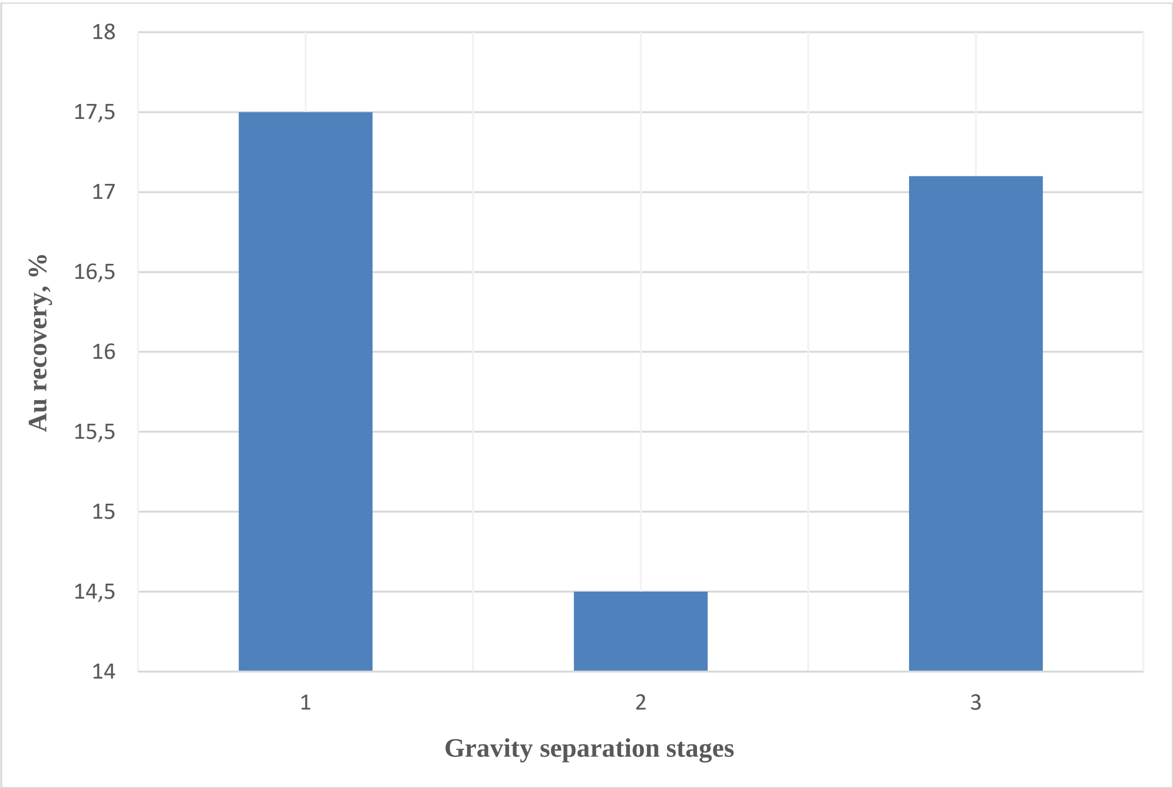

Fig. 8. Recovery of gold by concentration stage

Table 2 data show that the total gold recovery is more than 41%. The efficiency of each stage of the gravity separation (recovery at each stage) in the GRG test is shown in Fig. 8.

The highest gold recoveries were achieved at the first stage at 100 % ore particles passing 1.6 mm, and at the third stage at 80% passing 0.071 mm. This indicates that both relatively large gold grains and fine free gold grains (from 0.06 to 0.20 mm) are present in the ore. This is also confirmed by the mineralogical analysis (Figs. 9–11).

Total percentage of gravity recoverable gold depending on the ore grain size is presented in Fig. 12.

Fig. 12 shows that the highest percentage of gold recovery is achieved at ore grinding to 80 % passing 0.071 mm.

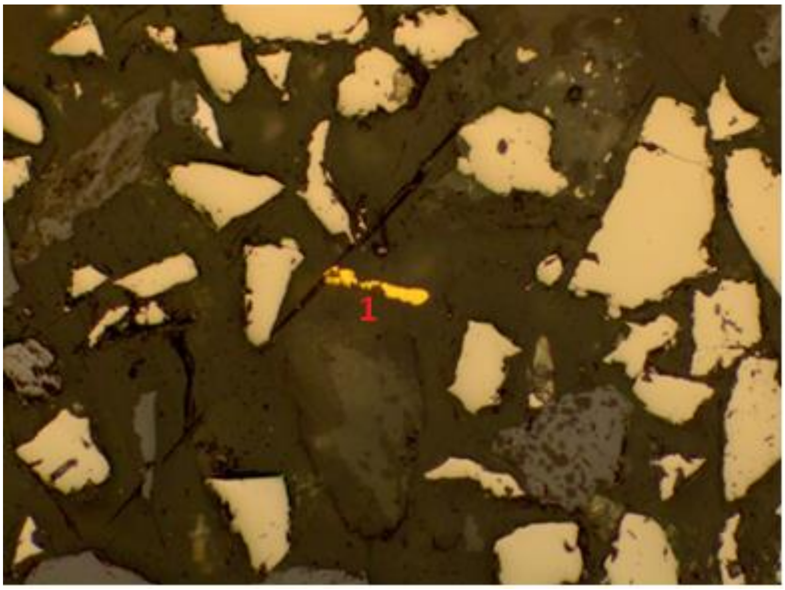

Fig. 9. Platy gold (1); heavy fraction of gravity concentrate, ×200

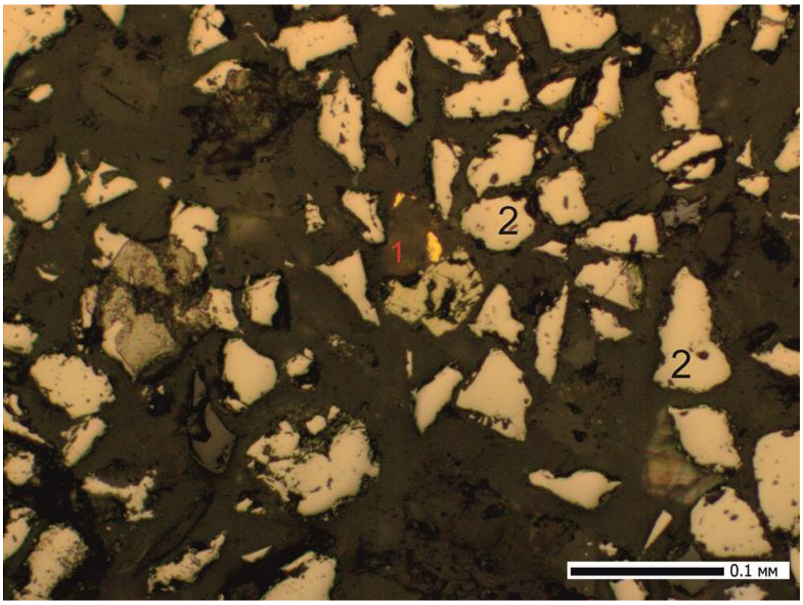

Fig. 10. Platy gold (1), not fully released, in the plane of polished section, and pyrite (2); heavy fraction of gravity concentrate, ×200

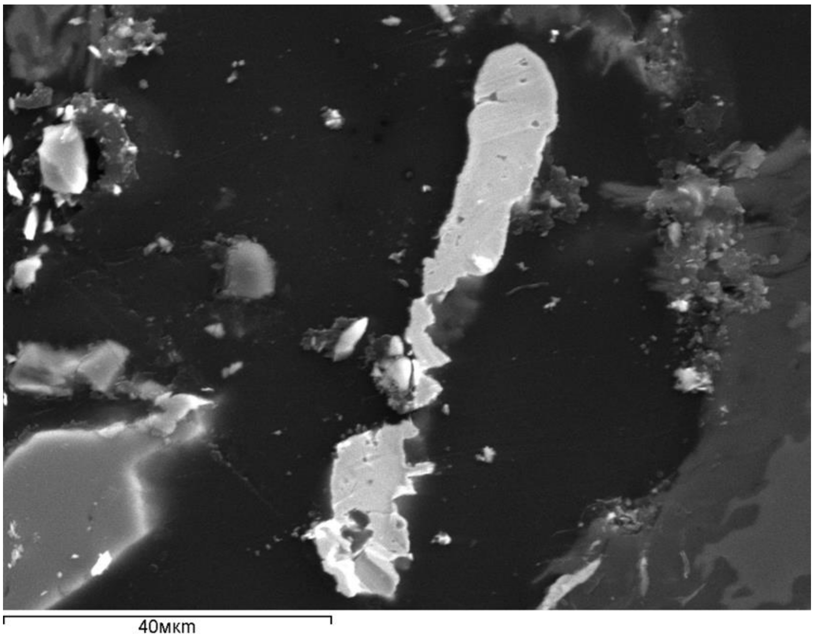

Fig. 11. Electron microprobe analysis for gold; composition (%): Au – 96.54; Ag – 2.78; Fe – 0.68

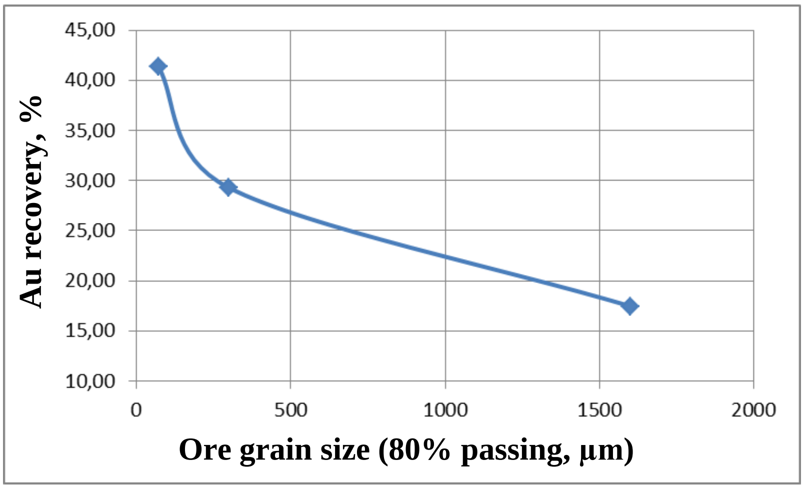

Fig. 12. Total percentage of gold recovered by gravity depending on the ore grain size

Conclusion

The GRG test results showed that the gold ore can be effectively concentrated using centrifugal concentrators. The level of gold recovery by gravity at the multi-stage ore grinding is quite high. When developing the ore beneficiation process flow sheet, gravity separation in centrifugal concentrators should be included.

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