Код МРНТИ 52.45.23

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TECHNOLOGIES FOR EXTRACTING NANOGOLD FROM NATURAL AND TECHNOGENIC ORES

Abstract. Innovative technologies for separating nanogold from natural and technogenic ores are disclosed. The main forms of presence of gold nanoparticles in mineral raw materials are described: in the crystal structure of carrier minerals, crystal structure defects, microcracks, and films of newly formed minerals. It is shown that the main minerals – concentrates of nanosized gold are chalcedonic quartz, albite, valensionite, arsenic pyrite, arsenopyrite, chalcopyrite, marcasite, iron oxides, realgar, clay minerals, etc. When developing a technology for the enrichment of gold-bearing ores, in which the presence of gold nanoparticles is established, it is necessary to take into account their physical and chemical properties that affect the essence of the technology used and its parameters, as well as characteristics.

Key words: *gold-bearing ores, gold nanoparticles, properties and characteristics, processing technologies, reduction of losses, technogenic ores, minerals-concentrates, crystal structure defects, microcracks, films of newly formed minerals.*

Табиғи және техногенді кендерден нанозолот бөлу технологиялары

Аңдатпа. Табиғи және техногенді кендерден нанозолот бөлудің инновациялық технологиялары ашылды. Алтын нанобөлшектерді минералды шикізатта табудың негізгі формалары сипатталған: тасымалдаушы минералдардың кристалды құрылымында, кристалдық құрылымның ақауларында, микрокректерде және жаңадан пайда болған минералдардың пленкаларында. Нанокөлшемді алтынның негізгі минералдары-концентраттары халцедон тәрізді кварц, альбит, валенсионит, мышьякты пирит, арсенопирит, халькопирит, марказит, темір оксидтері, реальгар, сазды минералдар болып табылады. Құрамында алтыны бар кендерді байыту технологиясын жасау кезінде алтынның нанобөлшектерінің болуы белгіленген олардың қолданылатын технологияның мәніне және оның параметрлеріне әсер ететін физикалық және химиялық қасиеттерін, сондай-ақ сипаттамалары.

Түйінді сөздер: *құрамында алтыны бар кендер, алтынның нанобөлшектері, қасиеттері мен сипаттамалары, өңдеу технологиялары, шығындарды азайту, техногендік кендер.*

Технологии выделения нанозолота из природных и техногенных руд

Аннотация. Раскрыты инновационные технологии выделения нанозолота из природных и техногенных руд. Описаны основные формы нахождения наночастиц золота в минеральном сырье: в кристаллической структуре минералов-носителей, дефектах кристаллической структуры, микротрещинах и пленках новообразованных минералов. Показано, что основными минералами – концентратами наноразмерного золота являются халцедоновидный кварц, альбит, валенсионит, мышьяковистый пирит, арсенопирит, халькопирит, марказит, оксиды железа, реальгар, глинистые минералы. При разработке технологии обогащения золотосодержащих руд, в которых установлено наличие наночастиц золота, необходимо учитывать их физические и химические свойства, влияющие на сущность используемой технологии и ее параметры, а также характеристики.

Ключевые слова: *золотосодержащие руды, наночастицы золота, свойства и характеристики, технологии переработки, снижение потерь, техногенные руды.*

Introduction

At present, the concept of «nano» in ore mineralogy and the complex processing of natural and technogenic mineral raw materials has not yet been fully formed. At the same time, finely dispersed ores are taken into development, the nanoparticles of which become the main factor in the technologies for obtaining a useful component from them. The involvement of industrial nanominerals in production leads to a change in the concept of the most useful component. It should be noted that nanoscale technologies involve the study and implementation of mechanisms for extracting valuable components already at the molecular, atomic and electronic levels.

Nanogold (particle size of which is less than 1 nm) is an important component and variable part of finely dispersed (less than 10 μm) gold and often belongs to its associated type[1, 2] [1-5]. The following forms of presence in mineral raw materials were established for it: in the crystal structure of carrier minerals (pyrite, arsenopyrite, quartz, and others), defects in the crystal structure (dislocations, grain boundaries, twin and interfacial boundaries), microcracks and films of newly formed minerals [3, 4]. According to numerous analytical studies, the amount of nanogold contained in sulfide, arsenide, and other ore minerals can be quite significant, reaching contents of 2-5 g/t for the entire mass of gold-bearing ore [6].

The main minerals-concentrates of nanosized gold are chalcedonic quartz, albite, valensionite, arsenic pyrite, arsenopyrite, chalcopyrite, marcasite, iron oxides, realgar, clay minerals, etc. In primary ores formed due to hydrothermal activity, the highest contents of nanogold, as a rule, are associated with sulfide minerals. For example, very high contents of nanogold were found in arsenic pyrite of the following gold deposits [6]: Fairview (South Africa) – 1400 g/t Au; Carlin (USA) − 4000 g/t Au; Getchell (USA) − 2400 g/t Au. In Kazakhstan, at the Bakyrchik gold deposit, nano- and submicroscopic dust- and amoeboid segregations of gold in pyrite and arsenopyrite also prevail [7].

In secondary gold deposits, especially those formed due to hypergene enrichment, visible and nanogold are mainly associated with iron oxyhydroxides. They contain crystalline, fine-spongy, film-sheeted, drop-shaped, emulsion, porous forms (Figure 1) of nanogold.

Materials and Methods

Currently, most experts agree that the main losses in the industrial production of gold are associated with its microscopic and nanosized fractions. The size, shape and composition

[1]*Vorobiev A.E., Gladush A.D. Nanoengineering of the fuel and energy complex. – T 2: Nanoassociates of rocks and nanominerals. – M.: RUDN, 2019. – 411 p. (in Russian)*
[2]*Peregudov V.V., Shautenov M.R. Gold mineralization of Kazakhstan. – Almaty: KazNITU named after. K.I. Satpaev, 2018. – 413 p. (in Russian)*
[3]*Osovetsky B.M. New gold. – Perm: Perm State National Research University, 2016. – 116 p. (in Russian)*
[4]*Osovetsky B.M. Natural nanogold. – Perm: Perm State National Research University, 2013. – 176 p. (in Russian)*

of gold nanoparticles determines their physicochemical characteristics (solubility, density, hardness, strength, specific conductivity, electrokinetic potential, zeta potential, electric charge, melting temperature, etc.), which determines their behavior in processes extraction at processing plants.

In particular, when enriching gold-bearing ores, it should be taken into account that gold nanoparticles have special physical and chemical properties that directly depend on their size, shape, and dielectric environment. Thus, it was experimentally established that gold particles of the nanoscale level are quite different from macroscopic gold in their mechanical, chemical, electrical, magnetic and other properties.

In particular, macroscopic gold is a typical diamagnet, and its 1.9 nm nanoparticles exhibit pronounced ferromagnetic properties [6]. Short, oxygenated gold nanowires conduct electricity, while longer nanowires often become insulators.

In addition, anisotropic gold nanoparticles have unique optical and electronic properties due to the occurrence of localized surface plasmon resonance during their processing. Thus, anisotropic gold nanoparticles (due to their nonspherical structure) have two absorption maxima: at about 520 nm and in the range of 700-900 nm (depending on the ratio of their geometric parameters). In addition, gold in the state of nanosized particles dramatically changes its chemical properties and is easily oxidized in air [8].

Results and Discussion

In order to ensure the efficient industrial extraction of nanogold from gold-bearing ores, it is necessary to establish and evaluate its content and parameters in various gold-bearing samples. Nanogold in gold-bearing ores is distributed extremely unevenly, and a special technology is used to objectively assess its content in mineral raw materials. In addition, it follows from numerous new data that each individual nanosized gold grain is extremely heterogeneous in its composition and forms of occurrence, and bears the same traces of a very long formation (Figure 2), which also affects the level of their extraction.

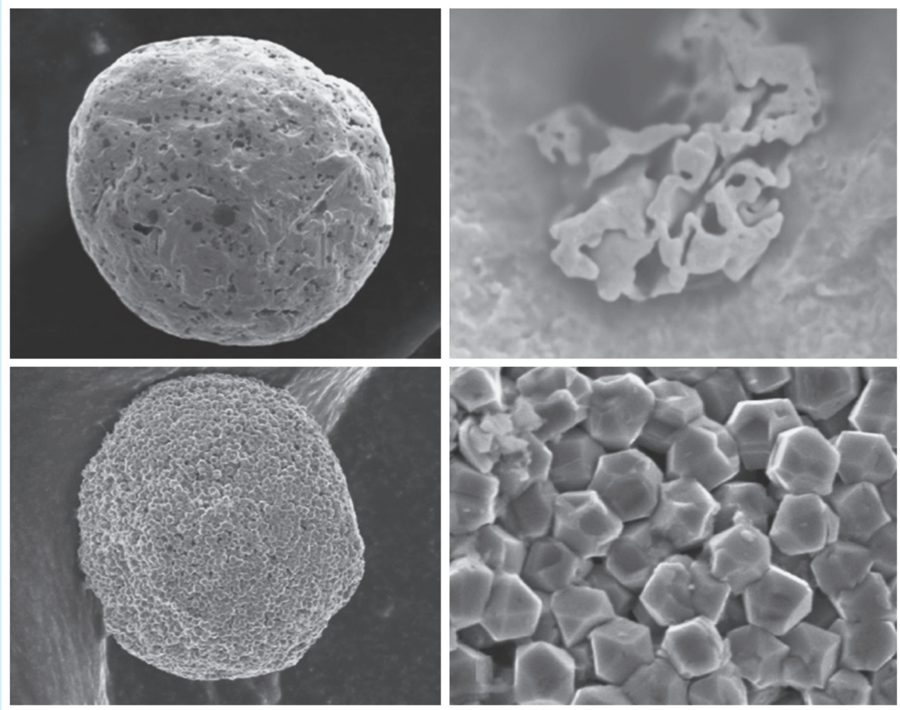


Figure 1. Various forms of finding nanogold.
Сурет 1. Нанозолотты табудың әртүрлі формалары.
Рис. 1. Различные формы нахождения нанозолота.

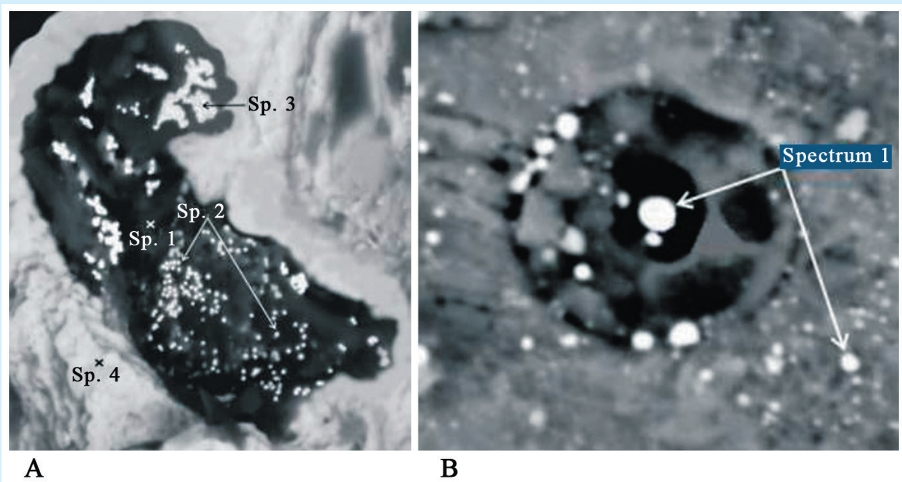


Figure 2. A – valencianite (Sp. 1), containing fayalite, electrum spheroids (Sp. 2) and electrum clusters (Sp. 3), is replaced by native gold (Sp. 4): magnification × 3000; nanominerals in native iron: B – spheroidal nanogold inside multilayer carbon fullerite and on the surface of native iron (Sp. 1): magnification × 7000.
Сурет 2. А – құрамында фаялит бар валенсианит (Сп. 1), электрум сфероидтары (Сп. 2) және электрум кластерлері (Сп. 3) қолдан жасалған алтынмен ауыстырылады (Сп. 4): үлкейту × 3000 ауыстырылады; туынды темірдегі наноминералдар: Б – көпқабатты көміртекті фуллерит ішінде және табиғи темір бетінде (Сп. 1) сфероидты наноголд: үлкейту × 7000.
Рис. 2. А – Валенсианит (Сп. 1), содержащий фаялит, сфероиды электрума (Сп. 2) и кластеры электрума (Сп. 3) замещаются самородным золотом (Сп. 4): увеличение × 3000; наноминералы в самородном железе: Б – сфероидальное нанозолото внутри многослойного углеродного фуллерита и на поверхности самородного железа (Сп. 1): увеличение × 7000.

To improve the efficiency of extracting nanogold from ores, it is proposed to process the material of the gold-bearing sample in a clearly regulated sequence with the separation into separate products of all gold particles of different dimensions from large (+0.25 mm), small (–0.25+0.10 mm), thin (–0.10+0.01 mm (10 µm)) and fine (–10 µm –0.001 mm (1 nm)) (Figure 3). The separation of gold concentrates according to the size of gold grains and gold grains is achieved by a combination of devices operating in passive (screw separator, jigging, hydrocyclone) and intensive (centrifugal devices) gravity fields (Figure 4).

The technological scheme of the Carla plant was developed by V.V. Peregudov and named after his granddaughter. It is assembled in a modular design from separate devices and modules, which, depending on the tasks to be solved, can change places, etc. The best achievements of Soviet technologists of the late 50s – early 60s of the last century, as well as Leading Research Institute of Chemical Technology (Moscow) were used in the technology.

The technological scheme of the chain of apparatuses is an experimental laboratory model of industrial installations, which are completed in an industrial version with hydrometallurgical installations for the intensive leaching of gold from gravity concentrates.

As a result, for each sample, various-sized free native gold is obtained in separate concentrates of centrifugal apparatuses with a grain size of gold particles from 10 microns (with an extraction of more than 90%), others, i.e. in rich ore microaggregates). The final tailings contain mainly finely dispersed gold (nanogold).

Conclusion

Thus, a distinctive feature of such a technological scheme is:

- the entire geomaterial of the sample without any reductions (including boulder-pebble) goes into processing, undergoing preliminary mechanical processing in the self-grinding mill;
- after mechanical treatment of wet screening, a sand fraction (-2+0 mm) is released, which undergoes a two-stage enrichment, first (main) on a vibrating screw separator, and then (control)

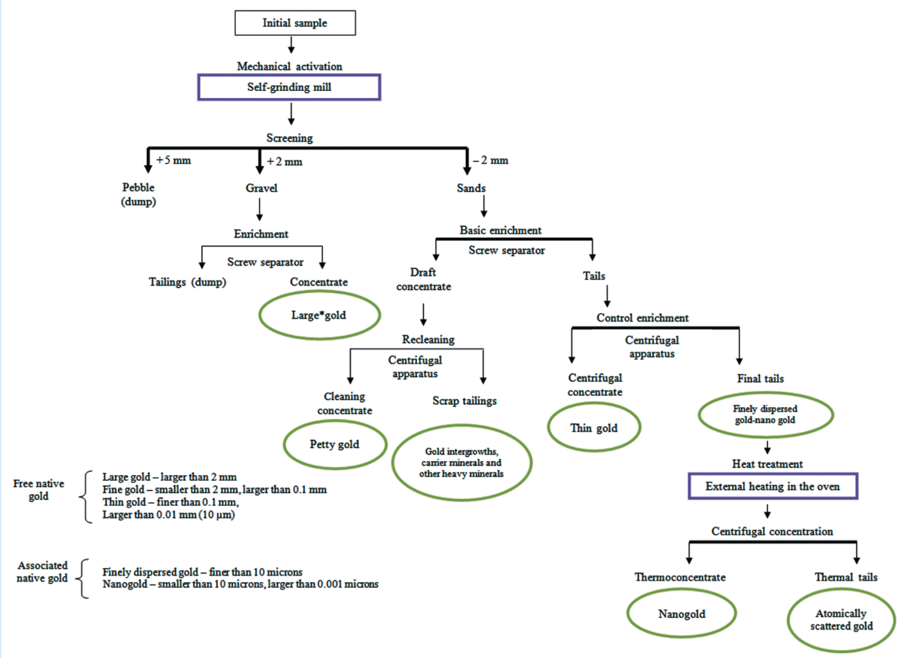
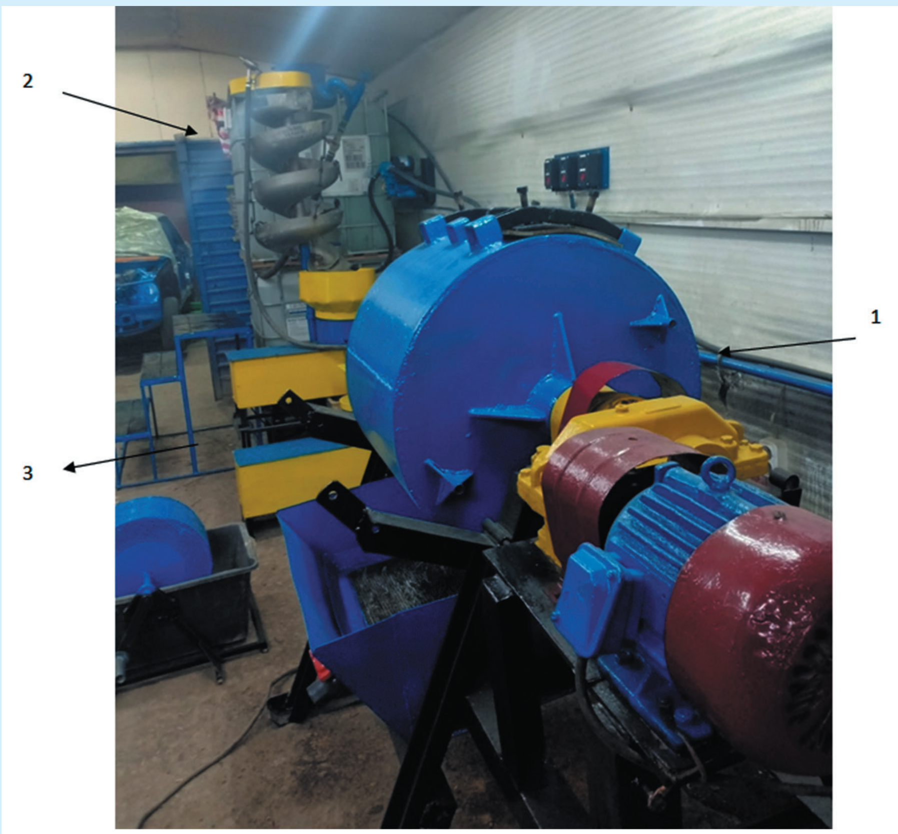


Figure. 3. Principal technological scheme for processing samples for gold.
Сурет. 3. Алтынға үлгілерді өңдеудің негізгі технологиялық схемасы.
Рис. 3. Принципиальная технологическая схема обработки проб на золото.



1 – self-grinding mill;
2 – screw separator;
3 – centrifugal bowl devices

Figure 4. Carla plant for processing geological samples.
Сурет 4. Геологиялық үлгілерді өңдеуге арналған Carla зауыты.
Рис. 4. Установка Carla по обработке геологических проб.

on vibrocentrifugal apparatus, which allows you to separate and more or less evenly distribute among the enrichment products free (large, fine and thin) and bound (fine) native gold;

▪ quantitative determination and study of free native gold in enrichment products pre-treated in a self-grinding mill is carried out by mineralogical, chemical and hydrometallurgical analyzes using X-ray diffractometry, optical and electron microscopy, microprobe X-ray spectral analyzes of the composition of individual grains of minerals, etc.;

▪ quantitative determination of finely dispersed gold in the final enrichment tailings is carried out with their preliminary heating (heat treatment). Due to external heating, the nanometer dimension of grains of native gold is enlarged to micron, gravitated. It should be noted that the value of the melting temperature of macroscopic gold is 1064°C, and gold nanoparticles with a size of 2.2 nm are melted only at 126°C [8], which should also be really reflected in the technological schemes for processing gold ores.

The subsequent enrichment of the heat-treated material in centrifugal apparatuses and analysis of the enrichment products makes it possible to determine its amount by the methods of scintillation spectrometry, chemical, neutron activation and hydrometallurgical analyzes. All studies are accompanied by optical and electron microscopy.

REFERENCES

1. *Vorobyov A.E., Vercheba A.A. and Trabelssi S. Osnovnye nanoformy zolota mestorozhdenij i texnogennogo mineral'nogo syr'ya [Basic nanoforms of gold deposits and technogenic mineral raw materials]. // Razvedka i oxrana nedr = Exploration and protection of subsoil. – 2015. – №4. – P. 21-25 (in Russian)*
2. *Vorobyov A.E., Nasyrov U.F., Ibragimov R.R., Trabelssi S., Kholikulov D.B. Vyyavlennye nanoformy zolota v geogennom i texnogennom mineral'nom syr'e [Identified nanoforms of gold in geogenic and technogenic mineral raw materials]. // Gornyj vestnik Uzbekistana = Mining Bulletin of Uzbekistan. – 2015. – №2(61). – P. 18-27 (in Russian)*
3. *Vorobyov A.E., Trabelssi S. Vidy nanoform zolota, v geogennom i texnogennom mineral'nom syr'e [Types of gold nanoforms in geogenic and technogenic mineral raw materials]. // Gornyj zhurnal Kazaxstana = Mining Journal of Kazakhstan. – 2015. – №2. – P. 18-21 (in Russian)*
4. *Vorobyov A.E., Tcharo H. Sravnitel'nyj analiz svojstv nanorel'efa razlichnyx `zolotosoderzhashhix sul'fidov [Comparative analysis of the properties of the nanorelief of various gold-bearing sulfides]. // Vestnik Rossijskogo universiteta druzhby narodov. Seriya: Inzhenernye issledovaniya = Bulletin of the Peoples' Friendship University of Russia. Series: Engineering Research. – 2016. – №1. – P. 78-84 (in Russian)*
5. *Vorobyov A.E., Shamshiev O.Sh., Maralbaev A.O. Tipizaciya nanoform zolota v geogennom i texnogennom mineral'nom syr'e [Typification of gold nanoforms in geogenic and technogenic mineral raw materials]. // Inzhener = Engineer. – Bishkek, 2015. – №9. – P. 65-81 (in Russian)*
6. *Moiseenko V.G., Dementienko A.I. Resursy nanorazmernogo zolota v mineral'nom syr'e // Voprosy geologii i kompleksnogo osvoeniya prirodnyx resursov Vostochnoj Azii [Resources of nanosized gold in mineral raw materials]. // Sbornik dokladov Vtoroj Vserossijskoj nauchnoj konferencii «Voprosy geologii i kompleksnogo osvoeniya prirodnyx resursov Vostochnoj Azii» = Collection of reports of the Second All-Russian scientific conference «Issues of geology and integrated development of natural resources of East Asia». – Blagoveshchensk: IGiP FEB RAS, 2012. – P. 103-105 (in Russian)*
7. *Zimanovskaya N.A. Nanozoloto v uglerodisto-zolotosul'fidnyx rudax mestorozhdeniya Bakyrchik [Nanogold in carbonaceous-gold-sulfide ores of the Bakyrchik deposit]. // Vestnik VKGTU = Bulletin of EKSTU. – 2014. – №1. – P. 3-6 (in Russian)*
8. *Zhmodik S.M., Kalinin Yu.A., Roslyakov N.A. Nanochasticy blagorodnyx metallov v zone gipergeneza [Noble metal nanoparticles in the hypergenesis zone]. // Geologiya rudnyx mestorozhdenij = Geology of ore deposits. – 2012. – Vol. 54. – №2. – P. 168-183 (in Russian)*

ПАЙДАЛАНЫЛҒАН ӘДЕБИЕТТЕР ТІЗІМІ

1. *Воробьев А.Е., Верчеба А.А., Трабелсси С. Алтын кен орындарының және техногендік минералды шикізаттың негізгі наноформалары. // Жер қойнауын барлау және қорғау. – 2015. – №4. – Б. 21-25 (орыс тілінде)*
2. *Воробьев А.Е., Насыров У.Ф., Ибрагимов Р.Р., Трабелсси С., Холикулов Д.Б. Геогендік және техногендік минералды шикізаттардағы алтынның анықталған наноформалары. // Өзбекстан тау-кен хабаршысы. – 2015. – №2(61). – Б. 18-27 (орыс тілінде)*

3. *Воробьев А.Е., Трабелсси С. Геогендік және техногендік минералды шикізаттардағы алтын наноформаларының түрлері. // Қазақстан кен журналы. – 2015. – №2. – Б. 18-21 (орыс тілінде)*
4. *Воробьев А.Е., Тчаро Х. Құрамында алтыны бар әртүрлі сульфидтердің нанорельефінің қасиеттерін салыстырмалы талдау. // Ресей халықтар достығы университетінің хабаршысы. Серия: Инженерлік зерттеулер. – 2016. – №1. – Б. 8-84 (орыс тілінде)*
5. *Воробьев А.Е., Шамшиев О.Ш., Маралбаев А.О. Геогендік және техногендік минералды шикізаттағы алтын наноформаларын типтеу. // Инженер. – Бішкек, 2015. – №9. – С. 65-81 (орыс тілінде)*
6. *Моисеенко В.Г., Дементиенко А.И. Минералды шикізаттағы наноөлшемді алтынның ресурстары. // «Геология және Шығыс Азияның табиғи ресурстарын кешенді игеру мәселелері» атты Екінші Бүкілресейлік ғылыми конференцияның баяндамалар жинағы. – Благовещенск: ИГиП ДВО РАН, 2012. – Б. 103-105 (орыс тілінде)*
7. *Зимановская Н.А. Бақыршық кен орнының көміртекті-алтын-сульфидті кендеріндегі наноалтын. // Вестник ШҚМТУ. – 2014. – №1. – Б. 3-6 (орыс тілінде)*
8. *Жмодик С.М., Калинин Ю.А., Росляков Н.А. Гипергенез аймағындағы асыл металл нанобөлшектері. // Геология кен орындары. – 2012. – Т. 54. – №2. – Б. 168-183 (орыс тілінде)*

СПИСОК ИСПОЛЬЗОВАННЫХ ИСТОЧНИКОВ

1. *Воробьев А.Е., Верчеба А.А., Трабелсси С. Основные наноформы золота месторождений и техногенного минерального сырья. // Разведка и охрана недр. – 2015. – №4. – С. 21-25 (на русском языке)*
2. *Воробьев А.Е., Насыров У.Ф., Ибрагимов Р.Р., Трабелсси С., Холикулов Д.Б. Выявленные наноформы золота в геогенном и техногенном минеральном сырье. // Горный вестник Узбекистана. – 2015. – №2(61). – С. 18-27 (на русском языке)*
3. *Воробьев А.Е., Трабелсси С. Виды наноформ золота в геогенном и техногенном минеральном сырье. // Горный журнал Казахстана. – №2. – 2015. – С. 18-21 (на русском языке)*
4. *Воробьев А.Е., Тчаро Х. Сравнительный анализ свойств нанорельефа различных золотосодержащих сульфидов // Вестник Российского университета дружбы народов. Серия: Инженерные исследования. – 2016. – №1. – С. 78-84 (на русском языке)*
5. *Воробьев А.Е., Шамшиев О.Ш., Маралбаев А.О. Типизация наноформ золота в геогенном и техногенном минеральном сырье. // Инженер. – Бишкек. – 2015. – №9. – С. 65-81 (на русском языке)*
6. *Моисеенко В.Г., Дементиенко А.И. Ресурсы наноразмерного золота в минеральном сырье. // Вопросы геологии и комплексного освоения природных ресурсов Восточной Азии: Вторая Всерос. науч. конф.: сб. докладов. – Благовещенск: ИГиП ДВО РАН. – 2012. – С. 103-105 (на русском языке)*
7. *Зимановская Н.А. Нанозолото в углеродисто-золотосульфидных рудах месторождения Бакырчик. // Вестник ВКГТУ. – 2014. – №1. – С. 3-6 (на русском языке)*
8. *Жмодик С.М., Калинин Ю.А., Росляков Н.А. и др. Наночастицы благородных металлов в зоне гипергенеза. // Геология рудных месторождений. – 2012. – Т. 54. – №2. – С. 168-183 (на русском языке)*

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