ГИАБ. Горный информационно-аналитический бюллетень /
MIAB. Mining Informational and Analytical Bulletin, 2023;(1):84-94
ОРИГИНАЛЬНАЯ СТАТЬЯ / ORIGINAL PAPER

УДК 622:577.4 DOI: 10.25018/0236_1493_2023_1_0_84

# СТРУКТУРНО-ГЕОЛОГИЧЕСКИЕ ОСОБЕННОСТИ РУДНЫХ ЗОН ЮГО-ВОСТОЧНОЙ ЧАСТИ СИБИРСКОЙ ПЛАТФОРМЫ

**И.И. Босиков[1], Р.В. Клюев[2], В.Ч. Ревазов[1], Д.Э. Пилиева[1]**

[1] Северо-Кавказский горно-металлургический институт
(государственный технологический университет), Владикавказ, Россия, e-mail: igor.boss.777@mail.ru
[2] Московский политехнический университет, Москва, Россия

***Аннотация:*** Представлены результаты проведенного структурного районирования Эганджинской площади, анализа пространственного распределения трещинно-разрывных систем юго-восточной части сибирской платформы с целью выделения перспективных серебро-полиметаллических участков для проведения поисково-оценочных работ. Проведенные исследования показывают, что зоны дробления формировались в условиях интенсивных подвижек с неоднократным подновлением их контактов, выразившихся в дроблении и метасоматическом замещении. Устанавливается как минимум два этапа: раскрытие трещин кварцевой и кварц-карбонатной минерализацией в условиях растяжения, ориентированного перпендикулярно стенкам этих трещин; вертикальные перемещения вдоль трещин и формирование линзовидных тел брекчиевого строения, в которых дробятся ранние кварц-карбонатные жильно-прожилковые образования и цементируются поздними прожилками нескольких генераций карбонатов. Выявлены локальные аномалии поляризуемости, площадные аномалии повышенной поляризуемости вдоль Западной рудно-тектонической зоны, а также слабоконтрастные аномалии магнитного поля в северо-западной части Северной зоны. Наблюдается корреляция хребтов с минимумами магнитного поля. Исследования сереброрудных объектов позволили выявить как принципиальное определенное сходство их состава в полиметаллических рудах, так и значительные черты отличия, объясняемые в первую очередь составом магматизма.

***Ключевые слова:*** структура и морфология рудных зон, разломы субширотного простирания, зоны поперечных разрывных нарушений, зоны дробления, метасоматическое замещение, аномалии поляризуемости, Сибирская платформа, разломы, складчатость, минерализация.

***Для цитирования:*** *Босиков И. И., Клюев Р. В., Ревазов В. Ч., Пилиева Д. Э.* Структурно-геологические особенности рудных зон юго-восточной части Сибирской платформы // Горный информационно-аналитический бюллетень. – 2023. – № 1. – С. 84–94. DOI: 10.25018/0236_1493_2023_1_0_84.

## Structural and geological features of ore zones in the southeast of the Siberian Platform

**I.I. Bosikov[1], R.V. Klyuev[2], V.Ch. Revazov[1], D.E. Pilieva[1]**

[1] North Caucasian Institute of Mining and Metallurgy (State Technological University), Vladikavkaz, Russia, e-mail: igor.boss.777@mail.ru
[2] Moscow Polytechnic University, Moscow, Russia

***Abstract:*** The article presents the results of the structural zoning of the Eganja area, the analysis of the spatial distribution of fracture systems in the southeastern part of the Siberian platform in order to identify promising silver-polymetallic areas for prospecting and appraisal work. The conducted studies show that the crushing zones were formed under conditions of intense movements with repeated renewal of their contacts, expressed in crushing and metasomatic replacement. At least two stages are established: opening and filling of cracks with quartz and quartz-carbonate mineralization in a tension setting oriented perpendicular to the walls of these cracks; vertical displacements along fractures and formation of lenticular bodies of breccia structure, in which early quartz-carbonate vein-veinlets are crushed and cemented by late veinlets of several generations of carbonates. Local anomalies of polarizability, areal anomalies of increased polarizability along the Western ore-tectonic zone, as well as low-contrast anomalies of the magnetic field in the northwestern part of the Northern zone were revealed. The correlation of the ridges with the minima of the magnetic field is observed. Studies of silver ore objects made it possible to reveal both a fundamental similarity in their composition in polymetallic ores, and significant differences, primarily explained by the composition of magmatism.

***Key words:*** structure and morphology of ore zones, sublatitudinal faults, transverse fault zones, crushing zones, metasomatic replacement, polarizability anomalies, Siberian platform, faults, folding, mineralization.

***For citation:*** Bosikov I. I., Klyuev R. V., Revazov V. Ch., Pilieva D. E. Structural and geological features of ore zones in the southeast of the Siberian Platform. *MIAB. Mining Inf. Anal. Bull.* 2023;(1):84-94. [In Russ]. DOI: 10.25018/0236_1493_2023_1_0_84.

## Introduction

The Eganja group of manifestations, which includes the Central ore occurrence, is localized within the north-northwest strike anticline of the same name (strike azimuth 340°) and composed of the Middle and Upper Triassic rocks. The fold of the box-shaped structure is characterized by a wide (23—25 km) domed vault and relatively flat wings. The hinge of the fold is subhorizontal, in the area of the middle course of the Eganja River it weakly sinks to the north at angles of 2—30° [1, 2].

The core of the anticline is complicated by a large fault of the north-northwest strike (strike azimuth 330—340°), along which the rocks of the Anisian tier are pushed over the Ladin rocks and shifted relative to similar outlets to the north by 1 km. The amplitude of vertical displacements is estimated from the section of the lower and middle strata of the Ladinsky tier and is 700 m.

The western wing of the anticline is flat (the angle of incidence is 15—25°), composed of rocks of the Upper Triassic and Jurassic. The general monocline occurrence of rocks is complicated (between streams. Gnat and Flat) with a shallow fractured folding with steep and subvertical hinges. These folds (axonoclines) are confined to shear zones. The rocks are broken by dikes and small rods of diorite porphyrites, often of complex configuration (in plan) with numerous apophyses up to 100—500 m long, stretched along the main fault systems of the east-northeast and northwest strike.

The eastern wing of the anticline is steeper (the angle of incidence is 20—40°), composed of rocks of the Middle-Upper Triassic and Early Jurassic. The monocline occurrence of rocks along the strike is complicated by z-shaped kinks confined to the zones of transverse discontinuous faults.

The folded structure of the Eganja anticline is complicated by faults in three directions: sublatitudinal (azimuth of strike 80—100°), northeastern (azimuth of strike 50—70°) and north-northeast (azimuth of strike 30—40°), which make up the Derbe-Nelgesinsky fault zone with a width of about 10 km.

The faults of the sublatitudinal strike are most widely manifested along the left tributaries of the Eganja River — the Tractor and Topographic streams and the right tributaries of the Soguru River — the Diorite and Green streams and are traced into the valley of the Kondekan River. The faults are represented by a series of converging backstage breaks up to 10 km long, the separate displacements of which are clearly visible on satellite images in the form of rectilinear ledges along the slopes and wide depressions on the watersheds [3, 4].

The most intensively mineralized areas of the crushing zones are accompanied by medium-sized dikes. In these areas, the ore zones of the Tractor section are localized.

The faults of the north-eastern strike are most widely developed in the central part of the Eganja square and are traced through its entire territory by a wide (about 3 km) strip between the Komar and Pologiy streams. In the zone of faults thickening (between the Komar and Tent streams), the western wing of the Eganja anticline is deployed by almost 90° and is complicated by small folds with steeply falling hinges, the asymmetry of which indicates right-shift movements along the faults. The amplitudes of horizontal displacements are estimated by the displacement of the layers and reach 1—1.5 km. Between these faults are z-shaped wings of right-sided shifts with smaller displacement amplitudes, to which the ore zones of the Central and Clear-Perevalny sections are confined.

Intensively mineralized areas are represented by magmatic and hydrothermal formations and brecciated fragments of both sedimentary and igneous rocks with quartz-chlorite-sulfide or quartz-carbonate-sulfide mineralization. Mineralization intervals can be traced to a distance of 100 to 700 m, their thickness varies widely from 1—2 m to 20—25 m.

The faults of the north-northeastern strike are limited, mainly in the northwestern part of the Eganja area. The largest fault is traced along the valley of the stream Oleniy (left tributary of the Eganja River) in the lower course of the stream. Kanavny (right tributary of the Soguru River). Here the rocks of the western wing of the Eganja anticline of the monocline structure, composed of rocks of the Upper Triassic along the entire length of the fault, are in contact with the horizontally overlying upper stratum of the Carnian tier. The amplitude of vertical movements is 150—250 m, horizontal up to 2 km.

The fault is practically not mineralized, «dry». Along its separate displacements, fragmented rocks are developed to varying degrees — from structureless kakirites to almost undisturbed, in places horizontally lying.

**Structure and morphology of ore zones**

The method of correlation of the stages of structure and ore formation, the method of structural modeling, and the analysis of the spatial distribution of magmatic bodies are used as mathematical research methods.

The conducted structural zoning of the Eganja square revealed its heterogeneous «block» structure, due to the predominance of certain discontinuous systems or stable combinations of them. Analysis of the spatial distribution of fractured-discontinuous systems shows that two ore fields can be preliminarily identified within the Eganja area — the western one, combining the Central and Tractor sections, and the eastern one, combining the Clear-Perevalny and Geological sections [2—4].

The ore zones of the Tsentralny site are localized within the western wing of the Eganja anticline, composed of sandy-clay deposits of the Carnian and Norian tiers of the Upper Triassic with a gentle fall to the southwest (angle of incidence 15—20°). The occurrence of rocks is complicated by numerous close mineralized ruptures of the northeastern strike (strike azimuth 60—70°). The main fault zone (their thickening) runs between the Komar and Tent streams. An extended zone is allocated along the fault zone, for which a back-slide-shear structure has been established during detailed studies. The axes of the wings obey the general direction of the ore-containing fault and have a length of 0.5 to 1.5 km.

Similar recess between the Bolotny and Tent streams control the position of the main silver ore zones of the Central section.

The discontinuous structure is emphasized by an extended dike of diorite porphyrites with a length of about 350—400 m, which consists of separate fragments (short segments). The dikes are tectonic, as a rule, along the crushing zones in which the material is crushed, both dikes and host rocks. Sometimes dike contacts are telescoped by veins of quartz-limonite composition, which also develop along the dike and host rocks [5, 6].

The dike is accompanied by a halo of quartz-carbonate-limonite veining with a thickness of 0.5—3.5 m in intensely fractured sandstones. At certain intervals, fracturing passes into low-power crushing zones.

Some of them were opened by ditches No. 1 (re-opened by ditch k-35) and No. k-2. In the k-35 ditch, a mineralized fracture zone with a thickness of 3 to 5 m was opened at intervals of 119—123 and 129—132 m. The cracks are subvertical, the azimuth of incidence is 130—140°, the angle of incidence is 75—90°, crack planes are complicated by weak bends in the fall. The cracks are streaked with veins of quartz-carbonate-sulfide composition with a thickness of 2—3 cm. A rim of quartz crystals of a comb structure is symmetrically developed along the veins of the vein selvage, indicating the opening of cracks perpendicular to the bands. Galena develops in the form of a later metasomatic superimposed inclusions along the bands of veins or in the form of nests along siderite [7, 8].

Lenses with a thickness of up to 0.3—0.5 m, stacked with multi-stage breccias, are localized in the areas of crack thickening. Fragments of brecciated sandstones with quartz-carbonate veins are repeatedly crushed and cemented or intersected by later veins of several generations of carbonates (double and triple breccias). Inside the lenses, galena develops both in the form of independent veins and veinlets, and in the form of metasomatic nests and inclusions replacing carbonates. The nature of the structure of the lenses indicates their formation as a result of vertical (upward) movements along the cracks [9, 10]. Veins of white coarse — crystalline calcite with a thickness of up to 5—7 cm are developed along separate cracks. Streakiness is noted in the veins due to the relics of chloritized host rocks oriented parallel to the contacts. The contacts of the veins are lapped, smooth, straight [11—13].

## Results of the work and their discussion

The conducted examinations at the studied intervals show that the crushing zones were formed under conditions of intense movements with repeated renewal of their contacts, expressed in crushing and metasomatic substitution [14, 15]. At least two stages are established:

- cracks opening by quartz and quartz-carbonate mineralization in an environment of stretching oriented perpendicular to the walls of these cracks;
- vertical movements along cracks and the formation of lenticular bodies of breccia structure, in which early quartz-carbonate vein formations are crushed and cemented by late veins of several generations of carbonates (siderite + ankerite+calcite) [16, 17].

The silver mineralization of the Nelgessin zone is considered by some researchers as part of the polymetallic mineralization of the cassiterite-sulfide formation, others distinguish it into an independent silver-polymetallic formation. To determine the formation affiliation of the studied silver ore objects of the Nelgessin zone, it is necessary to consider their geological, structural and mineralogical features.

The analysis of the spatial distribution of magmatic bodies of different composition and age, as well as the accompanying mineralization, shows that the structures of this direction are characterized by various morphogenetic features, kinematic characteristics, the presence of crushing products of both sedimentary and igneous rocks and hydrothermal formations [8, 9].

Within the limits of the Eganja area, the most seasoned ore bodies are confined to structures that have developed for a long time, have been repeatedly renewed with the manifestation of shear, shear and discharge movements along them, albeit of insignificant amplitude.

We try to consider the composition of these structures in more detail on the example of Eganja square.

The earliest high-temperature quartz mineralization of quartz-muscovite, quartz-chlorite or quartz-carbonate composition is localized within entire separate blocks. These blocks also contain dike bodies of quartz diorites and diorite-porphyrites. For dikes where contacts of the intrusive type have been preserved, uneven, often bay-shaped borders are characteristic. The veins and veinlet are characterized by salband rims, folded with combed quartz, indicating the opening of cracks perpendicular to their walls.

Carbonate mineralization of several generations is localized along the main (most tectonically developed) rupture systems, in which dikes of diorite porphyrites and the material of earlier high-temperature quartz veins are crushed. The crushing zones are composed of brecciated fragments of both sedimentary and igneous rocks cemented with carbonate.

Carbonate-sulfide mineralization is localized along the contacts of the crushing zones in the form of veins, feathering the main breaks (i.e., obliquely located) or telescoping their contacts. Sulfides (mainly galena) develop by metasomatic substitution of carbonates in the form of inclusions, nests and dotted veins.

The selected stages, in fact, reflect the evolution of the Derbe-Nelgekhinsky fault shear zone: advancing fracturing, rupture formation, feathering systems. At the same time, the development of structures occurs against the background of converging mineralogical zonality. Areal metasomatites and zones of veined mineralization are replaced by wide extended mineralized crushing zones, in which veins are embedded, telescoping contacts of crushing zones, halos of inclusions among breccias.

Taking into account the fact that microscopic studies have previously established that most veins are confined to cleavage-crack structures, the following sequence of deformation events can be assumed.

The folding-thrust stage is associated with regional deformations of terrigenous strata of the Verkhoyansk complex. The rocks bend into wide box-shaped anticlines — Eganja and Kieng-Yuryakhskaya, and narrow slit-shaped synclines — Sordongskaya and Kondekanskaya. These large folded structures were mapped during geological survey work and shown on geological maps. Smaller structural forms accompanying folding were recorded directly in the ditches: small flexural kinks of separate layers, intra-layer cracks of interlayer cleavage, layer-by-layer disruptions of thrust kinematics. No mineralization associated with fold-thrust deformations has been established.

The shear stage is manifested in stages in the Derbek-Nelgesinsky fault zone. Early shear deformations are associated with the formation of shear folds. The folds are asymmetric dragging folds, which are accompanied by the formation of subvertical cleavage cracks of the north-eastern direction. The formation of cleavage-fractured structures corresponds to the stage of formation of the so-called advanced fracturing in shear zones [18—20].

Subsequent shear deformations in the Nelgesinsky fault zone are associated with the activation of previously formed cleavage-fracture systems in shear stress fields. Cleavage cracks are curved in the form of wings, which merge and unite into zones of discontinuous violations of shear kinematics. At the intersection of these shear systems (in the area of interaction), diamond-shaped stretching sectors are formed (in plan), within which long-lived (long-developing) hydrothermal magmatic systems of the Sordongsky, Kondekan-Eganja and Bugdagar ore nodes function.

The Kondekansky massif is represented by a number of small (up to 0.25 km) outputs of extremely rugged or bay-shaped rocks. These massifs are united by a common field of 6 km$^2$ of contact-metamorphic rocks, which is elongated in a north-easterly direction and complicated by a knee-shaped bend at the northern end. The intrusions are composed of fine-grained quartz diorites and diorite porphyries, which are replaced by granodiorites in the central most eroded part. According to V.A. Trunilina it may be distinguishes three phases of implementation that are close in time, taking place against the background of a gradual disclosure of the structure: granodiorites; quartz diorites and diorite porphyries; dacite porphyries.

According to our ideas, the opening of the magmatic chamber of the Kondekansky massif occurred in the stretching zone, confined to the area of intersection of the sublatitudinal left and northeastern right shifts and structurally implemented as a shear duplex of stretching with magmatic filling. The complex configuration of the array is due to the fact that the structures stretch only in rare cases.

Structural deformations of the Derbe-Nelgessin zone are oriented strictly along the long axis of diamond-shaped structures, since most often they inherit previously formed cleavage-fracture zones. They reach the maximum deviation on the flanks of magmatic bodies, where their splitting into a series of dikes is recorded.

At the southwestern end of the Kondekan massif, its splitting into a series of wedging apophysis and dikes forming a kind of «horse tail» is observed. Among the intrusive bodies, a high-temperature greisen-like quartz-chlorite-muscovy mineralization is localized, which performs the same structures, but as it moves away from the massif, it is replaced by a lower-temperature mineralization of quartz-chlorite-carbonate composition. This mineralization is the earliest in the ores of the Albynny site.

To the northeast of the Kondekan massif, at the same time, another extension duplex was formed, within which there are several small (up to 0.5 km) rod-shaped outlets of the Eganja massif, accompanied by numerous dikes of the northeastern and sublatitudinal strike. The rocks are represented by quartz diorite porphyrites, for which gradual transitions along the strike into granodiorite porphyry were noted. The main feature of the Eganja duplex is the small magnitude of the ratio of the amplitudes of shear displacements to the lengths of the stretching zones, as a result of which the strike of intrusions often coincides with the strike of shifts or passes into formations of dikes, which were accompanied by the formation of greisen mineralization in the same structures.

In the future, tectonic processing of duplex structures with magmatic execution by later right shifts of the northeastern strike (strike azimuth 60 — 70°) is observed. These shifts cross the intrusive bodies of the Conde Kan massif and are accompanied by crushing zones in quartz diorites, along which displacements of their contacts by tens to the first hundreds of meters are sometimes recorded. In the areas of Eganja and Albynny, right shifts develop along previously formed stretching structures, which are transformed into crushing zones composed of fragments of igneous rocks, early quartz-chlorite-carbonate veins and cemented by late carbonate-polymetallic mineralization.

Thus, the change in the composition of magmatic formations noted in all ore nodes with a sequential change of stages of mineralization from early greisen-like quartz–muscovite, quartz–chlorite, quartz–chlorite-carbonate to late carbonate-polymetallic (galena, sphalerite) reflects a directed decrease in the temperature of solutions, apparently, a single and continuous flow, the current of which was interrupted by the opening and development of cracks of certain systems. These crack formation pulses determined the change in the physicochemical conditions of the solution and, accordingly, the change of mineral associations [21], and also in some cases, caused the spatial separation of various successive mineral associations.

**Conclusion**

According to the results of research, 14 local polarizability anomalies associated with gold-quartz-sulfide and sulfide ore bodies were identified.

Areal anomalies of increased polarizability and low values of electrical resistance along the Western ore-tectonic zone were revealed. They are associated with metasomatic processes within the Western zone of discharge shifts.

Low-contrast magnetic field anomalies in the northwestern part of the Northern Zone were noted on the work area. The strong influence of the relief on the nature of the magnetic field is noted, as a result of which the correlation of the ridges with the minima of the magnetic field is observed.

Studies of silver ore objects of the southwestern flank of the Nelgesin zone have revealed both a certain fundamental similarity of their composition in polymetallic ores, and significant differences due primarily to the composition of magmatism. In silver-bearing ores, the main productive formations are polysulfide stages.

## СПИСОК ЛИТЕРАТУРЫ

1. *Augustin J., Gaboury D.* Multi-stage and multi-sourced fluid and gold in the formation of orogenic gold deposits in the world-class Mana district of Burkina Faso — Revealed by LA-ICP-MS analysis of pyrites and arsenopyrites // Ore Geology Reviews. 2018, vol. 104, pp. 495 — 521. DOI: 0.1016/j.oregeorev.2018.11.011.

2. *Антипова О. А.*, *Постникова О. В.*, *Якушев В. С.*, *Милосердова Л. В.* Литофациальные модели продуктивных отложений мошаковской свиты юго-запада Сибирской плат-

формы // Известия высших учебных заведений. Геология и разведка. — 2019. — № 4. — С. 44 — 49. DOI: 10.32454/0016-7762-2019-4-44-49.

3. *Рассказов С. В.*, *Чувашова И. С.* Вулканизм и транстенсия на северо-востоке Байкальской рифтовой системы. — Новосибирск: Гео, 2018. — 374 с.

4. *Кирсанов А. А.*, *Липияйнен К. Л.*, *Смирнов М. Ю.*, *Кирсанов Г. А.* Новый метод выявления околорудных гидротермально измененных пород по космическим гиперспектральным данным на примере Ломамского потенциально золоторудного района, Республика Саха (Якутия) // Региональная геология и металлогения. — 2021. — № 86. — С. 97 — 106. DOI: 10.52349/0869-7892_2021_86_97-106.

5. *Кадашникова А. Ю.*, *Сорокин А. А.*, *Пономарчук В. А.*, *Травин А. В.*, *Пономарчук А. В.*, *Эйриш Л. В.* Закономерности локализации оруденения, возраст и источники вещества золоторудного месторождения Маломыр (восточная часть Монголо-Охотского складчатого пояса) // Геология рудных месторождений. — 2019. — Т. 61. — № 1. — С. 3 — 17. DOI: 10.31857/S0016-77706113-17.

6. *Бойцов В. Е.*, *Пилипенко Г. Н.*, *Дорожкина Л. А.* Золоторудные и золото-урановые месторождения Центрального Алдана // Крупные и суперкрупные месторождения рудных полезных ископаемых. Т. 2. — М.: ИГЕМ РАН, 2006. — С. 215 — 240.

7. *Молчанов А. В.*, *Терехов А. В.*, *Шатов В. В.*, *Петров О. В.*, *Кукушкин К. А.*, *Козлов Д. С.*, *Шатова Н. В.* Золоторудные районы и узлы Алдано-Становой металлогенической провинции // Региональная геология и металлогения. — 2017. — № 71. — С. 93 — 111.

8. *Каженкина А. Г.*, *Никифорова З. С.* Прогнозирование возможных коренных источников золото-платиноидной минерализации на территории Лено-Вилюйского междуречья (восток Сибирской платформы) // Вестник СПбГУ. Науки о Земле. — 2018. — Т. 63. — № 4. — С. 520 — 532. DOI: 10.21638/spbu07.2018.407.

9. *Ganapathy G. P.*, *Zaalishvili V. B.*, *Chandrasekaran S. S.*, *Melkov D. A.* Integrated monitoring of slope process in India and Russia // Sustainable Development of Mountain Territories. 2020, vol. 12, no. 4, pp. 572 — 581. DOI: 10.21177/1998-4502-2020-12-4-572-581.

10. *Luo D., Zeng G.* Application and effects of singularity analysis in evaluating the denudation degree of Carlin-type gold deposits in southwest Guizhou, China // Ore Geology Reviews. 2018, vol. 96, pp. 164 — 180. DOI: 10.1016/j.oregeorev.2018.04.018.

11. *Nassani A. A.*, *Aldakhil A. M.*, *Zaman K.* Ecological footprints jeopardy for mineral resource extraction: Efficient use of energy, financial development and insurance services to conserve natural resources // Resources Policy. 2021, vol. 74, article 102271. DOI: 10.1016/j.resourpol.2021.102271.

12. *Sebutsoe T. C.*, *Musingwini C.* Characterizing a mining production system for decision-making purposes in a platinum mine // Journal of the Southern African Institute of Mining and Metallurgy. 2017, vol. 117, no. 2, pp. 199 — 206.

13. *Sinclair L., Thompson J.* In situ leaching of copper: Challenges and future prospects // Hydrometallurgy. 2015, vol. 157, pp. 306 — 324. DOI: 10.1016/j.hydromet.2015.08.022.

14. *Song X., Pettersen J. B., Pedersen K. B., Roberg S.* Comparative life cycle assessment of tailings management and energy scenarios for a copperore mine. A case study in Northern Norway // Journal of Cleaner Production. 2017, vol. 164, pp. 892 — 904. DOI: 10.1016/j.jclepro.2017.07.021.

15. *Tyulenev M. A.*, *Zhironkin S. A.*, *Garina E. A.* The method of coal losses reducing at mining by shovels // International Journal of Mining and Mineral Engineering. 2016, vol. 7, no. 4, pp. 363 — 370. DOI: 10.1504/IJMME.2016.079990.

16. *Tyulenev M. A.*, *Markov S. O.*, *Gasanov M. A.*, *Zhironkin S. A.* Numerical Modeling in the Structural Study of Technogenic Rock Array // Geotechnical and Geological Engineering. 2018, vol. 36, no. 5, pp. 2789 — 2797. DOI: 10.1007/s10706-018-0501-3.

17. *Klyuev R., Bosikov I., Gavrina O., Madaeva M., Sokolov A.* Improving the energy efficiency of technological equipment at mining enterprises // Advances in Intelligent Systems and Computing. 2021, vol. 1258. DOI: 10.1007/978-4-030-57450-5_24.

18. *Раимжанов Б. Р.*, *Хасанов А. Р.* Оценка структурной нарушенности массива горных пород по рейтинговым классификациям для рудников Зармитанской золоторудной зоны // Горный информационно-аналитический бюллетень. — 2020. — № 5. — С. 115—127. DOI: 10.25018/0236-1493-2020-5-0-115-127.

19. *Босиков И. И.*, *Выскребенец А. С.*, *Таскин А. В.*, *Егорова Е. В.* Комплексный анализ качества и зональности руд Главного и Западного рудных тел Джезказганского месторождения // Горный информационно-аналитический бюллетень. — 2020. — № 11-1. — С. 54—65. DOI: 10.25018/0236-1493-2020-111-0-54-65.

20. *Клюев Р. В.*, *Босиков И. И.*, *Майер А. В.* Комплексный анализ генетических особенностей минерального вещества и технологических свойств полезных компонентов Джезказганского месторождения // Устойчивое развитие горных территорий. — 2019. — № 3. — С. 321—330. DOI: 10.21177/1998-4502-2019-11-3-321-330.

21. *Мирошникова Л. К.*, *Мезенцев А. Ю.*, *Семенякина Н. В.*, *Котельникова Е. М.* Геолого-геохимические признаки и критерии потенциально рудоносного Тангаралахского интрузива // Горный информационно-аналитический бюллетень. — 2020. — № 6. — С. 115—130. DOI: 10.25018/0236-1493-2020-6-0-115-130. ГИАБ

## REFERENCES

1. Augustin J., Gaboury D. Multi-stage and multi-sourced fluid and gold in the formation of orogenic gold deposits in the world-class Mana district of Burkina Faso — Revealed by LA-ICP-MS analysis of pyrites and arsenopyrites. *Ore Geology Reviews*. 2018, vol. 104, pp. 495—521. DOI: 0.1016/j.oregeorev.2018.11.011.

2. Antipova O. A., Postnikova O. V., Yakushev V. S., Miloserdova L. V. Lithofacial models of productive deposits of the Moshakov formation within the southwesten part of the Siberian platform. *Proceedings of higher educational establishments. Geology and Exploration*. 2019, no. 4, pp. 44—49. [In Russ]. DOI: 10.32454/0016-7762-2019-4-44-49.

3. Rasskazov S. V., Chuvashova I. S. *Vulkanizm i transtensiya na severo-vostoke Baykal'skoy riftovoy sistemy* [Volcanism and transtension in the northeastern Baikal rift system], Novosibirsk, Geo, 2018, 374 p.

4. Kirsanov A. A., Lipiyainen K. L., Smirnov M. Yu., Kirsanov G. A. A new method of identification of hydrothermally altered wallrock based on satellite hyperspectral data: example of the Lomamsky potential gold ore field, Republic of Sakha (Yakutia). *Regional Geology and Metallogeny*. 2021, no. 86, pp. 97—106. [In Russ]. DOI: 10.52349/0869-7892_2021_86_97-106.

5. Kadashnikova A. Y., Sorokin A. A., Eirish L. V., Ponomarchuk V. A., Travin A. V., Ponomarchuk A. V. Distribution of mineralization, ages and sources of the malomyr gold deposit, eastern part of the Mongol-Okhotsk fold belt. *Geology of Ore Deposits*. 2019, vol. 61, no. 1, pp. 3—17. [In Russ]. DOI: 10.31857/S0016-77706113-17.

6. Boytsov V. E., Pilipenko G. N., Dorozhkina L. A. *Zolotorudnye i zoloto-uranovye mestorozhdeniya Tsentral'nogo Aldana. Krupnye i superkrupnye mestorozhdeniya rudnykh poleznykh iskopaemykh.* T. 2 [Gold ore and gold-uranium deposits of the Central Aldan. Large and super-large deposits of ore minerals. Vol. 2], Moscow, IGEM RAN, 2006, pp. 215—240.

7. Molchanov A. V., Terekhov A. V., Shatov V. V., Petrov O. V., Kukushkin K. A., Kozlov D. S., Shatova N. V. Gold ore districts and ore clusters of the Aldanian metallogenic province. *Regional Geology and Metallogeny*. 2017, no. 71, pp. 93—111. [In Russ].

8. Kazhenkina A. G., Nikiforova Z. S. Prediction of possible primary sources of gold-platinoid mineralization within the Lena-Viluy interfluve (East Siberian platform). *Vestnik of Saint Petersburg University. Earth Sciences*. 2018, vol. 63, no. 4, pp. 520—532. [In Russ]. DOI: 10.21638/spbu07.2018.407.

9. Ganapathy G. P., Zaalishvili V. B., Chandrasekaran S. S., Melkov D. A. Integrated monitoring of slope process in India and Russia. *Sustainable Development of Mountain Territories*. 2020, vol. 12, no. 4, pp. 572—581. DOI: 10.21177/1998-4502-2020-12-4-572-581.

10. Luo D., Zeng G. Application and effects of singularity analysis in evaluating the denudation degree of Carlin-type gold deposits in southwest Guizhou, China. *Ore Geology Reviews*. 2018, vol. 96, pp. 164—180. DOI: 10.1016/j.oregeorev.2018.04.018.
11. Nassani A. A., Aldakhil A. M., Zaman K. Ecological footprints jeopardy for mineral resource extraction: Efficient use of energy, financial development and insurance services to conserve natural resources. *Resources Policy*. 2021, vol. 74, article 102271. DOI: 10.1016/j.resourpol.2021.102271.
12. Sebutsoe T. C., Musingwini C. Characterizing a mining production system for decision-making purposes in a platinum mine. *Journal of the Southern African Institute of Mining and Metallurgy*. 2017, vol. 117, no. 2, pp. 199—206.
13. Sinclair L., Thompson J. In situ leaching of copper: Challenges and future prospects. *Hydrometallurgy*. 2015, vol. 157, pp. 306—324. DOI: 10.1016/j.hydromet.2015.08.022.
14. Song X., Pettersen J. B., Pedersen K. B., Roberg S. Comparative life cycle assessment of tailings management and energy scenarios for a copperore mine. A case study in Northern Norway. *Journal of Cleaner Production*. 2017, vol. 164, pp. 892—904. DOI: 10.1016/j.jclepro.2017.07.021.
15. Tyulenev M. A., Zhironkin S. A., Garina E. A. The method of coal losses reducing at mining by shovels. *International Journal of Mining and Mineral Engineering*. 2016, vol. 7, no. 4, pp. 363—370. DOI: 10.1504/IJMME.2016.079990.
16. Tyulenev M. A., Markov S. O., Gasanov M. A., Zhironkin S. A. Numerical Modeling in the Structural Study of Technogenic Rock Array. *Geotechnical and Geological Engineering*. 2018, vol. 36, no. 5, pp. 2789—2797. DOI: 10.1007/s10706-018-0501-3.
17. Klyuev R., Bosikov I., Gavrina O., Madaeva M., Sokolov A. Improving the energy efficiency of technological equipment at mining enterprises. *Advances in Intelligent Systems and Computing*. 2021, vol. 1258. DOI: 10.1007/978-4-030-57450-5_24.
18. Raimjanov B. R., Khasanov A. R. Ratings of structural rock mass quality for Zarmitan gold mines. *MIAB. Mining Inf. Anal. Bull.* 2020, no. 5, pp. 115—127. [In Russ]. DOI: 10.25018/0236-1493-2020-5-0-115-127.
19. Bosikov I. I., Vyskrebenets A. S., Taskin A. V., Egorova E. V. Integrated ash content and quality analysis of the Main and Western ore bodies in Dzhezkazgan deposit. *MIAB. Mining Inf. Anal. Bull.* 2020, no. 11-1, pp. 54—65. [In Russ]. DOI: 10.25018/0236-1493-2020-111-0-54-65.
20. Klyuev R. V., Bosikov I. I., Mayer A. V. Complex analysis of genetic features of mineral substance and technological properties of useful components of Dzhezkazgan deposit. *Sustainable Development of Mountain Territories*. 2019, no. 3, pp. 321—330. [In Russ]. DOI: 10.21177/1998-4502-2019-11-3-321-330.
21. Miroshnikova L. K., Mezentsev A. Yu., Semenyakina N. V., Kotel'nikova E. M. Geological and geochemical signs and criteria of potential mineralization in the Tangaralakh intrusion. *MIAB. Mining Inf. Anal. Bull.* 2020, no. 6, pp. 115—130. [In Russ]. DOI: 10.25018/0236-1493-2020-6-0-115-130.

## ИНФОРМАЦИЯ ОБ АВТОРАХ

*Босиков Игорь Иванович*[1] — канд. техн. наук,
доцент, зав. кафедрой,
e-mail: igor.boss.777@mail.ru,
ORCID ID: 0000-0001-8930-4112,
*Клюев Роман Владимирович* — д-р техн. наук,
доцент, профессор,
e-mail: kluev-roman@rambler.ru,
Московский политехнический университет,
ORCID ID: 0000-0003-3777-7203,

*Ревазов Владимир Черменович*[1] — канд. пед. наук,
доцент, e-mail: revazov.v@yandex.ru,
ORCID ID: 0000-0003-1784-6531,
*Пилиева Дина Эдуардовна*[1] — канд. социол. наук,
доцент, e-mail: diplil@yandex.ru,
ORCID ID: 0000-0003-0734-0406,
[1] Северо-Кавказский горно-металлургический институт.
**Для контактов**: Босиков И.И., e-mail: igor.boss.777@mail.ru.

## INFORMATION ABOUT THE AUTHORS

*I.I. Bosikov*[1], Cand. Sci. (Eng.),
Assistant Professor, Head of Chair,
e-mail: igor.boss.777@mail.ru,
ORCID ID: 0000-0001-8930-4112,
*R.V. Klyuev*, Dr. Sci. (Eng.),
Assistant Professor, Professor,
e-mail: kluev-roman@rambler.ru,
Moscow Polytechnic University,
107023, Moscow, Russia,
ORCID ID: 0000-0003-3777-7203,
*V.Ch. Revazov*[1], Cand. Sci. (Pedagogy),
Assistant Professor,
e-mail: revazov.v@yandex.ru,
ORCID ID: 0000-0003-1784-6531,
*D.E. Pilieva*[1], Cand. Sci. (Social),
Assistant Professor, e-mail: diplil@yandex.ru,
ORCID ID: 0000-0003-0734-0406,
[1] North Caucasian Institute of mining and metallurgy
(State Technological University),
362021, Vladikavkaz, Russia.
**Corresponding author**: I.I. Bosikov, e-mail: igor.boss.777@mail.ru.

Получена редакцией 11.04.2022; получена после рецензии 06.07.2022; принята к печати 10.12.2023.
Received by the editors 11.04.2022; received after the review 06.07.2022; accepted for printing 10.12.2023.

## ОТ РЕДАКЦИИ

В Горном информационно-аналитическом бюллетене № 12, 2022 в статье Бочаров В. А., Игнаткина В. А., Абрютин Д. В., Каюмов А. А., Каюмова В. Р. (Корж) «Влияние модификаторов класса сульфоксидов на флотируемость сульфидных минералов и технологические показатели флотации руды» на с. 28 допущена техническая ошибка:

| № стр. | Опубликовано | Должно быть |
|---|---|---|
| 28 | Индекс селективности флотации сульфидов меди при параметрах флотации $Na_2S_2O_3$ = 0,3 г/л, pH–8,0; ОВП = +120 мВ составляет 3,31 против 1,68 при $Na_2S_2O_3$ = 0,3 г/л, pH–8,0; ОВП = +120 мВ. | Индекс селективности флотации сульфидов меди при параметрах флотации $Na_2S_2O_3$ = 0,3 г/л, pH–8,0; ОВП = +120 мВ составляет 3,31 против 1,68 при $Na_2S_2O_3$ = 1 г/л, pH–11,5; ОВП = –30 мВ. |