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The chemical composition and environmental damage of cyanidation waste from the Berikul gold mining plant (Kemerovo Region)

Natalia V. Yurkevich[1,2,3]✉, **Sofiya P. Mishenina**[4], **Svetlana B. Bortnikova**[4], **Irina V. Provornaya**[4]

[1] *Institute of Ecology of the Peoples' Friendship University of Russia, Moscow, Russia*

[2] *V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia*

[3] *Novosibirsk State Technical University, Novosibirsk, Russia*

[4] *Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia*

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Abstract

The article presents the results of a comprehensive study of the stored waste from the Berikul gold mining plant (Kemerovo Region), using geochemical, geophysical, and econometric methods. Using electrical tomography method, geoelectric sections (transverse and along the dam's contour) and a 3D model of the storage facility were constructed; they describe the location of zones with a specific electrical resistance varying within the range of 3-800 Ohm·m, which makes it possible to determine the configuration of conductive zones in the internal structure. From the stored waste, which has a thickness of 5-7 m, mineralized water filters into the underground horizons, resulting in the formation of a depression characterized by an electrical resistivity (ER) of ~200 Ohm·m, which is significantly lower than the ER of the surrounding rocks. The zone of reduced resistance extends deeper than 40 m, which clearly indicates the vertical spread of the drainage system, possibly along a weakened zone in the granodiorite massif. Additionally, the formation of highly conductive areas is clearly visible on resistance maps up to 20-40 m. Samples of solid matter and water were taken from the resulting small bodies of water to determine their chemical composition. The stored waste is characterized by a contrasting composition in different parts of the storage facility; accordingly, both the physicochemical parameters and the ability of elements to transfer into solutions vary over a wide range. The majority of the waste material produces an acidic reaction in the pore waters and has a high mineralization. Water extracts from the samples cakes indicate a significant proportion of easily soluble compounds in the waste material. The content of metals and metalloids in water from surface ponds (maximum Fe 7800, Al 590, Zn 160, As 1600, Be 0.022 mg/l) indicates a high environmental hazard posed by these waste materials, while also suggesting the potential attractiveness of the site for the further recovery of useful components. An assessment has been carried out of the damage caused by the storage facility to water bodies within its influence zone – 470 million rubles.

Keywords

cyanidation cakes; gold-bearing ores; electrotomography; geoelectric zonation; metals and metalloids; mobility; environmental damage

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Introduction

The cyanidation waste from gold-bearing ores, accumulated in tailings dumps and waste heaps of mining and processing plants, is one of the most complex environmental impact issues. According to the Federal Waste Classification Catalogue, the sludge from the reagent-based treatment of cyanide wastewater belongs to the fifth hazard class (Order N 242 of Rosprirodnadzor dated 22.05.2017), but

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its long-term storage in open conditions is associated with the transformation of cyanide-containing wastewater components and the formation of highly toxic compounds [1-3]. The main threat to ecosystems comes from the drainage waters of tailings storage facilities. [4-6]. The long-term accumulation of waste (the volumes of which at some enterprises reach millions of tons) forms technogenic deposits containing both toxic elements and valuable components, which makes their comprehensive study highly relevant [7-9].

The results of laboratory modeling show that when atmospheric precipitation interacts with cyanide leaching residues, alkaline solutions (pH > 9.0) are formed, in which sulfate and cyanide ions, as well as ions of heavy metals (copper, zinc, cobalt, chromium, molybdenum, wolfram), accumulate due to the breakdown of cyanide complexes and the oxidation of sulfides [10-12]. The presence of arsenic poses a particular danger, as its concentrations in drainage waters exceed the maximum permissible levels for fish-bearing water reservoirs; this is due to the oxidation of arsenopyrite contained in the original ores [11-13]. The reality of this threat is confirmed by emergencies – leaks in slurry pipelines at gold mining enterprises lead to cyanide-containing wastewater entering river systems, creating a threat of mass mortality of aquatic organisms and requiring urgent intervention by regulatory authorities [14].

In addition to liquid runoff, gas emissions from waste dumps pose a significant threat. Instrumental studies conducted in the sharply continental climate of Western Siberia, using a gas analyzer and electrical resistivity tomography, have identified active “breathing” zones in the tailings storage facilities, where sulfur-containing gases (dimethyl sulfide, carbon disulfide, sulfur dioxide) and nitrogen-containing compounds are detected [15]. Concentrations of carbon disulfide (CS_2) – a toxic compound of the second hazard class – in the surface layer of the air were 6-8 times higher than the average daily norms. The formation of volatile sulfur and selenium compounds is associated with the seasonal transformation of waste – oxidation processes in the summer and methylation in the winter [15].

At the same time, cyanidation waste represents a valuable technogenic resource. The accumulated volumes of old tailings contain significant amounts of gold, silver, and non-ferrous metals [16-18]. Studies show that the gold content in the solid phase of the tailings can reach 3.02 g/t, and the silver content can be 10.8 g/t; the content of antimony and iron is also of industrial interest [19-21]. The involvement of technogenic raw materials in processing makes it possible to replenish the mineral resource base without the costs associated with the search for and exploration of new deposits; moreover, technogenic facilities are located in developed areas with well-developed infrastructure [22-24]. Modern methods of physicochemical treatment (magnetic-pulse and hydroacoustic processing, ultrasonic activation) make it possible to increase gold recovery from thrust tailings to 72-74 % by breaking down fine-dispersed forms of the metal [4, 25, 26]. A high degree of removal of harmful substances is achieved through a combination of processes, such as the hydrolysis of cyanides to formic acid and polymers, the evaporation of hydrocyanic acid, bacterial decomposition, and the oxidation of cyanides and thiocyanates by atmospheric oxygen, as well as the precipitation of metals in the form of sparingly soluble compounds [27-29].

Effective assessment of the environmental risks and resource potential of cyanide waste requires the use of a set of complementary methods. Geochemical methods (laboratory modeling, ICP-MS analysis) are necessary to determine the composition of the solid and liquid phases and to predict the formation of acidic and alkaline drainages [11, 19, 30]. Geophysical methods (electrical resistivity tomography) make it possible to map the internal structure of waste dumps and identify zones of active gas emission [15, 28, 31]. Econometric methods are in demand for the feasibility study of processing technogenic raw materials, for assessing capital and operating costs when selecting a technology (heap leaching, sorption methods, biohydrometallurgy), and for optimizing production parameters using mathematical modeling [11, 32].

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Thus, the aim of this work is to conduct a comprehensive assessment of the environmental hazard posed by cyanidation waste from gold-bearing ores, using drainage water, gas emissions, and the migration of heavy metals as examples.

Object and methods

The object of the study is cyanidation waste (cakes) of the Berikul Gold Mining Plant (BGMP), village of Novy Berikul, Tisulsky district, Kemerovo Region (Fig.1), where mainly ores from the Staro-Berikul deposit were processed (Table 1). This is one of the most significant deposits in the Mariinsky Taiga and part of the Berikul ore field, which is located at the western contact of the Dudetsky granitoid pluton.



Fig.1. Geographical location and placement of waste BGMP (cyanidation cakes of flotation concentrate)

The plant began its operations in 1937-1940. Gold extraction was carried out by cyanidation of the sulfide flotation concentrate, which resulted in high contents of typomorphic elements in the waste [33]. The enterprise ceased operations in 1999, and in 2004, the accumulated waste was transferred to the territory of the Komsomolsk tailings storage facility.

Table 1

Content of silicate group oxides in the substance of cyanidation cakes, %

Element	Average	Minimum	Maximum	Standard deviation
SiO_2	24.30	16.89	50.77	9.74
TiO_2	0.52	0.37	1.00	0.18
Al_2O_3	7.30	4.17	16.39	3.11
Fe_2O_3	26.91	11.53	37.06	6.96
MnO	0.085	0.033	0.28	0.070
MgO	2.24	1.21	2.96	0.54
CaO	5.94	4.34	9.77	1.39
Na_2O	0.67	0.47	2.77	0.66
K_2O	1.25	0.75	1.69	0.26
P_2O_5	0.11	0	0.21	0.048
BaO	0.067	0.034	0.33	0.087
S_{tot}	23.63	1.63	30.5	6.65
$S_{sulfate}$	4.53	1.05	10.02	2.54
As	1.2	0.17	2.3	0.63

Note. Number of analyses – 17.

Today, to the south of the settling pond of the Komsomolsky Gold Mining Plant (KGMP), there are cyanidation cakes from the BGMP; technogenic ponds have formed on their surface, and the water in them is dyed in reddish hues up to black-brown. These waste materials are bounded on the southeastern side by the natural terrain, and on the northwestern side by an embankment dam. A dam has also been built between the relocated cakes and the waste from the Komsomolsk tailings storage facility to prevent the movement of cake material and water from the ponds to the adjacent area (Fig.2).

The Berikul cyanidation cakes are an example of self-regenerating objects. In this case, the soil is formed through the interaction of rock, biota, climate, relief, and time [34], and activation is achieved by creating a sown phytocenosis, which triggers the processes of humus formation, soil stabilization, and subsequent reproduction of the phytocenosis. It should be noted that vegetation does

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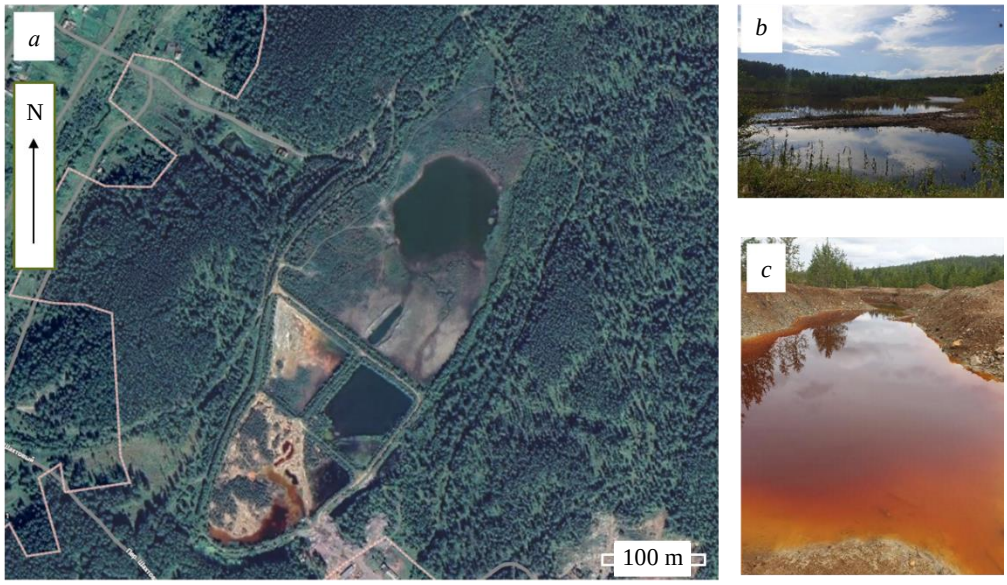


Fig.2. Satellite image of the waste storage facility for KGMP and BGMP (*a*), photos of ponds on the surface of the BGMP cakes (*b*, *c*).

not form a continuous cover but appears in separate areas whose soil has a near-neutral pH. An acidic reaction completely blocks the formation of phytocenoses.

Field work. *Electrotomography.* During the fieldwork, as a result of reconnaissance focused on the color and moisture content of the deposits, a site was selected for two- and three-dimensional studies. The measurements were carried out using the Skala-48 hardware and software complex (developed by Electrometry Design Bureau LLC).

Two-dimensional studies were carried out along six profiles running along the dam (Fig.3), one after another, continuously. This sequence is denoted by the term "roll-along". The measurement interval along the profile was 5 m, the number of electrodes in the profile was 48, the total length of each profile was 240 m; each profile overlaps the next one by the length of one electrode strip – 24 electrodes, 120 m. Three-dimensional studies were carried out inside the roll-along ring and represent a platform with five parallel profiles, each with an inter-electrode spacing of 5 m, a length of 120 m, and a distance of 25 m between the profiles; during processing, these profiles were combined into a single array.

Primary data filtering was carried out using the Siber Tools software (developed by the IPGG SB RAS, Electrometry Design Bureau LLC, Novosibirsk). The detection of boundaries where the electrical resistivity (ER) changes was performed using the robust method with inversion, which minimizes the effect of data blocks influencing each other (Res2DInv software, GeoTomo, Malaysia). For all profiles, the error in solving the inverse problem at the fifth iteration was 1.5-2 %, which confirms the correctness of the chosen method. In technogenic waste dumps of this type, it is generally assumed that the layers of different mineralization are horizontally bedded, and accordingly, the anomalies are distributed laterally. In this case, given the prior geological information, the optimal survey setting is a four-electrode Schlumberger survey with data inversion using the robust method. The results of the electrotomographic measurements were visualized using Surfer and Voxler software (Golden Software, USA) for two- and three-dimensional visualization, respectively. As a result, geoelectric sections were constructed, which allow to see the distribution of electrical resistance. The inversion results were converted to a single scale. The layout of the electrotomography profiles is shown in Fig.3.

Sampling. To determine the composition of the substance, samples were collected from three pits in the northern, central, and southern parts of the Berikul cakes (Fig.3). The depth of the pits is 200 cm; samples were taken from each visually distinct layer 15-20 cm thick. In total, 56 samples

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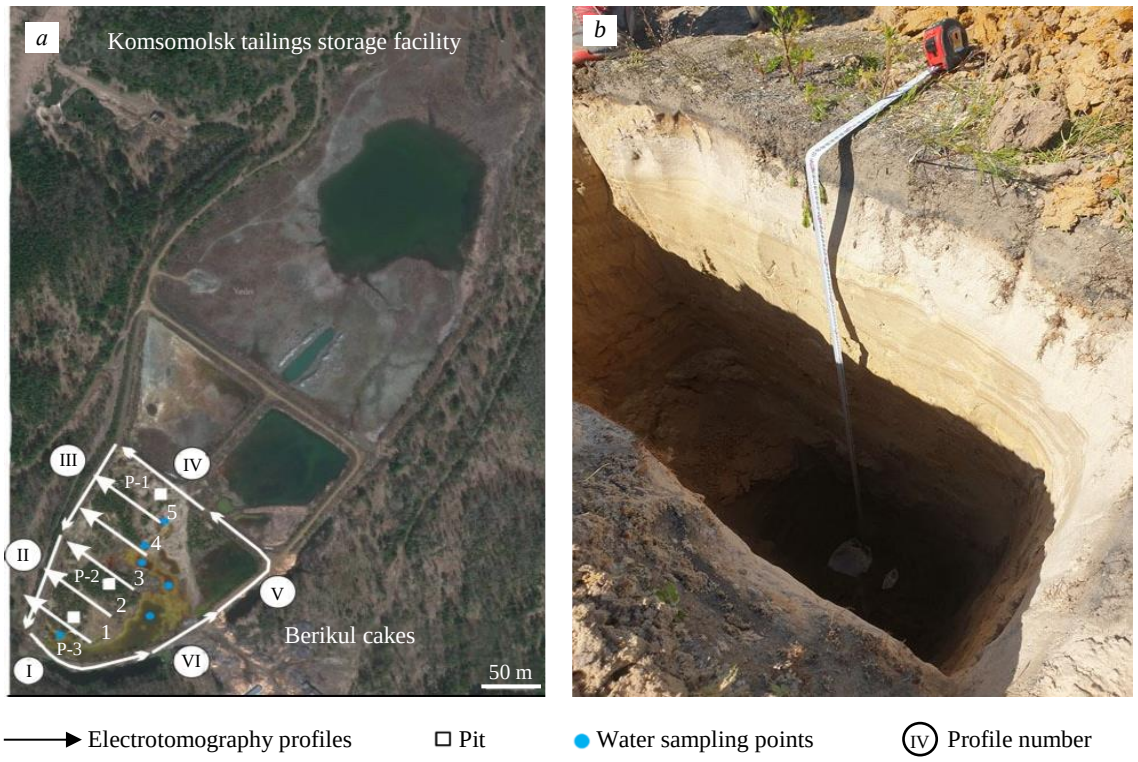


Fig.3. Survey plan (*a*) and photo of the pit (*b*)

of 200 g each were collected using a plastic scoop; each sample was packed in double polyethylene bags for transportation to the laboratory.

On site, a suspension (paste) was prepared from a portion of each sample; for this purpose, distilled water was added to the solid substance in a 2:1 ratio. This method is well known in foreign literature [35] and provides initial information about the parameters of the liquid phase formed when waste substances come into contact with atmospheric water. Another part of the sample was packed in sealed plastic bags for transportation. The specific electrical conductivity (SEC) in the pastes and solutions was determined using the direct conductometric method with the Cond315i instrument (Wissenschaftlich-Technische Werkstätten, Germany). The determination was carried out in the range of 0-500 mS/cm with a relative error of ±0.5 %. The pH values were measured using the direct potentiometric method with a portable device, Expert-001 (Ekoniks-Expert, Moscow), or with a pH/T meter, HI 9025 C (HANNA Instruments, USA). Before measuring the pH, the device was calibrated using standard solutions with known pH values (3.56; 4.01; 6.86; 9.18). The accuracy of the method was ±0.05 pH.

Hydrochemical testing. The ponds on the surface of the cakes, as well as the bypass ditch bordering the waste storage facility on the eastern, southeastern, and southern sides, were sampled at a total of six points (Fig.4). Samples were taken into pre-rinsed with the sample being collected 200 ml plastic bottles for the main ion composition and 50 ml test tubes for the concentration of trace elements. SEC and pH values were measured on site using the instruments described above.

Laboratory tests, experiments, and calculations. The waste samples were dried under laboratory conditions at room temperature and divided into two parts. One part was intended for obtaining aqueous extracts, while the other was ground to –200 mesh for analytical determinations. Aqueous extracts were obtained by adding distilled water to the dry substance of the samples in a 1:10 ratio (solid/water); the prepared suspension was placed on a magnetic stirrer and left for 24 h. Then the solution was filtered through a membrane filter < 0.45 μm, the pH and SEC values were measured in one part, the second part was sent to the laboratory to determine the basic ionic composition and trace elements.

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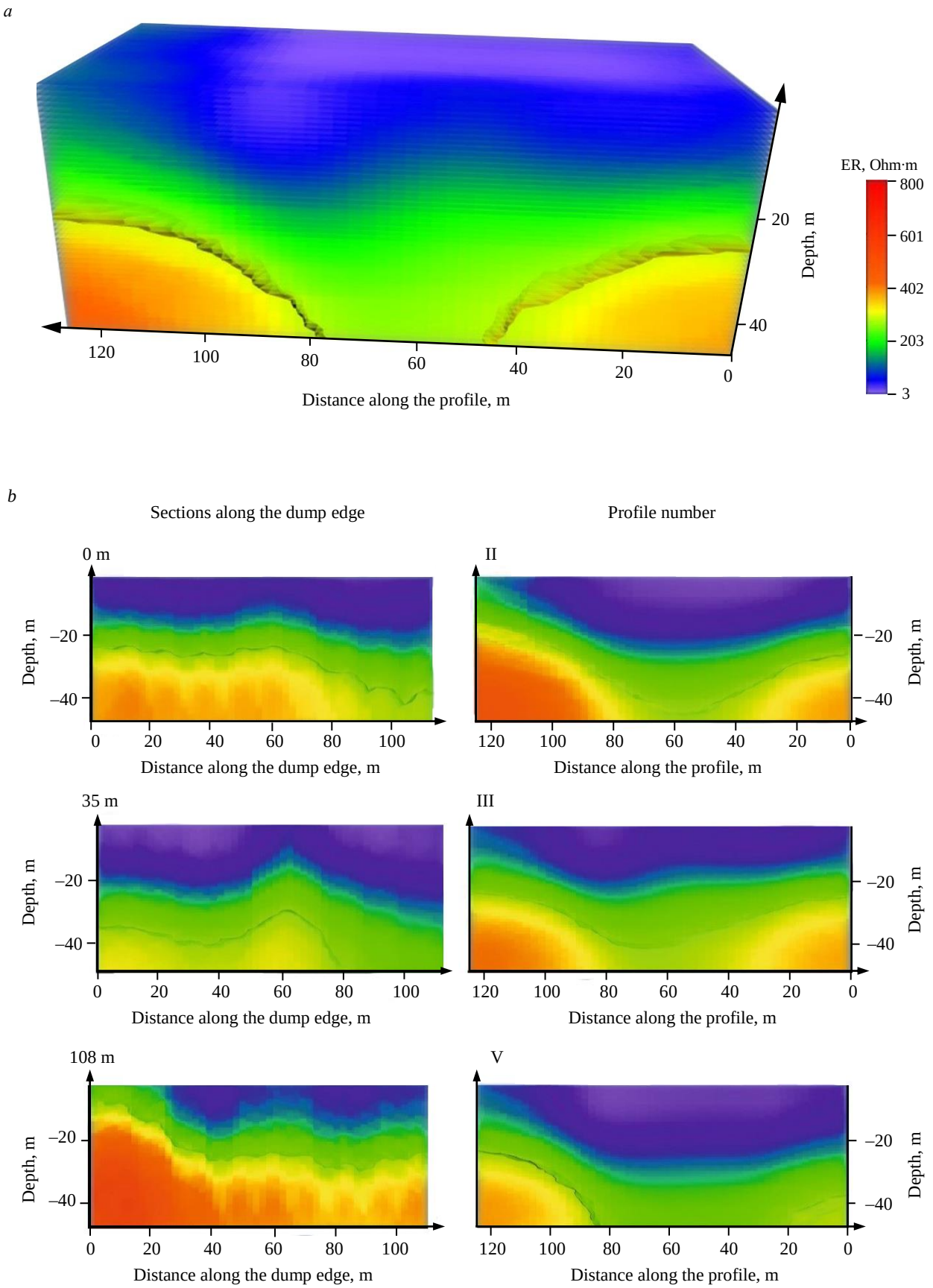


Fig.4. 3D geoelectric model of the cake storage facility, constructed based on six cross-sections (*a*), and resistance maps at depths of 0, 35 and 108 m (*b*)

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In solid samples, the content of oxides of the silicate group was determined by the XFA method (IGM Analytical Center SB RAS) on an ARL-9900XP spectrometer (Thermo Fisher Scientific, USA) (analyst N.G.Karmanov) at the Center for Multielement and Isotope Studies SB RAS. The elemental composition of solid samples was determined by inductively coupled plasma mass spectrometry (ICP-MS) at the "Plasma" Chemical Analysis Center (Tomsk, analyst N.V.Fedyunina) for the content of Cu, Zn, Cd, Pb, Sn, Ni, Co, Mo, Ag, Au, As, Sb, Bi, Ga, In, Tl, Be and other.

The composition of water samples (water extracts, water from ponds) was determined by the ICP-MS method on a NexION 300D mass spectrometer (PerkinElmer, USA) with a UCT background location cell (Problematic Research Laboratory of Hydrogeochemistry "Water" of the Engineering School of Natural Resources of the Tomsk Polytechnic Institute, analyst A.A.Khvashchevskaya). All measurements were carried out in three parallels for each element. The standard deviation did not exceed 13 %.

Econometric calculations. An estimate of the damage caused by the discharge of pollutants into surface and underground water bodies[1] is calculated based on the specific economic damage from wastewater discharges into reservoirs and the reduced mass of the discharge of harmful substances by the source into reservoirs of the agricultural area per year.

Correctness of the methodology application [31] is due to the unique status of the facility as a preserved source of potential but unrealized environmental hazards. The methodology makes it possible to calculate the hypothetical damage that would be caused to water bodies in the event of a dam breach or lack of maintenance, thereby quantifying the environmental and economic efficiency of the existing containment system and the preventive value of monitoring the facility. This makes the methodology the only possible tool for a comprehensive scientific assessment of the risks and resource potential of stale cyanidation waste in the right vacuum of the post-production stage.

Discussion of the results

Geoelectric zonality. According to electrotomography data, the geoelectric zonality of the Berikul cakes storage was determined along the contour and six profiles (see Fig.3). Six transverse profiles are assembled into a 3D geoelectric model that clearly demonstrates the volumetric structure of the storage (Fig.4). The parent rocks (underlying granodiorites) correspond to ER > 400 Ohm·m, waste is a highly conductive medium, its ER is 0.1-10 Ohm·m, which is a consequence of the composition of the solid substance – a high content of sulfides (sulfide flotation concentrate was subjected to cyanidation at the BGMP); at high humidity of the waste, since the surface was not leveled during storage, and its relief is an alternation of hills and depressions in which water reservoirs are formed and stored; as well as mineralization of surface and pore waters.

From the stored waste, which has a capacity of 10-16 m, insoluble waters are filtered into underground horizons, resulting in a peculiar funnel characterized by a ER ~200 Ohm·m, which is significantly lower than the ER of the host rocks. The zone of reduced resistance goes deeper than 40 m, which clearly indicates the vertical spread of drainage, possibly through a weakened zone in the granodiorite massif. The formation of highly conductive sections on resistance maps up to 20-40 m is also clearly traced (Fig.4).

The roll-along profile reflects a high contrast of resistances. The upper low-ohm deposits (not exceeding 300 Ohm·m) are obvious, rooted deep at elevations from the beginning of the profile to 200 m and from 660 to 700 m (Fig.5). The dam on the northwestern and northeastern sides of the stored waste navigable through geoelectric sections reliably limits surrounding areas from seepage of drainage solutions. However, just as in the transverse profiles, from the southwest, the highly conductive anomaly continues below the sounding depth, which confirms the presence of leakage channels – sources of high concentrations of ammonia in the drinking waters of the settlement.

[1] Methodology for Determining Prevented Environmental Damage. Approved by V.I.Danilov-Danilyan, Chairman of the State Committee of the Russian Federation for Environmental Protection, on November 30, 1999. URL: http://docs.cntd.ru/document/1200035561 (accessed 02.04.2026).

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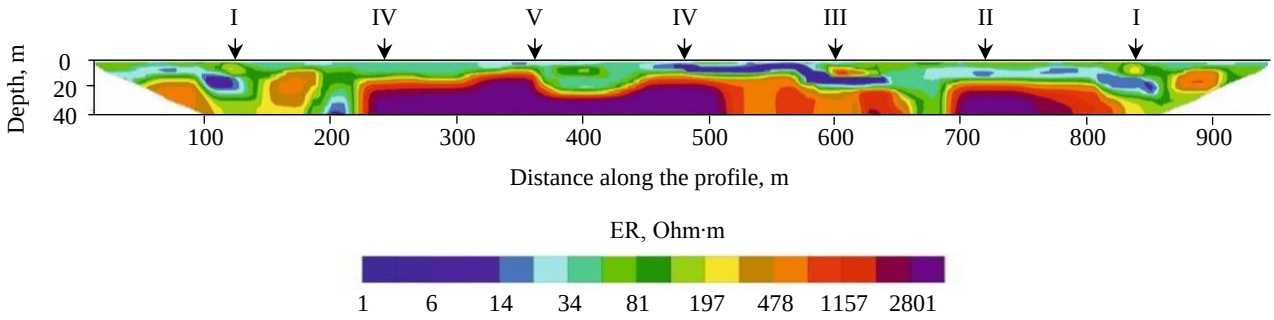


Fig.5. Geoelectric section along the roll-along profile (along the dam of the tailings storage). The middle of each setting is marked by arrows. The roll-along profile is located on the sides of the dump in a circle and closes during processing (the profile begins and ends with the first setting)

Composition of the solid matter. The stored waste is characterized by a contrasting composition in different parts of the storage, therefore, the physico-chemical parameters and the ability of elements to transition into solutions vary in a wide range. The pH values of the sample pastes vary from 2.69 to 4.95, i.e. from ultra to slightly acidic, the specific electrical conductivity is from 340 to 6900 μS/cm, which indicates changing parameters. Nevertheless, a large mass of waste matter results in an acidic reaction and high mineralization in the pore waters.

The substance of the cakes is quite contrasting in composition, which reflects both the heterogeneity during storage and the results of hypergenic processes of redistribution of elements (Tables 1, 2). The total sulfur content, which is determined mainly by the amount of pyrite and its oxidation products, ranges from 1.6 to 30.5 %. At the same time, the sulfate form of sulfur in most samples is ~50 % of the total content, and in near-surface samples, where abundant precipitates form, it reaches 99 %, which leads to easy dissolution of sulfates by seasonal precipitation and the appearance of an acidic environment.

The content of rock-forming components reaches a high level for the sulfide flotation concentrate (up to ~70 % SiO_2 + Al_2O_3), indicating resistant composition of the ores of the Berikul deposit, which are not amenable to effective flotation (see Table 1).

Table 2

Microelement composition of cyanidation cake samples, g/t

Element	Average	Minimum	Maximum	Standard deviation
Cu	780	42	1300	370
Zn	2700	69	17000	4700
Pb	530	130	4300	1200
Co	19	14	28	4.1
Ni	24	16	32	5.4
Cr	52	34	92	19
Ag	28	3.8	42	13
Cd	39	0.45	133	42
Sb	72	29	143	37
Mo	6.1	2.6	11	3.3
Sr	310	170	470	120
Rb	48	30	68	13
Hg	8.7	1.5	20	6.9
Au	2.2	0.26	3.6	1.2
Se	8.7	7.7	9.7	0.75
Tl	0.27	0.12	0.52	0.15
Be	0.58	0.09	1.4	0.58
Bi	39	12	110	30

Note. Number of analyses – 17.

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There are high concentrations of ore-forming elements, reaching, g/t: As 23,000; Pb 4300; Cu 1300; Zn 17,000; as well as elements of the first hazard class, g/t: Hg 20, Be 1.4, Tl 0.52 (Table 2). Separately, we should focus on the content of residual gold in the substance of the cakes. According to our definitions, it reaches 3.6 g/t, which is a very attractive factor for the development of technology for the secondary extraction of precious metals. It should be taken into account that gold is probably contained in sulfides in the form of either an isomorphic impurity or a finely dispersed inclusions since it cannot be extracted during cyanidation of the flotation concentrate at the plant. This indicates the need for additional grinding of cakes to obtain marketable products, which leads to a significant increase in the cost of the technological process and calls into question the achievement of profitability in the processing of raw materials.

Returning to the environmental aspects of the problem of stored cakes, we summarize the results obtained. Given the acidity of the substance, one can immediately make an assumption about the high mobility of metals and metalloids, as well as the possibility of migration outside the storage. Indeed, aqueous extracts from cake samples indicate a significant proportion of easily soluble compounds in the waste substance (Table 3). The metal content in the solution corresponds to the composition of the solid substance – in the Ber-3 sample with the highest proportion of the sulfide component, the concentrations of metals and metalloids in aqueous extracts are much higher than in the Ber-1 sample. Solutions of this composition in natural components can lead to their radical contamination. The most toxic elements, Tl and Be, are found in relatively lower concentrations than most metals, but given their danger to living organisms, the scale of possible consequences for the surrounding territories becomes clear.

Table 3

Composition of water extracts from waste samples

Parameter	Ber-1	Ber-3	Parameter	Ber-1	Ber-3
pH	4.76	4.51	Ni, mg/l	0.013	0.89
SEC, μS/cm	334	3660	Cr, mg/l	0.0017	0.37
SO_4^{2-}, mg/l	110	4600	Cd, μg/l	6.1	192
Cl, mg/l	0.59	2.04	Ba, μg/l	30	11
PO_4^{3-}, mg/l	0.01	11	Sb, μg/l	1.5	12
Ca, mg/l	6.12	150	Se, μg/l	0.11	5.1
Mg, mg/l	4.30	49	Bi, μg/l	n/d	1.2
Na, mg/l	0.92	0.38	Mo, μg/l	n/d	19
K, mg/l	0.10	n/d	Pb, μg/l	2.4	0.90
Fe, mg/l	11	1500	Ag, μg/l	n/d	0.15
Mn, mg/l	0.20	2.19	Au, μg/l	0.004	0.018
Al, mg/l	0.92	140	Hg, μg/l	n/d	0.17
Si, mg/l	5.7	9.0	Sr, μg/l	48	216
As, mg/l	0.050	87	Rb, μg/l	0.31	0.55
Cu, mg/l	0.17	8.7	Tl, μg/l	0.0034	0.023
Zn, mg/l	0.25	10	Li, μg/l	22	68
Co, mg/l	0.012	0.65	Be, μg/l	0.23	1.3

Hydrochemical composition. Solutions from ponds on the storage surface are characterized by an acidic reaction of the medium (pH 2-2.45, Table 4), high concentrations of sulfate ion (2700-15,000 mg/l), metals Fe, Mn, Al, Cu, Zn, Cr, Co, Ni, Cd, Pb. Notable are the extreme concentrations of arsenic and beryllium, elements of the first hazard class (110-1600 mg/l and 4.5-22 μg/l, respectively).

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Table 4

Composition of solutions in ponds on the surface of cakes, mg/l

Parameter	Ber-1B	Ber-2B	Ber-3B	Ber-4B	Ber-5B	Ber-6B
pH	2.15	2.23	2.23	2.25	2.00	2.45
SO_4^{2-}	15,000	3000	9000	3500	18,000	2700
Fe	5400	2100	3600	1400	7800	780
Mn	13	8.3	14	5.8	24	4.5
Al	350	150	360	170	590	64
Cu	22	11	23	8.4	35	2.7
Zn	134	54	79	46	160	25
Cr	2.6	0.79	2.0	1.1	2.4	0.13
Co	2.7	1.1	2.5	0.88	4.3	0.57
Ni	4.9	2.1	4.4	1.7	8.3	1.0
Cd	3.3	1.2	2.0	1.1	5.6	0.61
Pb	13	2.8	5.3	1.3	7.2	0.70
As	1300	340	810	110	1600	63
Be	0.008	0.0045	0.011	0.0058	0.022	0.0002

The storage of cakes in the Komsomolsk Plant waste storage facility is made in such a way that the southern part, where the cakes were placed, is separated from the middle and northern by a special embankment dam. For several years, when observations were carried out and the stored sediments were studied, the surface of the storage morphologically represented a hilly area, in the lower parts of which reservoirs with black-brown water containing extremely high amounts of dangerous elements were formed. In hot, dry weather, their level decreased, and during the rainy season they filled up. In 2022, during a very rainy summer, reservoirs overflowed, and water from them began to flow through the destroyed dam into the northern part of the storage facility and beyond (Fig.6). The observed situations emphasize the need to take into account non-standard conditions, under the influence of which the onset of environmental disasters is possible.

Environmental damage caused by water pollution. Taking into account the presented data that the water level, as well as the concentration of matter in the lake, remain constant throughout the entire time of measurements, and the filtration losses of the lake for the area, according to geologists, are assumed to be equal to 40 % of the lake volume, it can be concluded that the conditional rate of



Fig.6. Photo of the pathway through which highly mineralized solutions from the reservoirs on the Berikul cakes (red water) flow out of the storage facility (photo by S.S.Volynkin)

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matter entering the lake may be considered as the rate of these filtration losses. Since the total area of the ponds is about 10,000 m^2 and the depth is 3 m, the volume of the lake, calculated as their product, is 30,000 m^3. At that time, the rate of matter intake is calculated as the product of the lake volume and the percentage of filtration losses, which is $30,000 \cdot 0.4 = 12,000$ m^3/year.

Based on the data on the rate of pollutants intake and hygiene standards, the relative hazard indicators A_i of the substance were determined and the reduced mass M_i was calculated (Table 5).

Table 5

Reduced mass of pollutants in the technogenic lake of the tailings dam

Substance	MPC*, mg/l	Class of hazard	Relative hazard index of the *i*-th substance A_i, t/ t	Total mass of *Mi* dump, t/year
Fe	0.3	3	3.33	103.2
Pb	0.01	2	100	0.077
Al	0.2	3	5	6.24
As	0.01	1	100	15.6
Ca				7.56
Cd	0.001	2	1000	0.041
Co	0.1	2	10	0.05
Cr	0.05	2	20	0.38
Cu	1	3	1	0.38
Mg	50	3		5.04
Mn	0.1	3	10	0.22
Ni	0.02	2	50	0.058
K	Not regulated			0.074
Na	200	2	0.005	0.26
Si	20	2	0.1	0.29
Zn	5	3	1	1,68
Total				1999

* Maximum permissible concentrations of chemicals in the water of the drinking system of centralized, including hot, and non-centralized water supply; water of underground and surface water bodies of economic, drinking, cultural and domestic water use; water of swimming pools, water parks, according to SanPiN 1.2.3685-21 "Hygienic standards and requirements for safety and (or) the harmlessness of environmental factors for humans".

In numerical terms, the specific damage of $U_{sp.wat}$ for the water resources of the Kemerovo Region belonging to the Ob River basin was determined based on the value of the indicator specified in the Methodology for Determining Prevented Environmental Pollution dated November 30, 1999. In 1999, based on these regulatory documents, the specific damage was estimated at 10,616.5 rub./conventional t. To obtain the value of the specific gravity estimate for 2025, the method of reduction to the current value was used. Based on the dynamics of inflation for 1999-2025, the specific damage to the water resources of the region $U_{sp.wat}$ = 202,645 rub./conventional t.

The value of the coefficient of ecological significance for the water bodies of the Kemerovo Region at the calculation level G = 1.16. The results of calculations of the annual environmental damage from water pollution have given an estimate of 470 million rubles.

Conclusion

The geoelectric zonality of the Berikul cakes storage was determined according to the data of electrotomography. Waste is a highly conductive medium, the ER is 0.1-10 Ohm·m, which is a consequence of the composition of the solid substance – a high content of sulfides; high humidity of waste, since the surface was not leveled during storage, and its relief is an alternation of hills and depressions in which reservoirs are formed and preserved; mineralization of surface and pore waters.

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The stored waste is characterized by a contrasting composition in different parts of the storage; therefore, the physico-chemical parameters and the ability of the elements to pass into solutions vary in a wide range. The largest mass of the waste substance gives an acidic reaction in the pore waters and leads to high mineralization. Aqueous extracts from cake samples indicate a high proportion of easily soluble compounds in the waste substance. The intake of solutions of this composition can lead to radical contamination of environmental components. Particularly toxic elements, Tl and Be, are found in lower concentrations than most metals. Given their danger to living organisms, the scale of the possible consequences for the surrounding areas becomes clear.

Thus, geophysical studies made it possible to choose the right sampling site for waste matter and water, and the results of geochemical studies, in turn, served as the basis for calculating environmental damage. The results of calculations of the annual environmental damage from water pollution have given an estimate of 470 million rubles.

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***Authors*: Natalia V. Yurkevich,** *Doctor of Geological and Mineralogical Sciences, Professor* (*Institute of Ecology of the Peoples' Friendship University of Russia, Moscow, Russia*), *Senior Researcher* (*V.S.Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia*), *Associate Professor (Novosibirsk State Technical University, Novosibirsk, Russia), yurkevich-nv@rudn.ru, https://orcid.org/0000-0001-8337-9148*, **Sofiya P. Mishenina,** *Candidate of Geological and Mineralogical Sciences, Researcher* (*Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia*), *https://orcid.org/0009-0001-7735-5913*, **Svetlana B. Bortnikova,** *Doctor of Geological and Mineralogical Sciences, Chief Researcher* (*Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia*), *https://orcid.org/0000-0003-2395-7406*, **Irina V. Provornaya,** *Candidate of Economics, Senior Researcher* (*Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk, Russia*), *https://orcid.org/0000-0001-6581-2921*.

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