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GEOLOGY OF MINERAL DEPOSITS

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Assessment of Berezkinskoye ore field prospectivity using Micromine software

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Abstract
The use of modern computer aided methods, in particular the use of the Micromine software, is an important part of the integrated research for the determination of deposit prospects for various ores. The paper is devoted to the analysis of prospects and estimation of reserves for open-pit and underground mining in the Berezkinskoye ore field. For this purpose, silver reserves were determined as the principal valuable component. The deposit balance reserves were estimated separately for all types of ores in the optimal open pit envelope adopted in the final mining feasibility study (FS of permanent exploration conditions for ore extraction). To vectorize and verify the geological information entered into the database, graphical materials in the form of cross-sections and plans with the corresponding borehole database were georeferenced using the Micromine software. The final inspection was carried out to ensure that the sample depth information entered was consistent with the excavation depth. The database contains information on the location of boreholes and trenches, the design of boreholes, the spatial positioning of the boreholes/trenches axes, the data of sample assays for silver and copper. For underground mining, the delineation of ore bodies was carried out based on the cross-sections identified in the boreholes at a cut-off grade of 10.7 g/t, taking into account the orientation of geological structures. Reliability of the ore bodies delineation was verified in a Micromine three-dimensional model. For open-pit mining, the position of small ore bodies may be clarified by operational exploration with possible subsequent upgrading their reserve categories. The wireframe model of ore zones and bodies was constructed using the outlines obtained by the developed methodology. A wireframe model of faults was based on the Berezkinsky area plans and cross-sections. The construction of the fault wireframe model was performed in several steps. Application of modern geoinformation system (GIS) technologies makes it possible to qualitatively assess the prospects and estimate the reserves at the deposits. The Berezkinskoye deposit ore material composition, metallurgical properties, hydrogeological and geotechnical features were investigated.

Keywords
ore field, Micromine software, silver, deposit, borehole, delineation of ore bodies, open-pit and underground mining, mineral, prospectivity

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ГЕОЛОГИЯ МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

Научная статья

Оценка перспективности территории Березкинского рудного поля при помощи программного продукта Micromine

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Аннотация
Важнейшим направлением проведения комплексных исследований по определению перспектив месторождений различных руд является использование современных компьютерных методов, в частности, программного продукта Micromine. В статье рассматривается Березкинское рудное поле, для

которого произведены анализ перспектив и подсчет запасов для открытого и подземного способов отработки. При этом определены запасы серебра в качестве основного полезного компонента, а также рассчитаны балансовые запасы раздельно для всех типов руд в контуре оптимального карьера, принятого в технико- экономическом обосновании постоянных разведочных кондиций для разработки руд. Для векторизации и проверки геологической информации, вводимой в базу данных, при помощи программного обеспечения Micromine, в пространственных координатах были привязаны графические материалы в виде планов разрезов с наложенной базой данных скважин. Конечной проверкой являлся контроль на соответствие глубины введенной информации относительно глубины выработки. База данных содержит информацию о местоположении выработок (скважин, канав), конструкции скважин, информацию с описанием пространственного положения оси выработок, данные с результатами опробования выработок на серебро и медь. Для подземного способа отработки оконтуривание рудных тел проводилось по сечениям, выделенным в скважинах по бортовому содержанию 10,7 г/т, с учетом ориентировки геологических структур. Надежность увязки рудных залежей проверялась в трехмерной модели, построенной в программе Micromine. Для условий открытой отработки в процессе эксплуатации возможно уточнение положения мелких рудных тел эксплуатационной разведкой и перевод их в более высокие категории. Построение каркасной модели рудных зон и тел производилось с использованием контуров по разработанной методике. В основу построения каркасной модели разломов положены планы и разрезы участка Березкинский. Построение каркасной модели разломов проводилось в несколько этапов. Применение современных геоинформационных систем (ГИС) технологий позволяет качественно провести оценку перспективности и подсчет запасов на месторождениях. На Березкинском месторождении изучены вещественный состав руд, технологические свойства, гидрогеологические и инженерно-геологические особенности месторождений.

Ключевые слова
рудное поле, программный продукт Micromine, серебро, месторождение, скважина, оконтуривание рудоносных залежей, открытый и подземный способ отработки полезных ископаемых, перспективность

Благодарности
Авторы выражают благодарность В.И. Голику, В.Б. Заалишвили и другим специалистам в области проведения оценки рудных месторождений с помощью геоинформационных технологий за содействие во внедрении полученных научных и практических результатов исследований.

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Introduction

Ores of the Berezkinskoye ore field belong to the silver-sulfide-quartz formation with vein-disseminated mineralization in terms of their mineralogical composition. Silver mineralization [1, 2] is characterized by vein-disseminated and pockety sulfide mineralization [3] in metasomatically altered rocks: quartz-sericite and sericite-quartz metasomatites and secondary quartzite, and less frequently in sericitized and silicified porphyrite and andesite.

The ore intersections vary significantly within a wide range of silver grades and their distribution is highly irregular.

A system of vertical, inclined boreholes and trenches, which are located extremely irregularly, was used during the exploration of the deposit. For the Southern and Eastern areas, mineralization has been studied in more details within the weathering crust zone, which was penetrated to its entire thickness by the numerous boreholes, and traced along the surface by the trenches. Deep horizons were studied less thoroughly, using an irregular network of boreholes.

Research Techniques

The most accurate way to estimate reserves is the geological block method [4, 5], using an ore-bearing ratio, both for ores occurring in the weathering crust as well as for the ores occurring below the weathering crust.

Findings Discussion

Ore reserves were estimated in accordance with permanent exploratory conditions for open-pit mining [6, 7]. Upon that, it is necessary to estimate the reserves of silver as a minor component. The deposit balance reserves should be estimated separately for all types of ores within an optimal pit envelope [8, 9] adopted in the final mining Feasibility Study (FS of permanent exploratory conditions for open-pit mining).

In addition, ore reserves for underground mining were estimated in accordance with the provisional exploratory conditions. It also includes estimates of silver as a minor component. However, the off-balance ores are to be considered as reserves that have been estimated according to the balance ore conditions, but which do not meet the commercial minimum standards.

The minimum ore reserves of separated bodies are provided in Table 1.

Input data for the reserve estimation

Input data for the reserve estimation were as follows:

1. Catalogues of coordinates of borehole collars and trenches (database).

2. Logbooks of borehole logging.

3. The results of laboratory assays of ordinary samples, as well as the results of determining the bulk density and moisture of ores.

Based on the input data, a database (DB) was compiled. All information on the completed workings for 2022 was entered into the database.

All data are presented in the form of scanned materials and spreadsheets in Excel format (the coordinate catalogues, Downhole Survey, laboratory assay/test results). All data was checked (adjustments were made if necessary) and brought into a consistent structure. The scanned information was digitized, checked, and added to the database.

The database comprises all the necessary data for the Berezkinskoye deposit reserve estimation.

4. Geological maps, plans and cross-sections of the Berezkinskoye deposit, areas on a scale of 1 : 1000 and 1 : 500.

The scanned graphic materials in the form of cross-sections and plans were georeferenced using Micromine software [10, 11] in spatial coordinates (Error! Reference source not found.). Graphic materials were used to interpret, vectorize, and verify the geological information entered into the database.

Database formation

The processed primary data were summarized using the Micromine software (Fig. 2). The accuracy of the data entry and processing was examined visually and using the software tools. The final inspection was carried out to ensure that the sample depth information

Table 1

Minimum ore reserves of separated bodies

Ag grade in ore body, g/t	Minimum ore reserves of separated bodies (kt) included in the reserve estimates at various distances from the main ore body						
	50	75	100	125	150	175	200
6.57	3.01	4.51	6.01	7.52	9.02	10.53	12.03
7.00	2.04	3.05	4.07	5.09	6.11	7.13	8.14
7.50	1.48	2.22	2.96	3.70	4.44	5.19	5.93
8.00	1.16	1.75	2.33	2.91	3.49	4.08	4.66
8.50	0.96	1.44	1.92	2.40	2.88	3.36	3.84
9.00	0.82	1.22	1.63	2.04	2.45	2.85	3.26
9.50	0.71	1.06	1.42	1.77	2.13	2.48	2.84

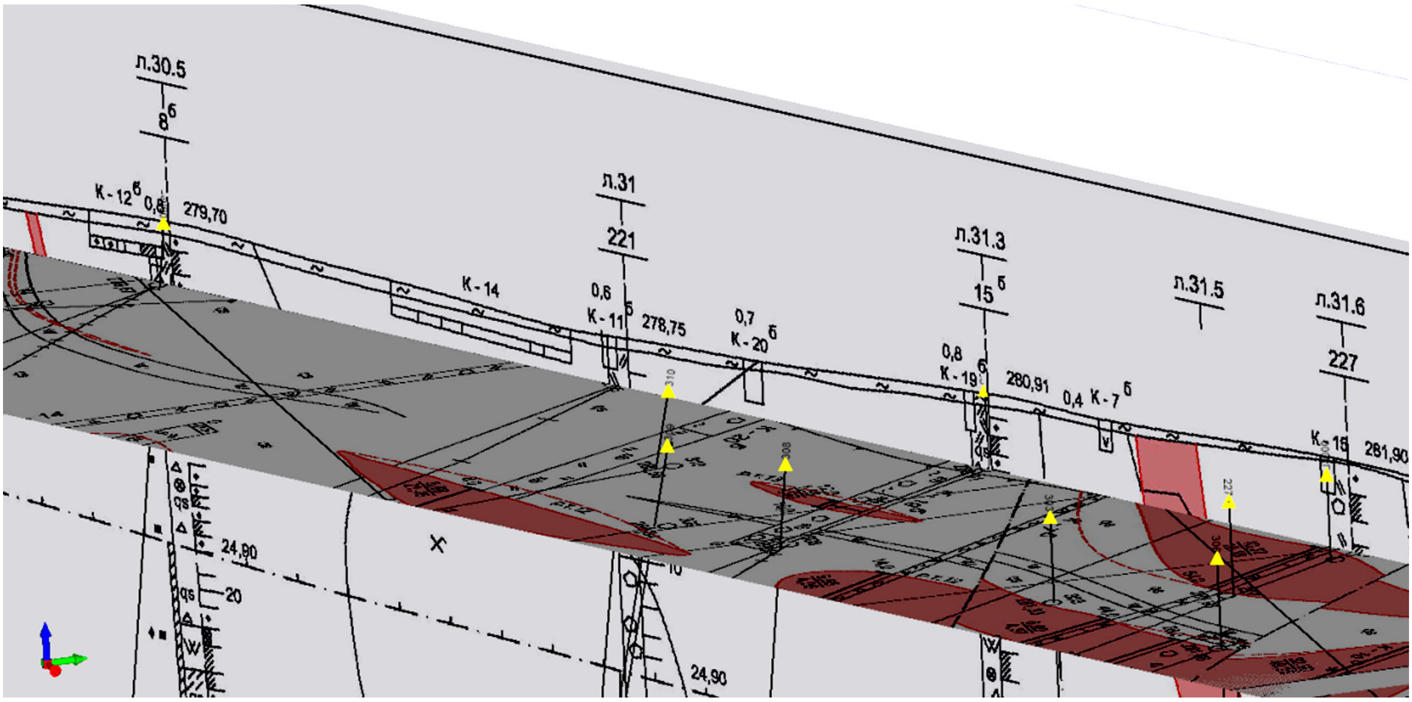

Fig. 1. Georeferenced plan and cross-section along line 128, Berezkinsky area with superimposed database of boreholes

entered was consistent with the excavation depth. The database contains information on the locations of workings (boreholes, trenches), borehole design, information describing the spatial position of the axis of the workings, data of assaying the samples from the workings for silver and copper (Fig. 2). The database structure is provided in Table 2.

Sampling

The "sampling" table included the data of sample assays performed for 2022. A total of 122 samples (including control sampling) were collected from the deposit, comprising 95 core samples from the exploration boreholes and 27 channel samples from the trenches.

The inspection revealed that the database contained duplicates, which were subsequently removed. Grade values included "0" as well as coded negative values, which were replaced by a value equal to half of the assay sensitivity of the 0.1 g/t for Ag.

The database contains 122 intervals, of which sample assaying data for Ag is available for 82 intervals.

Deliniation principles

Delineation of ore bodies for open-pit mining was carried out based on the boundary sections identified in the boreholes at a cut-off grade of 0.4 g/t, taking into account the orientation of geological structures. The validity of the delineation of the ore bodies was tested on a three-dimensional model [12, 13] built in Micromine.

The delineation of ore bodies was carried out taking into account pit envelopes. The blocks

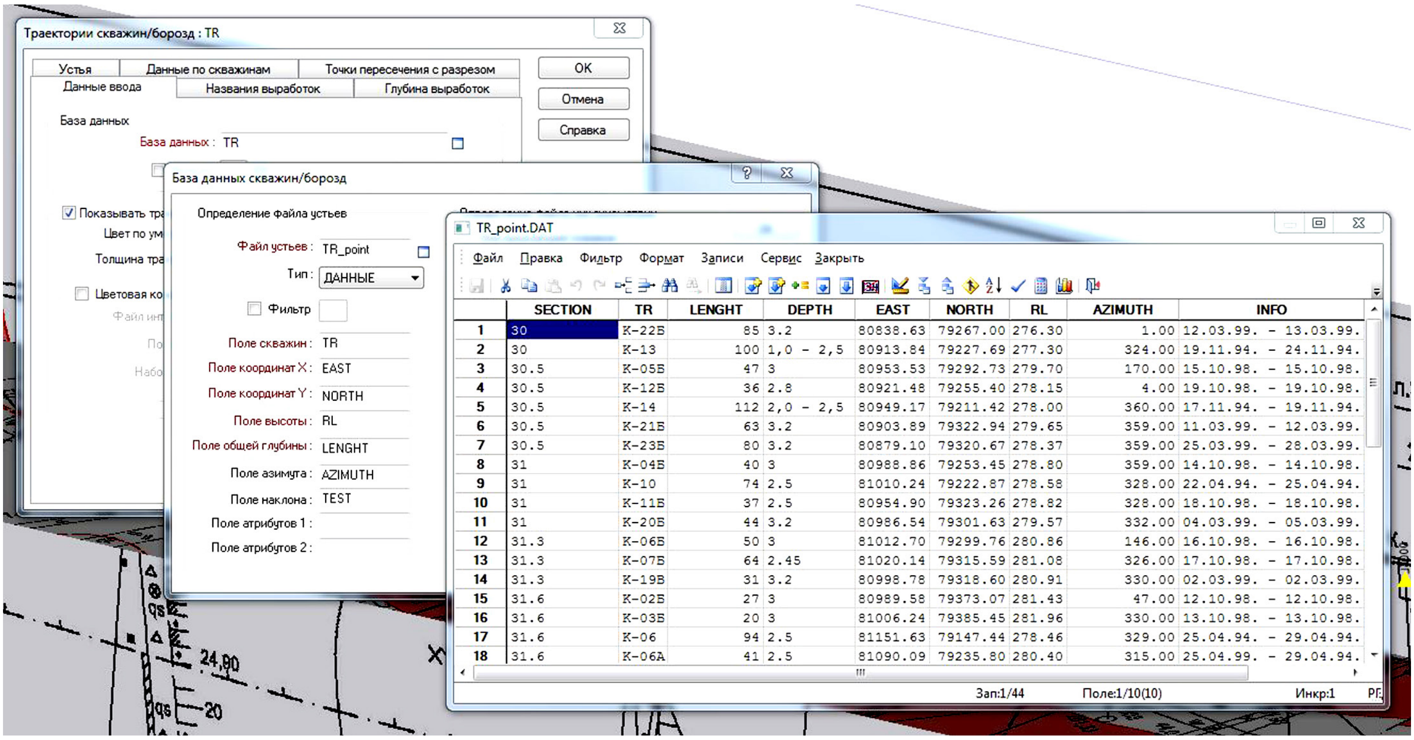

Fig. 2. Database of boreholes and trenches created with the use of the Micromine software

Table 2

Database Structure

Workings Data	Information about the coordinates of the beginning and additional information on a working. A working designation (identification number), an exploration line, the type of working, the coordinates of a working beginning (X – east, Y – north, Z – RL), the length of a working (accepted, based on drilling data, based on logging data), the length based on the logbook, the year of drilling/excavation, an area, comments.
Directional Survey	Information about the spatial position of the axis of workings. Boreholes: depth of measurement, true azimuth, vertical angle; Trenches: coordinates of beginning, end and bend points of a working.
Sampling	Information with the data of geological sampling of core, channel. A working designation, sample number, from, to, length of sampling interval, azimuth and dip angle of an ore body interception, true thickness, grades of valuable components in g/t, % (Ag, Cu), type of ore oxidized/fresh, grades of valuable component in mg (Ag), ore grade (sort), area, coordinates X, Y, Z.
Weathering crust	Information on the thickness and bottom of the weathering crust to determine the boundary of oxidized ores. From, to, interval length.
Structural Geology	Fault information. From, to, interval length, comments about the type of fault.

included in a pit envelope have been classified as balance reserves, while those not included have been classified as off-balance reserves. When estimating reserves, if the block was divided into two parts by a pit envelope, the ore bodies were delineated separately in cross-sections at a pit boundary [14]. The part of the ore body extending beyond the pit envelope but supported by workings inside the pit envelope has not been included in the off-balance reserve estimate. Likewise, the area of the body that is within the pit envelope but is supported by workings outside the pit envelope has not been included in the balance reserve estimate.

For underground mining, the delineation of ore bodies was carried out based on the cross-sections identified in the boreholes at a cut-off grade of 10.7 g/t, taking into account the orientation of geological structures [15]. Reliability of the ore bodies delineation was verified in a Micromine three-dimensional model.

Pursuant to the recommendations of the State Comission on Mineral Reserves (GKZ), when classifying reserves based on exploration maturity, blocks explored by grid spacing of 40–60 m and enclosed between estimation workings were attributed to C1 reserve category. The reserves attributed to category C2 included blocks explored by grid spacing of 40–60 m, delineated with limited extrapolation to half the distance between workings, but not exceeding 50 m, or up to 50 m from a working with the grade intersections meeting the exploratory conditions (commercial intersections).

Table 3 provides a list of commercial intersection intervals not included in the reserve estimation for open-pit mining, explaining the reasons for their rejection.

The vast majority of ore cross-sections excluded from the reserve estimation constitute intersections of ore bodies opened by a single section, not traceable at lower conditions (cut-off grades) too.

As shown in Table 3, the majority of intervals are less than the minimum true thickness of an ore body of 5.0 m, but satisfying the GT condition, and due to their boundary position between deposit complexity groups 3 and 4, it is impractical to classify these bodies as reserves. For open-pit mining, the position of small ore bodies may be clarified by operational exploration with possible subsequent upgrading their materials classification to reserve categories. Table 3 provides a list of commercial intersection intervals not included in the reserve estimation.

Method of constructing a wireframe model of ore zones and bodies of the Berezkinskoye deposit

A wireframe model of ore zones [16, 17] and bodies was constructed using the outlines obtained by the developed technique. The following methodology was used (step by step):

– the outlines of the ore zones and bodies were linked between cross-sections;

Table 3

List of commercial intersection intervals outside the reserve estimation

Borehole	Interval		Apparent thickness, m	True thickness, m	Ag grade, g/t	Reason
	from	to				
1	2	3	4	5	6	7
0005G	23.7	40.0	16.3	6.4	12.20	Sole intersection of ore body
217	122.8	124.2	1.4	0.9	12.60	Sole intersection of ore body
517-2	28.0	30.0	2.0	1.8	11.96	Sole intersection of ore body
517-1	39.0	41.0	2.0	0.8	17.40	Sole intersection of ore body
518-2	32.0	33.0	1.0	0.8	13.35	Sole intersection of ore body
209	215.3	215.7	0.4	0.4	17.00	Sole intersection of ore body
521-2	185.0	187.0	2.0	1.9	21.15	Sole intersection of ore body
804	37.0	39.0	2.0	1.3	22.48	Sole intersection of ore body
11501SE	64.8	112.5	47.7	20.5	20.77	Sole intersection of ore body, but the borehole was completed within the ore body
7202SE	8.5	19.5	11.0	3.6	10.66	Sole intersection of ore body
1165SE	29.0	41.0	12.0	5.8	10.48	Sole intersection of ore body
1165SE	45.0	61.0	16.0	7.9	20.60	Sole intersection of ore body
K63ASE	12.0	14.0	2.0	1.9	22.34	Sole intersection of ore body
11730	6.0	8.0	2.0	1.2	18.90	Sole intersection of ore body
11830	18.0	20.0	2.0	1.3	21.96	Sole intersection of ore body

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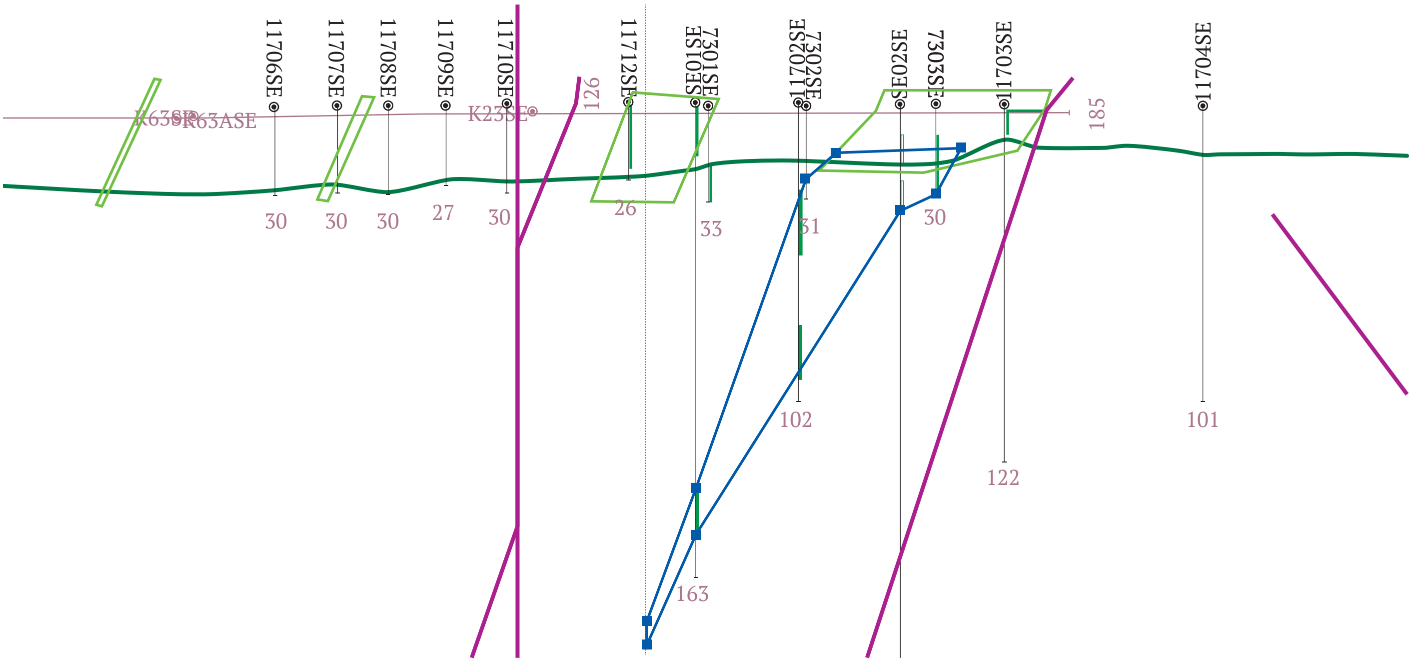


Fig. 3. Vectorization of ore zone outlines at cross-sections linked to composite intervals on P-15 line, the Berezkinsky area

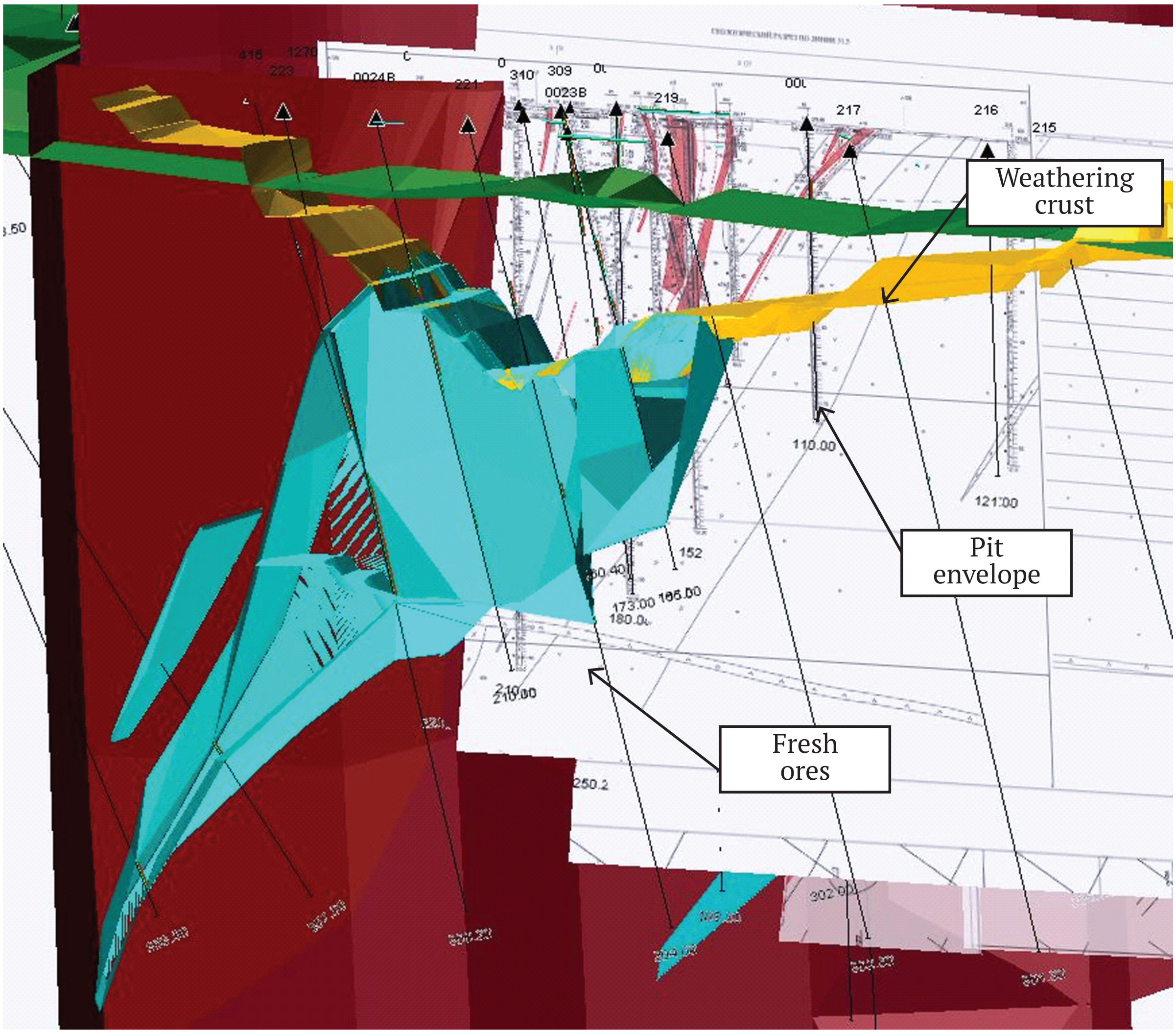


Fig. 4. Linking outlines between cross-sections taking into account weathering crust and current position of mining work. Construction of 3D wireframe model (cut-off grade of 28.3 g/ t, fresh ores) (lines P15, P57, Berezkinsky area)

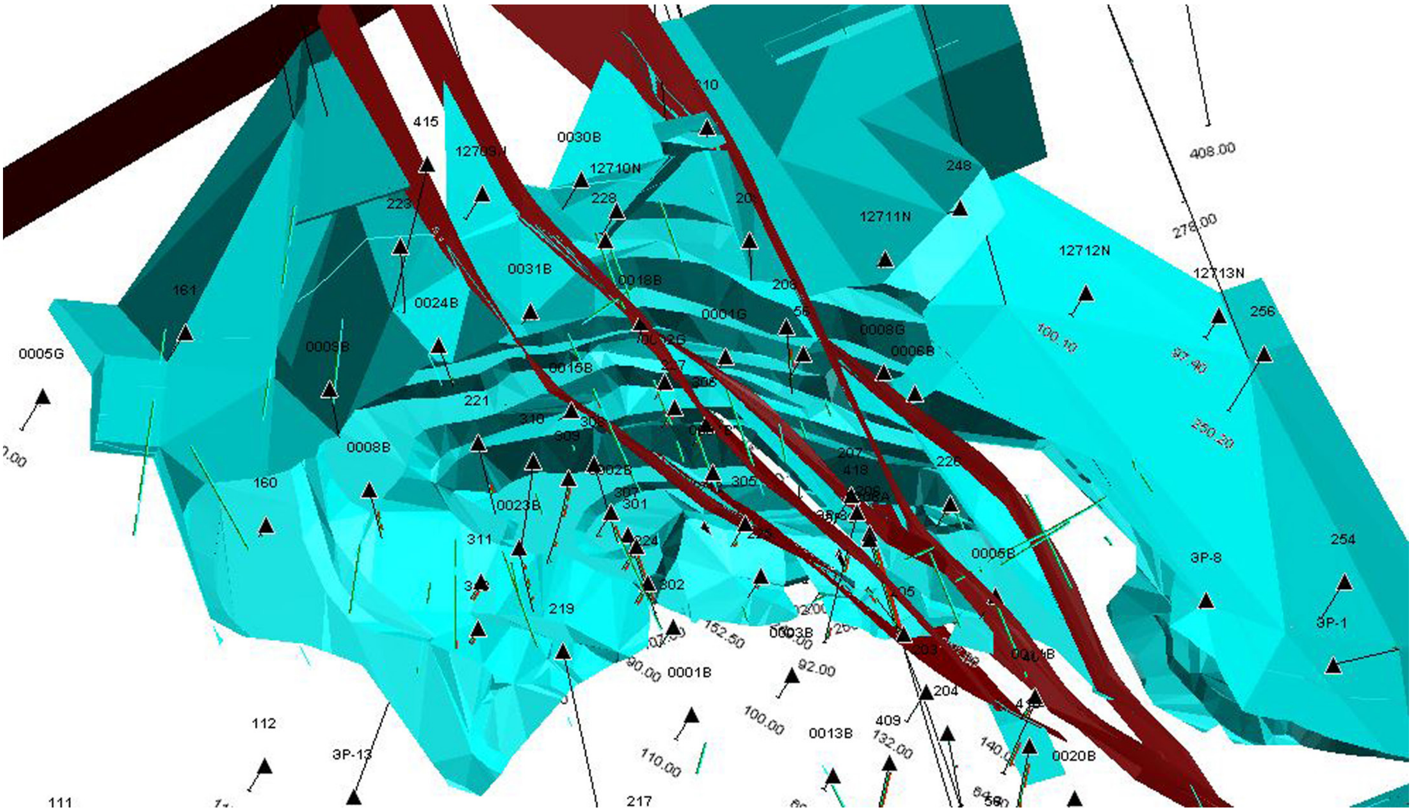


Fig. 5. Constructed wireframe model taking into account faults controlling plan, Berezkinsky area

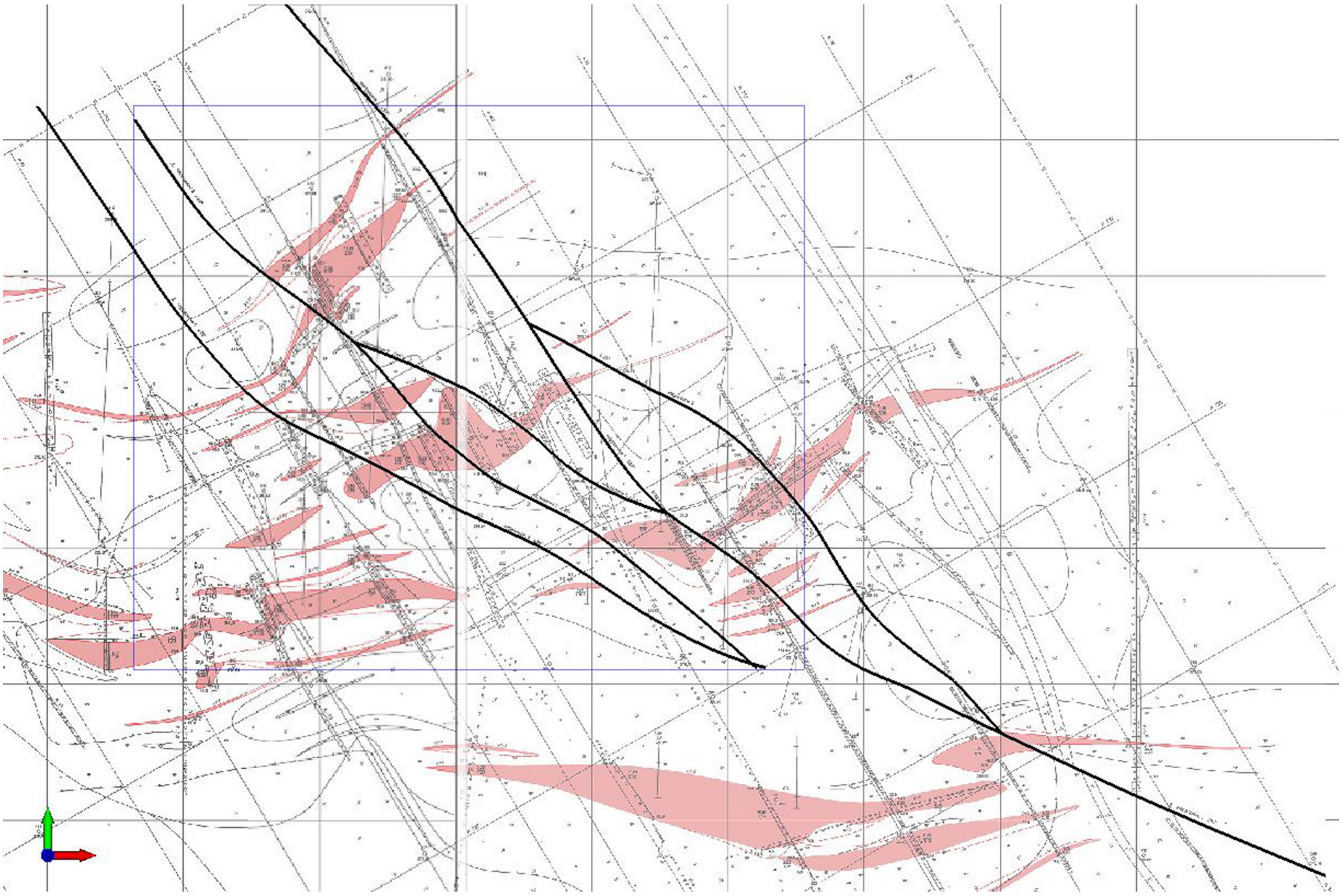


Fig. 6. Vectorization of faults in plan, Berezkinsky area

– the wireframe model was stretched for half the distance between exploration lines if an ore body or zone was not traced in an adjacent cross-section. The outer outline of an ore body or zone was depicted using extrapolation to a distance corresponding to the workings grid spacing for reserves of category C2 and equal to 50.0 m;

– the wireframe model was adjusted in 3D mode based on data from separate boreholes;

– to take into account the structural features of the deposit, the constructed wireframe model was limited by faults controlling ore bodies and zones, and truncated by the boundary between quaternary sediments and bedrock, and also corrected by the envelope of the existing pit (current extraction position) (Fig. 4).

Fig. 5 presents the constructed wireframe model, taking into account the faults controlling ore zones (Berezkinsky area).

A fault wireframe model construction

Fault activity in the area is intense and is characterized by strike-slip and shift faults of various signs and directions, from sublatitudinal to submeridional, as well as a large thrust fault.

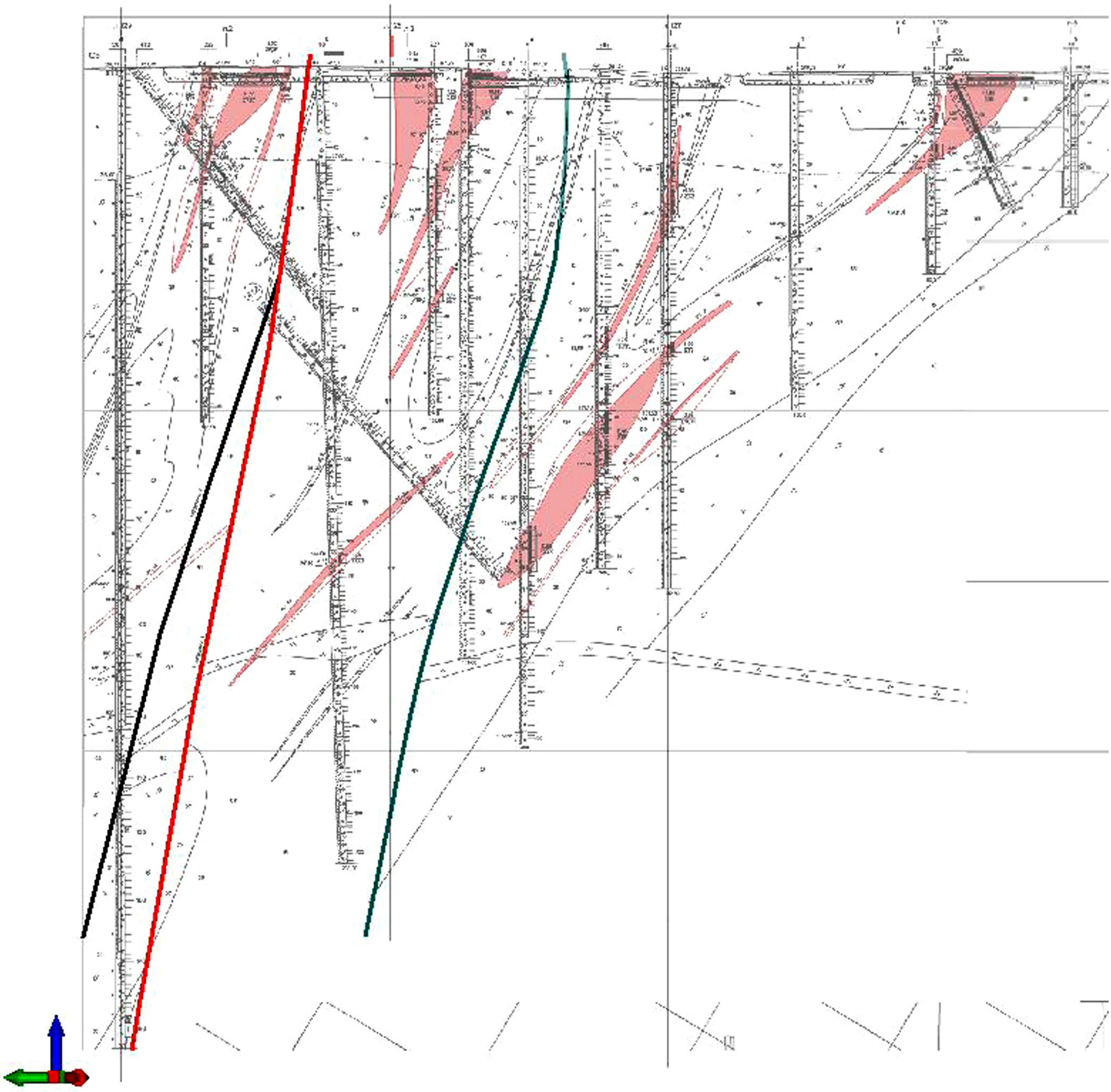


Fig. 7. Vectorization of faults in plan, Berezkinsky area

A wireframe model of faults was based on the Berezkinsky area plans and cross-sections. The model was constructed in several steps.

– vectorization of fault outlines on cross-sections and plans (Fig. 6);

– linking and adjusting between cross-sections and plans taking into account geological data;

– construction of the fault wireframe model based on the generated outlines by linking the outlines using the polygon method, considering the geological data on boreholes and trenches (Fig. 7).

Fig. 8 shows the linked wireframe model of faults, Plan - Cross-Section, Berezkinsky area.

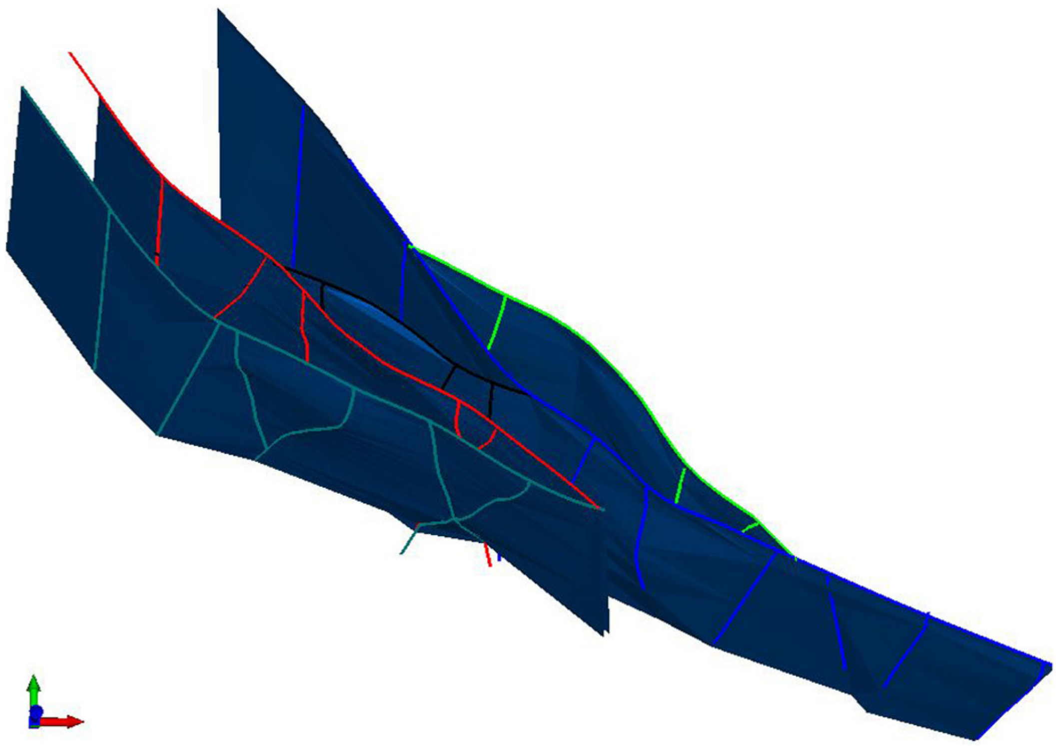
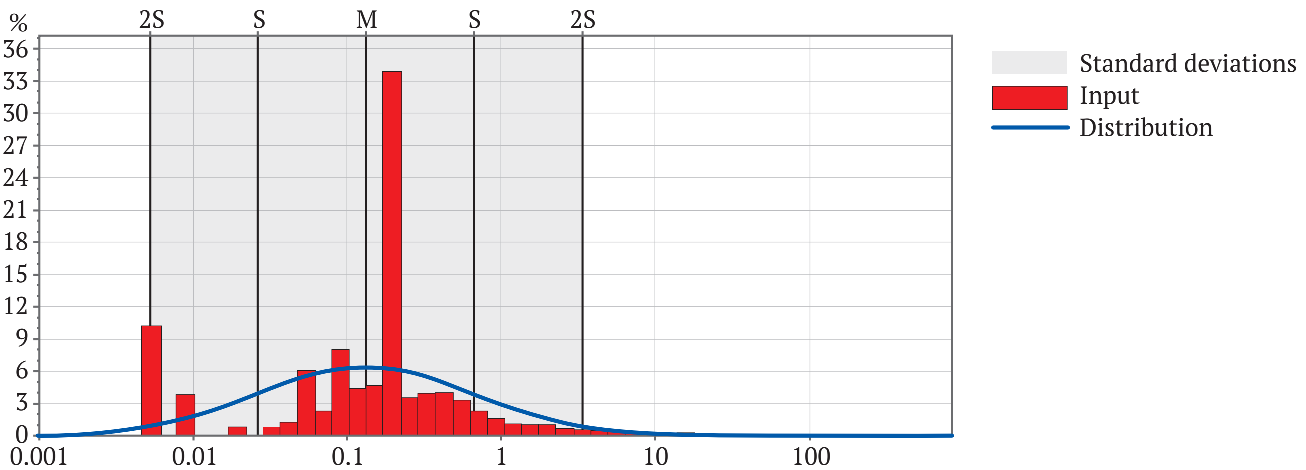
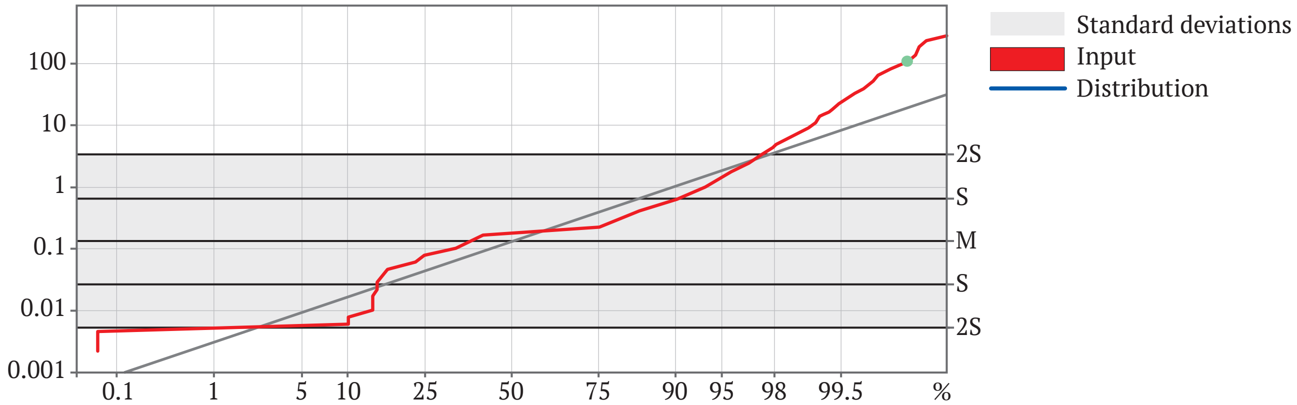


Fig. 8. Linked wireframe model of faults, Plan – Cross-Section, Berezkinsky area



Min value	0.002	Variance	154.849	Geometrical standard deviation	5.011
Max value	840.000	Standard deviation	12.444	Sishel estimate	0.484
2nd in height	617.270	Coefficient of variation	13.460	Sishel V	2.597
3nd in height	535.900	Median value	0.200	Sishel Gamma	3.663
4nd in height	444.080	Ln average	−2.025	Chi-square adjustment	37785.581
Count	14721	Ln standard deviation	1.612	Degrees of Freedom	38
Average	0.925	Geometrical mean	0.132		

Fig. 9. Log histogram of the distribution of silver grades in the fresh ores of the Berezkinsky area



Min value	0.002	Variance	154.849	Geometrical standard deviation	5.011
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Count	14721	Ln standard deviation	1.612	Degrees of Freedom	38
Average	0.925	Geometrical mean	0.132		

Fig. 10. Graph of the cumulative probability of silver grades distribution in the fresh ores of the Berezkinsky area

Silver

Based on the results of statistical analysis, one statistical population was identified at the Berezkinsky area (Figs. 9, 10). To identify grade outliers, a cumulative frequency curve was applied, with the selection of populations by grade, which were determined by the line bend on the graph (inflection point), making it possible to identify areas of an ore body with different mineralization intensity. Outliers with grade equal to 100 g/t of silver for fresh ores and 19.8 g/t of silver for oxidized ores were identified. All samples with a grade above this value were capped to a threshold level.

Conclusion

Application of modern geoinformation system (GIS) technologies makes it possible to qualitatively assess the prospects and estimate the reserves at the deposits [18–20].

The material composition of ores, technological properties, hydrogeological and geotechnical features of the Berezkinskoye deposit have been extensively investigated to ensure that C1 and C2 reserves can be estimated and developed using the open-pit mining method in the Eastern area of the Berezkinskoye deposit.

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SAFETY IN MINING AND PROCESSING INDUSTRY AND ENVIRONMENTAL PROTECTION

Research paper

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Formation of mine drainage in the Far Eastern region and its impact on the ecosphere and public health

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Abstract

The long-term development of the mining industry in the Komsomolsky, Kavalerovsky and Dalnegorsky districts of the Far East of Russia caused origination of large-scale mining technogenic systems. During the period of so-called "perestroika", mining production in the region was suspended, while mine workings (pits, adits) and tailings dumps were not subjected to any kind of preservation or reclamation. Only the boron and lead-zinc mining sectors in the Dalnegorsk district are currently in operation. The purpose of this paper is to assess the composition of mine waters, reveal the conditions of their formation, the presence of various aqueous species (coordination compounds and ions) of different elements and establish the parameters of precipitation of a number of hypergenic natural and technogenic minerals from these waters. This paper provides the hydrochemical characteristics of mine waters in the mining technogenic systems of tin-sulfide, copper-tin, tin-polymetallic, and polymetallic deposits, indicates the conditions of their formation and describes the adverse impact on the hydrosphere, as well as on human health in these districts. The studies of sulfide oxidation and mine water formation processes were carried out by the method of physicochemical simulation involving the use of the Selektor software package. The Eh–pH parameters of solutions, their composition with respect to stable aqueous species (complex compounds and simple ions), paragenetic associations (paragenesis) of precipitating hypergenic minerals with respect to the primary composition of ores and host rocks were established in a wide temperature range (from −25 to +45 °C). It has been established that the simulated micropore solutions participating in the formation of mine waters exhibit a wide range of Eh–pH parameters: Eh from 0.55 to 1.24 V and pH from 0.3 to 13.8. The technogenic minerals Fe, Cu, Zn, Pb and Sb belonging to oxide and hydroxide, sulphate, and arsenate classes are precipitated from them. Mine waters of high concentration, prior to and after the precipitation of technogenic minerals (weight of which reaches the hundreds of grams), are released into the hydrosphere. The simulated solutions contain all the elements of sulfide ores: Cu, Zn, Pb, Fe, Ag, As, Sb and S, whereas their concentrations in the form of aqueous species reach the tens of grams, while under cryogenic conditions the concentrations are by one or two orders of magnitude higher as a result of ice formation. The forms of migration of the elements depend on the temperature conditions. The negative impact of mine waters on the region hydrosphere and human health was demonstrated. In the districts under consideration, obvious trend of increasing morbidity (for almost all types of diseases) by 2 times both in adults and in children as compared to other Far Eastern regions was revealed. In addition, the morbidity of the child population for almost all the diseases under consideration proved much higher than in adults.

Keywords

mine slurry and drainage water, physicochemical simulation, sulfide minerals, hypergenesis, technogenesis, hypergenic natural minerals, technogenic minerals, processing tailings, paragenetic associations, toxicant, morbidity, Far East

For citation

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ТЕХНОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ В МИНЕРАЛЬНО-СЫРЬЕВОМ КОМПЛЕКСЕ И ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ

Научная статья

Формирование рудничных вод в Дальневосточном регионе России и их влияние на экосферу и здоровье населения

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Аннотация

Длительное развитие горнорудной промышленности в Комсомольском, Кавалеровском и Дальнегорском районах Дальнего Востока России позволило сформироваться крупномасштабным горнопромышленным техногенным системам. В период перестройки работа горнопромышленного производства была приостановлена, а горные выработки (карьеры, штольни) и хвостохранилища не подвергались какой-либо консервации или рекультивации. В настоящее время работает только борная и свинцово-цинковая промышленность в Дальнегорском районе. Цель данной статьи – оценить состав рудничных вод, показать условия их формирования, наличие ионов и молекул различных элементов и установить параметры кристаллизации из них ряда гипергенных природных и техногенных минералов. В публикации приведена гидрохимическая характеристика рудничных вод в горнопромышленных техногенных системах олово-сульфидных, медно-оловянных, олово-полиметаллических и полиметаллических месторождений, показаны условия их формирования и негативное воздействие на гидросферу, а также здоровье людей, проживающих в данных районах. Исследования процессов окисления сульфидов и формирования рудничных вод выполнены методом физико-химического моделирования с использованием программного комплекса «Селектор». В широком интервале температур (от −25 до +45 °C) установлены Eh–pH параметры растворов, их состав в отношении устойчивых водных частиц (комплексных соединений и простых ионов), парагенетические ассоциации (парагенезисы) осаждающихся гипергенных минералов в зависимости от первичного состава руд и вмещающих пород. Установлено, что моделируемые микропоровые растворы, формирующие рудничные воды, имеют широкий спектр Eh–pH параметров: Eh от 0,55 до 1,24 В и pH от 0,3 до 13,8. Из них кристаллизуются техногенные минералы Fe, Cu, Zn, Pb и Sb из классов оксидов и гидроксидов, сульфатов и арсенатов. Высококонцентрированные рудничные воды до и после осаждения из них техногенных минералов, масса которых составляет сотни грамм, попадают в гидросферу. Полученные моделированием растворы содержат все элементы сульфидных руд: Cu, Zn, Pb, Fe, Ag, As, Sb и S, а их концентрации в форме водных частиц достигают десятков грамм, причем в криогенных условиях они на порядок и два выше за счет кристаллизации льда. Формы миграции элементов зависят от температурного режима. Показано отрицательное воздействие рудничных вод на гидросферу региона и здоровье населения, проживающего в нем. Установлено, что в рассматриваемых районах отмечается тенденция роста практически всех видов болезней в два раза как у взрослых, так и у детей, причем заболеваемость детского населения практически по всем рассматриваемым болезням значительно выше, чем у взрослых.

Ключевые слова

рудничные шламовые и дренажные воды, физико-химическое моделирование, сульфидные минералы, гипергенез, техногенез, гипергенные природные минералы, техногенные минералы, хвосты обогащения, парагенетические ассоциации, токсикант, заболеваемость, Дальний Восток

Для цитирования

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Introduction

The mining industry in the Komsomolskiy, Kavalerovskiy and Dalnegorskiy districts of the Far East has been developing for 70 to 120 years. Cassiterite-sulfide and polymetallic deposits were mined by both open-pit and underground methods. In the region, cassiterite-sulfide, cassiterite-silicate, and polymetallic deposits were developed, from ores of which Sn, Cu, Pb, and Zn were extracted. During perestroika, from 1996 to 2000, mining and processing facilities located in the Komsomolsky, Kavalerovsky and Dalnegorsky districts (Krasnorechenskaya processing plant) were abandoned. The major sulfide minerals in the areas under consideration are: pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena and sphalerite. The deposits development was carried out both by open-pit and underground methods, resulting in increased access of weathering agents (water, oxygen, etc.).

The intensification of hypergenic processes in underground mine workings (adits) contributes to the formation of mine waters with high concentrations of sulfide ore elements: Cu, Zn, Pb, Fe, As, Sb and S. Cu, Zn, Pb, Fe, As, Sb and S. Studies of the composition of technogenic waters and their impact on natural waters were carried out both in Russia and abroad. Many authors have reported their adverse impact on natural waters in the Komsomolsky, Kavalerovsky [1–3], and Dalnegorsky districts [2–4] of the Far East, in the Kemerovo region [5], the Urals [6], and in the world: New Zealand [7], America [8, 9], Turkey [10], Spain [11], Argentina [12].

The study of the chemical composition of mine waters by the authors was carried out in the period from 2001 to 2019 by the method of atomic emission spectroscopy using a Plasmaquant-110 spectrometer (Table).

Table

Chemical characteristics of mine waters (mg/l)

Sampling location (district, deposit)	Cu	Pb	Zn	Fe	As
Komsomolsky District					
1. Perevalnoye, 2002	36.600	1.320	77.500	71.400	0.130
2. Festivalnoye, 2004	153.000	0.002	24.970	14.800	0.200
3. Perevalnoye, 2004	48.300	1.200	60.100	32.200	0.600
4. Festivalnoye, 2010	46.510	0.013	10.230	17.430	0.003
5. Perevalnoye, 2010	16.150	1.560	25.64	42.300	0.187
6. Festivalnoye, 2015	85.152	0.034	10.510	5.730	0.120
7. Perevalnoye, 2015	2.080	0.054	4.480	2.580	0.299
Kavalerovsky District					
8. Vysokogorskoye, 2008	0.032	0.003	0.175	0.410	0.002
9. Dubrovskoye, 2008*	0.222	0.001	4.314	0.080	0.002
10. Dubrovskoye, 2008**	0.110	0.002	2.290	0.830	0.002
11. Vysokogorskoye, 2009	0.012	0.001	0.120	0.230	0.001
12. Dubrovskoye, 2010*	0.250	0.002	2.970	1.080	0.003
13. Dubrovskoye, 2010**	0.361	0.003	2.090	5.770	0.002
14. Vysokogorskoye, 2010	0.420	0.001	0.530	0.770	0.001
15. Dubrovskoye, 2011	0.450	0.001	2.010	2.970	0.012
16. Dubrovskoye, 2012	0.687	0.011	2.440	3.190	0.019
17. Dubrovskoye, 2013	0.159	0.001	2.700	0.550	0.003
18. Dubrovskoye, 2014	0.081	0.001	1.512	1.323	0.009
19. Dubrovskoye, 2015	0.482	0.007	2.725	3.625	0.009
20. Dubrovskoye, 2016	0.160	0.001	50.460	3.210	0.018
21. Dubrovskoye, 2017	0.166	0.001	1.748	0.713	0.002
22. Dubrovskoye, 2018	0.067	0.004	1.971	0.020	0.001
23. Dubrovskoye, 2019	0.034	0.001	0.749	0.017	0.001
24. Dubrovskoye, 2021	0.053	0.001	1.161	0.005	0.001
Dalnegorsky District					
25. Sovetsky Mine, 2001	0.001	0.123	0.216	0.593	0.023
26. Sovetsky Mine, 2003	0.015	0.200	0.614	0.918	0.018
27. Sovetsky Mine, 2006*	0.011	0.584	1.281	2.895	0.056
28. Sovetsky Mine, 2006**	0.003	0.262	0.687	1.252	0.029
29. Sovetsky Mine, 2007	0.008	1.033	0.937	9.309	0.033
30. Sovetsky Mine, 2010	0.002	0.121	0.390	0.330	0.015
31. Sovetsky Mine, 2011	0.114	5.350	9.790	27.222	0.041
32. Sovetsky Mine, 2012**	0.004	0.246	0.532	0.938	0.030
33. Sovetsky Mine, 2013**	0.004	0.085	0.650	1.080	0.026
34. Sovetsky Mine, 2014**	0.014	0.447	1.208	2.148	0.034
35. Krasnorechenskoye, 2015	0.031	0.076	0.001	2.928	0.006
36. Sovetsky Mine, 2016	0.189	0.920	0.040	0.350	0.614
37. Sovetsky Mine, 2017	0.001	0.034	0.131	0.036	0.011
38. Sovetsky Mine, 2018	0.001	0.041	0.273	0.026	0.009
39. Sovetsky Mine, 2019	0.001	0.016	0.156	0.004	0.010
40. Sovetsky Mine, 2020	0.001	0.013	0.134	0.004	0.016
41. Sovetsky Mine, 2021	0.001	0.107	0.066	0.002	0.002

Notes: * – samples were taken in summer, if the sampling was performed repeatedly in that year: ** – samples were taken in autumn, *** – samples were taken in spring. The content of S in the mine waters of the Kavalerovsky district varies from 7.2 to 216 mg/l, and in the Dalnegorsky district, from 18.4 to 192 mg/l.

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In the Komsomolsky district, in the mine waters of the Festivalnoye deposit (copper-tin ores), the concentration of Cu reaches 153 mg/l, which is 76,500 times higher than the background characteristics, so its extraction from such waters was even recognized to be profitable. In the mine waters of Perevalnoye deposit (tin-polymetallic ores), the concentrations (mg/l) of Zn reaches 78, that of Pb, 1.56, exceeding the background values by 8,611 and 1,560 times, respectively. The waters are also distinguished by extremely high concentrations of Fe, 71.4 mg/l, As, 0.6 mg/l, exceeding the background values by 6490 and 1000 times, respectively (see Table 1). In the Kavalerovsky district, the maximum concentrations were detected for Cu, Pb, Zn, Fe, As at the Dubrovskoye deposit (mg/l): 0.687, 0.007, 50.46, 3.625, 0.019, respectively, exceeding the background values in 343.3, 7, 5,606, 329.5, 9.5 times, respectively. The mine waters of the 1st Sovetsky Mine in Dalnegorsky district contain: Cu, Pb, Zn, Fe, As in concentrations up to 0.189, 5.35, 9.79, 27.222, 0.614 mg/l, which exceed the background values by 94.5, 3,147, 1,088, 2,593, 1,023 times, respectively.

The mine drainage flow rate is inconsistent and varies considerably from mine to mine in the Kavalerovsky district, reaching 3,600 m^3/day. The volume of effluents at the mines of cassiterite-sulfide ores in this region in 1985–988 was (thousand m^3): 296 (Silinsky), 316 (Vysokogorsky), 758 (Ternisty), 895 (Tsentralny), 1208 (Yubileiny) and 1750 (Arsenievsky). In this period, the following quantities of a number of elements in the mine waters were found (kg): Fe, from 18 to 859, Cu, 2, and Zn, 62.

These high concentrations of sulfide ore elements are observed in the mine waters after precipitation of a wide range of technogenic minerals: posnjakite, serpierite, woodwardite, wroewolfeite, pitticite, glockerite, hisingerite, etc. They form stalactites, stalagmites or simply speleothems of white, blue, green, brown, and black colors of different shades permanently occurring in underground mine workings. Their thickness can reach 0.5 m [13–15].

Highly concentrated mine water was discharged year-round for many decades, untreated and unconfined, and polluted surface water and groundwater. Notice that some river waters, e.g. from the Silinka River (Komsomolsky district) and the Vysokogorka River (Kavalerovsky district) are actually used for supplying drinking water.

The purpose of this work is to assess the composition of mine waters, study the conditions of their formation, ionic/molecular speciation, establish the parameters of precipitation of a number of hypergenic natural and technogenic minerals from them and show their possible paragenetic associations using the 18–20 physicochemical simulation software package. One more objective is to demonstrate their adverse impact on the hydrosphere and the public health of those residing in the districts under consideration. To achieve this goal, the following tasks were addressed:

1. Establishing the Eh-pH parameters of micropore solutions and the composition of technogenic minerals that precipitate from them.
2. Determining the temperature conditions of their formation in the range of −25 to +45 °C.
3. Determining the paragenetic associations of precipitating (from solution) minerals.
4. Establishing the speciation of elements of sulfide ores in mine waters (aqueous species, coordination compounds and ions).
5. Demonstrating their impact on the hydrosphere and the public health in these districts.

Research techniques

In the simulation, the "Selektor" software was used (developed by I.K. Karpov et al., the A.P. Vinogradov Institute of Geochemistry of the Siberian Branch of the Russian Academy of Sciences), which was based on a convex programming mathematical approach, making it possible to establish equilibrium in heterogeneous systems by minimizing thermodynamic potentials (Gibbs free energy). The Selektor allows to calculate the phase and component composition of a thermodynamic multisystem under various temperatures and pressures, considering the activity coefficients. Isothermal changes in thermodynamic functions were calculated using equations of dependence of the change in the volume of condensed phases on temperature, pressure and semi-empirical equations of state of gases at the given parameters.

For model formation, thermodynamic parameters of the components were required at the initial stage: the independent ones – the chemical composition of the system, the dependent ones – the potentially formed in the system. The dependent components were represented by the following phases: gaseous (atmospheric and formed as a result of sulfide oxidation reactions), liquid aqueous (ions and molecules formed in solutions) and solid (hypogenic, hypergenic natural and technogenic minerals present in the mining technogenic system of the district) [16, 17]. Both thermodynamic parameters inherent in the software [18–20] and those found in the references [21, 22] were used in the simulation.

Models of the system are represented by the following chemical composition [23]: atmosphere (Ar – 3.209, C – 0.1036, N – 53.9478, O – 144.8472, moles), 10 kg [24], water (H_2O) – 1 kg, and ore–mineral (oxidizing), 0.1 kg. The calculations were performed taking into account both independent (Ar–N–C–Fe–Cu–Pb–Zn–Ag–S–As–Sb–H–O–ē) and dependent components: speciation of elements in solution (aqueous species, coordination compounds and ions), gases, minerals, solid solutions, and ice. The following thermobarometric conditions were defined for the simulation: temperature from −25 to +45 °C (varying in increments of 5 °C) at a constant pressure of 1 atm.

All of the above parameters were inputted into the "Selektor" software, which calculated the equilibrium composition of the gaseous, liquid and solid phases of the system. The obtained simulation results have been analyzed and verified.

The mineral composition of primary ores (weighing 0.1 kg) in the simulation for each of the three districts under consideration (Komsomolsky [25, 26], Kavalerovsky [27], Dalnegorsky [28]) was obtained from the relevant literary sources. The simulation of the mine water formation was undertaken for the oxidation conditions of various sulfides (chalcocite, covellite, bornite, pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, and sphalerite), and, in the Dalnegorsky district, Ag sulfides (argentite and acanthite) and Sb sulfides (pyrargyrite and jamesonite) were additionally input. The oxidation models for each sulfide were generated (at a rate of 100 %), then the oxidation was simulated in combinations of sulfides (in various combinations from 5 to 20 % of each mineral), and then with one mineral alternately excluded from the entire list of minerals involved (100 model variations were considered).

In the Komsomolsky district, when simulating, the calculations took into account: 11 independent and dependent components, of which: from 90 to 222 aqueous species, 18 gases, 3 to 40 minerals, including ice. In the Kavalerovsky district, the calculations took into account: 11 independent and dependent components, of which: from 99 to 238 aqueous species, 18 gases, 12 to 34 minerals, including ice. For the Dalnegorsky district, the calculations took into account: 13 independent and dependent components, of which: from 86 to 257 aqueous species, 18 gases, 1 to 30 minerals, including ice.

Research Findings and Discussion

The sulfide minerals forming the ore bodies at the deposits, which can be both monomineral and polymineral, have been chosen as the object of simulation. Hypergenic processes in the ore bodies of mine workings have been investigated both by direct observation [13, 15] and by the method of physicochemical simulation [29, 30]. Numerous micropore solutions formed during the oxidation of sulfides at various points of an ore body enter mine waters (drainage) and flow (untreated) from the workings outwards around the clock and all year round.

The simulation of the cementation zone minerals oxidation (chalcocite, covellite, and bornite) at negative temperatures in the Komsomolsky district showed that the simulated solutions (micropore) had the following Eh-pH parameters: Eh from 0.74 to 1.13 V and pH from 1.6 to 10.0, and the following minerals precipitated from the solutions: goethite $FeO \cdot OH$, chalcanthite $Cu[SO_4] \cdot 5H_2O$ and wroewolfeite $Cu_4[SO_4](OH)_6 \cdot 2H_2O$. At positive temperatures, the parameters were as follows: Eh 1.02–1.06 V and pH 1.6–3.3, and additional minerals posnjakite $Cu_4[SO_4](OH)_6 \cdot H_2O$ and antlerite $Cu_3[SO_4](OH)$ formed. The solutions for the simulation of sphalerite oxidation at negative temperatures had the following parameters: Eh 1.13–1.17 V and pH 1.3–1.9, and at positive temperatures, Eh 1.14–1.15 V and pH 1.3–1.5, and only at temperatures from −25 to −20 °C goslarite $ZnSO_4 \cdot 7H_2O$ precipitated, while at all other temperatures zinc and sulfur remained in solution. The oxidation of galena led to the formation of anglesite $PbSO_4$ in the entire temperature range under consideration, and the Eh-pH parameters of the solutions varied in the ranges of Eh 1.05–1.16 V and pH 1.5–2.6. During the oxidation of pyrite and pyrrhotite over the entire temperature range, solutions with parameters of Eh 1.17–1.21 V and pH 0.04–1.0 originated, from which goethite precipitated. The simulation of chalcopyrite oxidation showed precipitation of chalcanthite and goethite from solutions with parameters of Eh 1.16–1.2 V and pH 0.05–1.2. When arsenopyrite was oxidized at negative temperatures, goethite and scorodite $Fe[AsO_4] \cdot 2H_2O$ precipitated from solutions, while at positive temperatures only goethite precipitated, at the following parameters of micropore solutions: Eh 1.16–1.19 V and pH 0.6–1.3.

The rest eleven variants of sulfide oxidation (pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite, chalcocite, covellite and bornite) with alternate exclusion of each of the minerals listed in parentheses showed that Eh-pH parameters of the solutions were in the range of Eh 0.55–1.19 V and pH 0.5–2.0. At the same time, the following minerals precipitated from the solutions: goethite, chalcanthite, plumbojarosite $PbFe_6{}^{+3}[SO_4]4(OH)_{12}$ and scorodite. The absence of arsenopyrite in the system excluded scorodite from the paragenetic association of technogenic minerals, while the lack of galena excluded plumbojarosite.

It should be noted that under cryogenic conditions here and elsewhere, the concentrations of most species in solutions (liquid phase of water) reached hundreds g/l, since most of water was present in the system as a solid phase (ice). The solutions contained the following species (Fig. 1). In the range of positive temperatures, species $Cu(CO_3)_2{}^{2-}$, $Pb(SO_4)_2{}^{2-}$, $FeSO_4$ disappeared from the solutions, while the concentrations of the residual species decreased by an order of magnitude.

The simulation of oxidation of the minerals of the cementation zone: chalcocite, covellite, and bornite showed that under cryogenic conditions Eh-pH parameters of the solutions obtained for the Kavalerovsky district coincided with those obtained for the Komsomolsky district, while goethite disappeared from the paragenesis of the precipitated minerals and fibroferrite $Fe^{+3}[SO_4](OH)\cdot 5H_2O$ appeared. In the range of positive temperatures, the value of redox potential (Eh) reached 1.13 V, but the resulting paragenetic association of the technogenic minerals remained practically unchanged, with the exception of the change from goethite to fibroferrite. The simulated solutions for the oxidation of sphalerite had the following parameters at negative temperatures: Eh 1.16–1.17 V and pH 1.3–1.4, while at positive temperatures, Eh 1.14–1.15 V and pH 1.1–1.3. Same to the Komsomolsky district, at temperatures from −25 to −20 °C, goslarite precipitated, while in the other variants (scenarios) zinc and sulfur remained in the solution. The oxidation of galena also contributed to the precipitation of anglesite in the entire temperature range under consideration with the same Eh-pH parameters of solutions. With the oxidation of pyrite and pyrrhotite over the entire temperature range, fibroferrite precipitated, and the solutions exhibited the following parameters: Eh 0.84–1.24 V and pH 0.1–5.7. The simulation of chalcopyrite oxidation demonstrated the precipitation of chalcanthite with fibroferrite from solutions with the following parameters: Eh 1.08–1.14 V and pH 1.6–3.0. During the oxidation of arsenopyrite only fibroferrite was precipitated over the temperature range considered, and the Eh-pH parameters of the solutions were as follows: Eh 1.14–1.20 V and pH 0.7–1.2.

The following eleven sulfide oxidation variants (pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite, chalcocite, covellite, and bornite) with the successive exclusion of each of the minerals listed in parentheses showed that at negative temperatures Eh-pH parameters of the solutions came to the following limits: Eh 1.1–1.2 V and pH 0.6–2.3. At the same time, the following minerals precipitated from them: fibroferrite, chalcanthite, and anglesite. The absence of pyrite in the system led to the precipitation of duphthite $CuPb[AsO_4](OH)$ and bayldonite $Cu_3Pb[AsO_4]_2(OH)_2$, and when galena was excluded, chalcanthite and fibroferrite precipitated.

The solutions contained the following aqueous species (coordination compounds and ions), see Fig. 2. In the range of positive temperatures, Pb^{2+} ion and $PbSO_4$ neutral specie appeared in the solution, and the concentration of all ions, which occurred under cryogenic conditions, decreased by an order of magnitude or two.

The simulation of oxidation of the minerals of the cementation zone: chalcocite, covellite, and bornite over the considered temperature range in the Dalnegorsky district (on the example of the ores of the Sovetsky Mine) demonstrated the formation of paragenesis of chalcanthite and brochantite $Cu_4[SO_4](OH)_6$, while in the presence of bornite, goethite also precipitated. In this case, Eh-pH parameters of the solutions were as follows: Eh 0.66–1.13 V and pH 1.6–4.4 at positive temperatures and up to 11.7 at negative temperatures. The oxidation of sphalerite over the entire temperature range contributed to transfer of zinc and sulfur into the solution, which exhibited the following

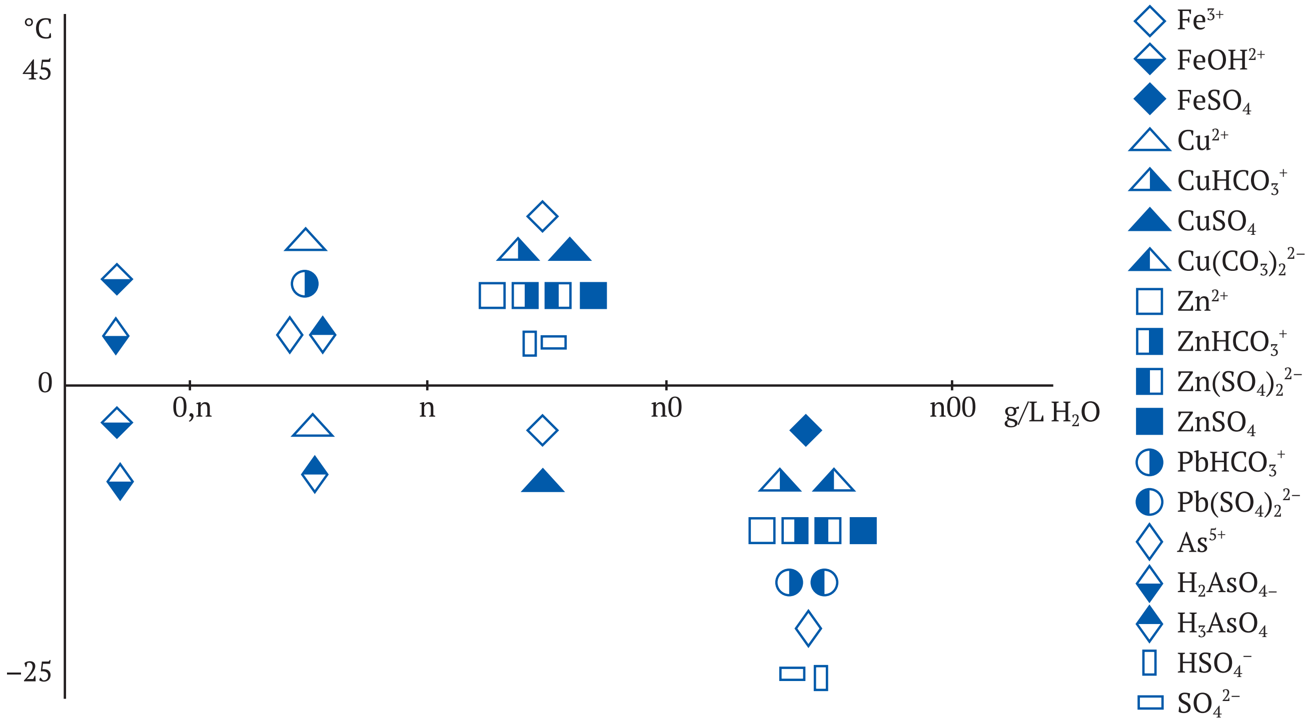

Fig. 1. Concentrations of aqueous species – speciation of elements of sulfide ores in micropore solutions forming mine water (g/l H_2O)

parameters: Eh 1.12–1.17 V and pH 1.3–1.9. The oxidation of galena in the range from −25 to +45 °C, same to the previous cases, led to precipitation of anglesite, while Eh–pH parameters of the solutions were as follows: Eh 1.05–1.19 V and pH 0.8–2.6. In the case of the oxidation of pyrite and pyrrhotite over the entire temperature range, goethite precipitated, and the solutions exhibited the following parameters: Eh 1.13–1.17 V and pH 0.7–2.1. The simulation of the chalcopyrite oxidation indicated the precipitation of chalcantite and goethite from solutions at the following parameters: Eh 1.13–1.16 V and pH 0.9–2.2. The oxidation of arsenopyrite resulted in the precipitation of goethite at the following parameters of solutions: Eh 1.11–1.14 V and pH 1.9–2.3.

Ag is extracted from the ores of the Dalnegorsky district containing argentite, acanthite, pyrargyrite, jamesonite. Then, let us simulate the oxidation of these minerals in an ore body, both separately and with their inclusion in the other variants. The oxidation of argentite, acanthite, and pyrargyrite contributed to the transition of silver to solutions both at negative and positive temperatures, and the parameters of the solutions were as follows: Eh 1.05–1.2 V and pH 0.6–2.5. In the case of the oxidation of jamesonite over the entire temperature range, anglesite and plumbojarosite precipitated at the following parameters of the solutions: Eh 1.16–1.2 V and pH 0.7–1.1.

The following fifteen sulfide oxidation variants (pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite, chalcocite, covellite, bornite, argentite, acantite, pyrargyrite and jamesonite) will be considered further with the successive exclusion of each of the minerals listed in parentheses. The oxidation simulation in eleven variants at negative temperatures showed the formation of goethite, chalcanthite (from −25 to −5 °C), plumbojarosite and adamine $Zn_2[AsO_4](OH)$ in the solutions with Eh 1.12–1.18 V and pH 0.8–2.3. The removal of arsenopyrite from the oxidizing sulfide association excluded, from the paragenesis (paragenetic association) of the precipitated minerals, goethite and adamine (at Eh 1.16–1.2 V and pH 0.6–1.2), the removal of pyrite excluded goethite (at Eh 1. 11–1.19 V and pH 0.7–2.1), the removal of sphalerite excluded adamine (at Eh 1.11–1.16 V and pH 1.1–2.3), and the removal of minerals of the cementation zone excluded plumbojarosite (at Eh 1.12–1.15 V and pH 1.3–2.2).

In eight variants of the association of the above-listed sulfides the oxidation in the range of positive temperatures led to the precipitation of goethite, plumbojarosite, and adamine at the following solution parameters: Eh 1.15–1.18 V and pH 0.8–1.3. The presence of argentite and acanthite in the association of oxidizing sulfides led to the formation of solutions with the following parameters: Eh 1.15–1.16 V and pH 0.9–1.1 and the replacement of plumbojarosite with anglesite in the list of the precipitated minerals. The absence of arsenopyrite and sphalerite in the initial association excluded adamine from the paragenesis of the precipitated minerals, and the parameters of the solutions became as follows: Eh 1.15–1.18 V and pH

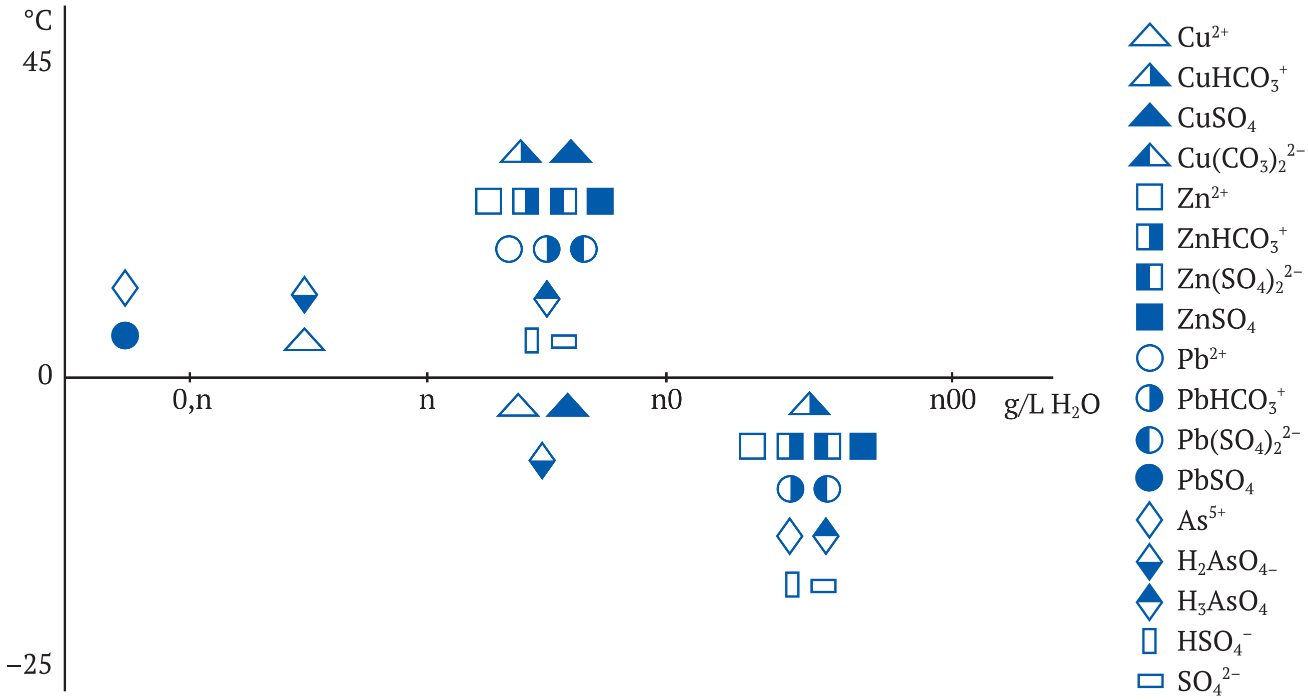

Fig. 2. Concentrations of aqueous species – speciation of elements of sulfide ores in micropore solutions forming mine water in the Kavalerovsky district (g/l H_2O)

0.8–1.2. The absence of chalcopyrite and galena in the initial association excluded goethite (Eh 1.14–1.18 V and pH 0.8–1.2) from the paragenesis of the precipitated minerals. Solutions with an Eh of 1.15–1.16 V and a pH of 0.8–1.3 were formed in the presence of pyrargyrite, resulting in the absence of plumboyarosite among the precipitated phases.

The solutions contained the following aqueous species (coordination compounds and ions), see Fig. 3. Over the range of positive temperatures, the following species were absent: $Cu(CO_3)_2^{2-}$, $Pb(SO_4)_2^{2-}$, Ag^+, while $FeOH^{2+}$, FeH_3AsO_4, $AgNO_3$ appeared. At the same time, the concentration of most species in the solution decreased by an order of magnitude.

The simulation of oxidation of the minerals of the cementation zone, chalcocite and covellite, over the range from −25 to +45 °C in the Dalnegorsky district (on the example of Krasnorechenskoye deposit) led to the transition of Cu and S into a solution with the following Eh-pH parameters: Eh 0.58–1.12 V and pH from 1.9 to 8.8 at positive temperatures and up to 13.8 at negative temperatures. The oxidation simulations for bornite solely and in combination with other minerals of the oxidation zone (covellite and chalcocite) at negative temperatures demonstrated the formation of solutions as follows: Eh 0.55–0.76 V and pH 8.6–13.8, from which fibroferrite precipitated. At positive temperatures, the parameters were as follows: Eh 0.72–0.76 V and pH 7.4–8.7, and, besides, goethite precipitated. When sphalerite was oxidized at temperatures from −20 to −15 °C (same to the two previous districts), goslarite precipitated additionally from the solutions with the following parameters: Eh 1.16–1.17 V and pH 1.4. At all other temperatures Zn and S remained in the solution (1.12–1.15 V and pH 1.3–1.5). The oxidation of galena over the considered temperature range, in accordance with usual practice, led to the precipitation of anglesite at the following Eh-pH parameters of the solutions: Eh 1.06–1.16 V and pH 1.5–2.6. In the case of the oxidation of pyrite over the entire temperature range, fibroferrite precipitated (the solution parameters: Eh 1.19–1.21 V and pH 0.3–0.7). The oxidation of pyrrhotite at negative temperatures resulted in the precipitation of fibroferrite (Eh 1.11–1.16 V and pH 1.5–2.1), while at positive temperatures goethite appeared (Eh 0.88–0.92 V and pH 5.2–5.6). The simulation of the chalcopyrite and arsenopyrite oxidation revealed the precipitation of fibroferrite (regardless of temperature) from the solutions exhibiting the following parameters: Eh 1.09–1.21 V, pH 0.3–2.0 at negative temperatures, and Eh 1.09–1.19 V, pH 1.2–9.9 at positive temperatures. The oxidation of argentite and acanthite contributed to the accumulation of Ag and S in solution over the entire temperature range, with the same parameters as in the previous variant considered (the oxidation of the Sovetsky Mine's ores). In the case of the oxidation of pyrargyrite and jamesonite in the entire temperature range, anglesite, fibroferrite and valentinite Sb_2O_3 precipitated, and the solutions exhibited the following parameters: Eh 1.18–1.21 V and pH 0.5–0.9.

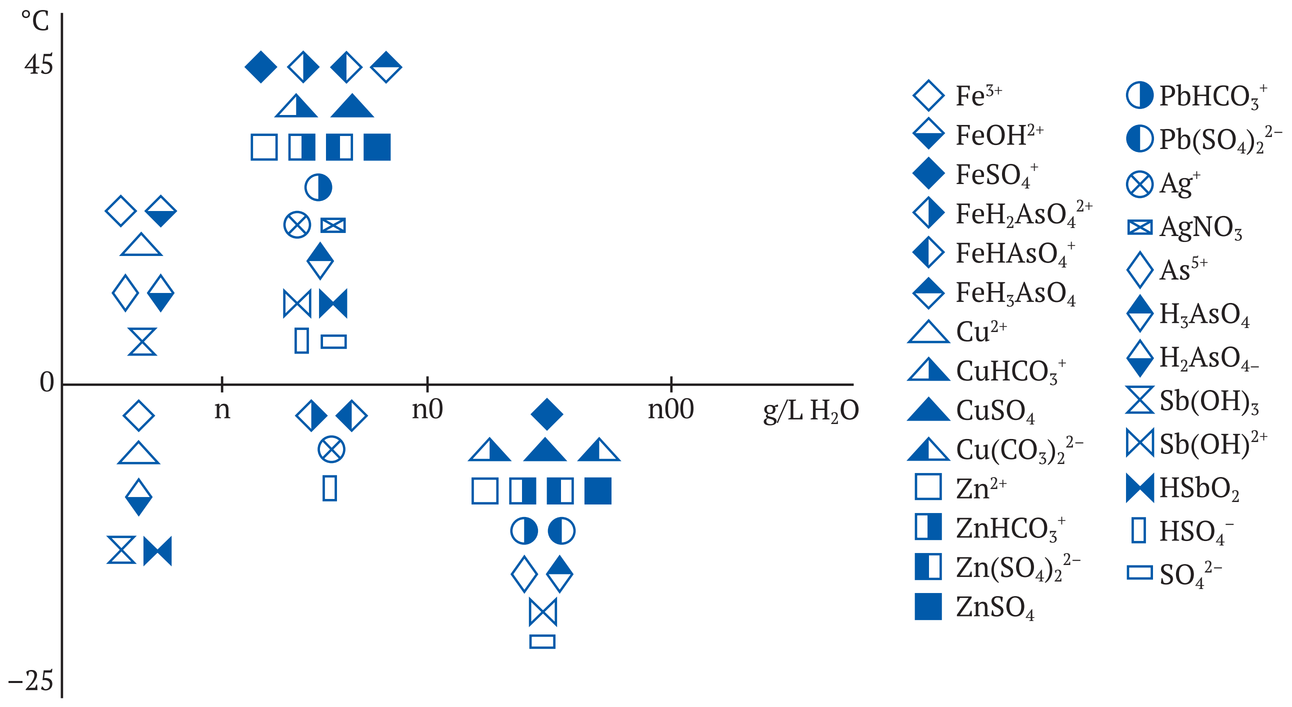

Fig. 3. Concentrations of aqueous species - speciation of elements of sulfide ores in micropore solutions forming mine water in the Dalnegorsky district (on the example of the Sovetsky Mine ores), g/l H_2O)

The following fifteen sulfide oxidation variants (pyrite, pyrrhotite, chalcopyrite, arsenopyrite, galena, sphalerite, chalcocite, covellite, bornite, argentite, acanthite, pyrargyrite and jamesonite) will be considered further with the successive exclusion of each of the minerals listed in parentheses. Wherever pyrargyrite and jemesonite (regardless of temperature) were present in the initial mineral association, the following mineral paragenesis was precipitated from solution under oxidation conditions: anglesite, fibroferrite and valentinite. The solutions exhibited the following Eh-pH parameters: Eh 1.11–1.19 V and pH 0.8–2.2. For the other variants, anglesite and fibroferrite were precipitated over the entire temperature range and the solution parameters were as follows: Eh 1.03–1.2 V and pH 0.7–3.5. The exclusion of galena from the initial association led to the disappearance of anglesite from the paragenesis of the precipitated minerals at the following solution parameters: Eh 1.11–1.17 V and pH 1.0–2.3.

The solutions contained the following aqueous species (coordination compounds and ions), see Fig. 4. Over the range of positive temperatures, the following species were absent in the solutions: Pb^{2+}, Ag^{2+}, $Pb(SO_4)_2^{2-}$ (which were present at negative temperatures), but Ag^{+} appeared. Similar to the previous case, the concentrations of most aqueous species in solutions decreased by an order of magnitude at positive temperatures compared to negative temperature conditions.

Over the range of negative temperatures, non-freezing aqueous solutions contained free, bound and vaporous water, as well as osmotically absorbed and capillary one [31–33]. The amount of water in the systems decreased along with decreasing temperature due to the increasing mass of crystallising ice, so concentrations of aqueous species could reach 900 g/l or even more.

Highly concentrated mine water has been entering surface water and groundwater around the clock for decades, as noted above. Therefore, to prevent their environmental impact, it is necessary to dilute them tens, hundreds, and even thousands of times, that is not the common case in nature. A study of river and underground (in wells) waters in the Far Eastern region [2, 3, 34] showed that they contained a wide range of sulfide ore elements in concentrations above the maximum permissible levels (both for fishery reservoirs and domestic waters) tens, hundreds, and even thousands of times, so their use as drinking water is unacceptable. For example, in the well waters in the villages of the Kavalerovsky district, the concentrations of elements are as follows (mg/l): Fe, 5.1–10.3, Cu, 0.09–1.5, Pb, 0.01–0.07, Zn, 0.3–17.2, As, 0.03–0.8, which are significantly higher than the corresponding permissible levels [35]. Both deficiencies and excesses of vital elements are well known to cause numerous diseases among people residing in mining districts [36, 37]. The toxic effects of elements on human health depend on: their chemical nature, the concentration and composition of their ions and compounds, as well as the individual characteristics of an organism [38], so it was important to establish the forms of migration of the elements under consideration.

It is well known that Pb is one of the strongest toxicants for living organisms, and its inorganic compounds, which contain Pb^{2+} ion, disrupt metabolism and act as enzyme inhibitors. Long-term consump-

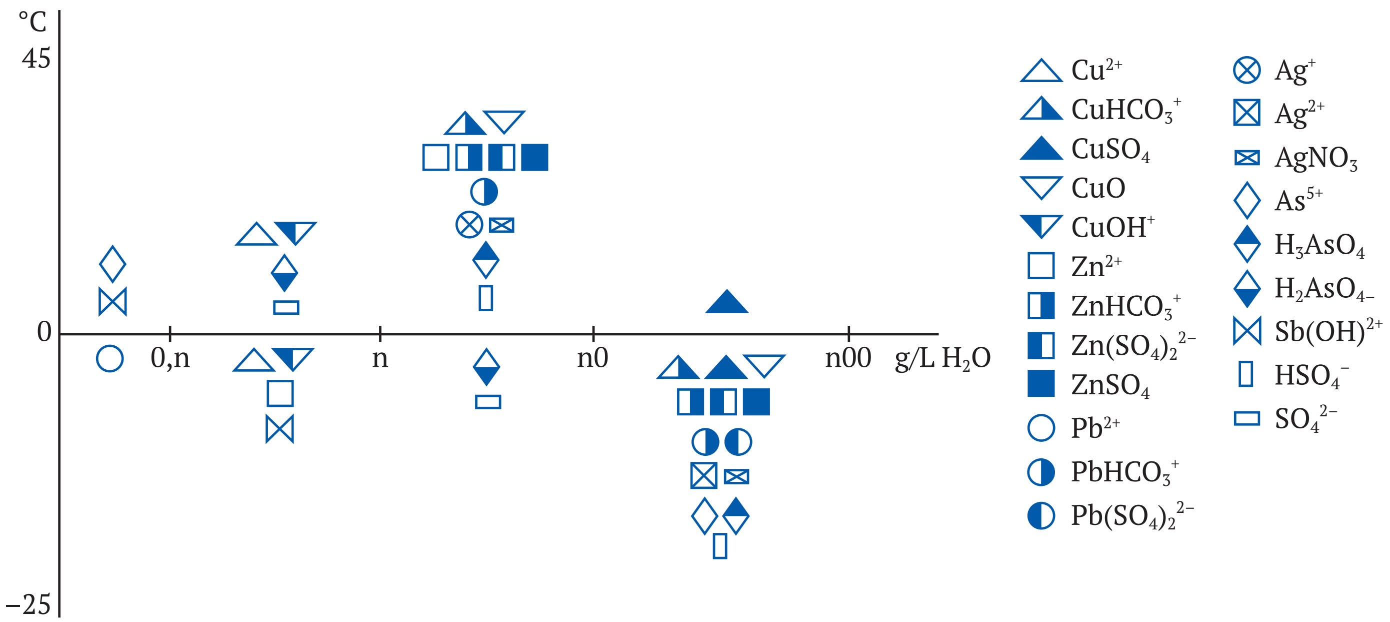

Fig. 4. Concentrations of aqueous species – speciation of elements of sulfide ores in micropore solutions forming mine water in the Dalnegorsky district (on the example of the Krasnorechenskoye deposit ores) (g/l H_2O)

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tion of Pb-containing water, even with low Pb concentration, is one of the causes of acute and chronic diseases. Zinc is an element that is necessary for humans and animals, but both a deficiency and an excess of it is harmful to living organisms. It migrates in six different forms, and at low temperatures Zn^{2+} form prevails, while with increasing temperature $ZnOH^{+}$ specie becomes dominant [39]. Cu compounds reacting with tissue proteins have a sharp irritating effect on the mucous membranes of an upper respiratory tract and gastrointestinal tract, and also cause acute poisoning. $CuSO_4$ ingestion is toxic for humans and causes nausea, vomiting, diarrhea, the rapid appearance of hemoglobin in the blood plasma and in the urine, jaundice, anemia, etc. Arsenic compounds act on a nervous system, the walls of blood vessels, cause an increase in permeability and paralysis of capillaries. Chronic exposure to As compounds leads to gastrointestinal disorders, lack of appetite, nausea, stomach pain, dyspepsia, recurrent enterocolitis, chronic hepatitis, and in severe cases, cirrhosis. Sulfur and its compounds are also highly toxic [36].

The author's analysis of the population morbidity in the period from 1991 to 2001 showed that the intensive morbidity rate in the Kavalerovsky district is steadily higher than in the Komsomolsky district. Among the most common diseases are: the digestive apparatus diseases, which affected up to 20 % of children and adults in the Komsomolsky district and up to 40 % and 70 %, respectively, in the Kavalerovsky district; respiratory diseases, which affected up to 20 % of children and 60 % of adults in the Komsomolsky district, and up to 20 % of children and 17 % of adults in the Kavalerovsky district; and diseases of nervous system, which affected up to 10 % of children and 10 % of adults in both Kavalerovsky and Komsomolsky districts. During the period under review, there was a trend towards a twofold increase in the morbidity rate for almost all types of disease in both adults and children, with the morbidity of the child population for almost all diseases being significantly higher than the morbidity rate for adults. It should be noted that during this period, due to “perestroika” in the country, the volumes of ore extraction and processing in the region decreased significantly, and the population decreased by 6 % in the Kavalerovsky district and by 18 % in the Komsomolsky district [15]. Intensive morbidity rates in the Kavalerovsky district are higher than in the Komsomolsky one. They are much higher or at the same level as compared to the Primorsky Krai as a whole for most of the diseases under consideration: digestive and respiratory organs, pancreas, nervous system, blood and hematopoietic organs, chronic bronchitis, allergic rhinitis, epilepsy, metabolic disorders, chronic rheumatic heart disease and acute myocardial infarction.

The results of analysis of biological material (hair of children under 14 in the village of Fabrichny, Kavalerovsky district) indicated that its content of heavy metal compounds exceeds such in other areas of Russia (Non-Black Earth Belt, Central Black Earth Zone, Crimea, etc.) by 1.8 or more [35]. The studies on the elemental status of children and adolescents residing in the Komsomolsky district made it possible to establish a correlation between the level of technogenic pollution of the natural environment and the changes in the elemental status of children and adolescents [40]. The authors found high levels of contamination in children and adolescents with heavy metals, including Pb, Cr, As, and calculated their individual and population carcinogenic risks (CR). The obtained value of individual carcinogenic risk $CR = 1{,}05 \cdot 10^{-3}$ belongs to the fourth range and is unacceptable neither for the population, nor for occupational groups.

Conclusion

The relationship between minerals and pollutants in the form of aqueous species (coordination compounds and ions) present in mine waters is a topical issue and a major problem in environmental mineralogy and geochemistry. The primary purpose of this type of research is to develop models that will be able to correlate the data obtained with macroscopic observations in the mine workings.

Minerals play a key role in controlling the mobility and spread of inorganic contaminants in the environment, including surface water and groundwater, because they are involved in the processes of alteration of primary phases (hypogenic) and the formation of secondary (hypergenic natural and technogenic ones).

The simulated micropore solutions that form mine waters are characterized by wide range of Eh–pH parameters: Eh from 0.55 to 1.24 V and pH from 0.3 to 13.8. From the solutions, technogenic minerals of Fe, Cu, Zn, Pb, and Sb, including oxides and hydroxides, sulfates, and arsenates precipitate. Mine waters of high concentration, prior to and after the precipitation of technogenic minerals, reaching up to hundreds of grams in weight, are released into the hydrosphere. The use of modern methods of analysis and thermodynamic simulation makes it possible, apart from assessing the elemental composition of waters and determining their chemical forms, to identify their potential transformation under changing physical conditions (temperature, etc.). The solutions obtained as a result of the simulation contain all the elements of sulfide ores: Cu, Zn, Pb, Fe, Ag, As, Sb, S, and their concentrations (in the form of aqueous species) reach tens of grams per liter, and under cryogenic conditions (at negative temperatures) they are one-two orders of magnitude higher due to ice formation. The forms of the elements migration depend on the temperature conditions.

It should be emphasized that this study involved thermodynamic simulation only. The simulation revealed thermodynamically equilibrium solution compositions and thermodynamically stable solid phases under the considered physicochemical conditions. In the case of real processes of hypergenesis at the considered deposits, at sufficiently low ambient temperatures, and, in particular, at negative temperatures, thermodynamic simulation provides only a rough estimation of the potential composition of solutions and precipitated phases. Under such conditions, the kinetics of mineral dissolution and precipitation reactions can play an extremely vital role. In this regard, the kinetic studies may constitute the subject of the subsequent stage of the study of hypergenic mineral formation, the identification of forms and paths of metal migration in the conditions of sulphide deposit development (in the considered and other mining districts).

Assaying hydrochemical samples of mine waters collected in the districts under consideration and the compositions of highly concentrated solutions obtained in the course of the simulation, which enter into surface water and groundwater prior and after precipitation of hypergenic minerals, showed the adverse impact of hypergenic natural and technogenic processes on the hydrosphere as a whole. Consumption of such waters by the local population has led to its high morbidity in the mining districts of the Far Eastern region.

It has been established that in the districts under consideration, there is a clear upward trend of the increasing morbidity (for practically all types of diseases) among both adults and children in two times compared to the other Far Eastern regions. Furthermore, the morbidity rate among the child population proved to be much higher than that among adults for practically all the diseases under consideration.

The application of simulation results makes it possible to assess the temporal evolution of water systems in the mining districts and may become a useful tool for monitoring and remediation activities.

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Nature of radioactivity of quarry drainage waters in the Novosibirsk region

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Abstract

This study is relevant for obtaining the first geochemical data (including information on radionuclides) on the drainage waters of developed and flooded quarries in the eastern areas of the Novosibirsk Region. The objective of the study was to identify the features of the chemical composition of drainage waters (a wide range of chemical elements from Li to U). The study was carried out by titrimetry, ion chromatography and mass spectrometry with inductively coupled plasma in a laboratory setting at the Hydrogeochemical Problem Research Laboratory (PNIL GGH) of the Engineering School of Natural Resources of Tomsk Polytechnic University (IShPR TPU). Measurements of ^{222}Rn in waters were carried out at the Alfarad Plus facility of the Laboratory of Siberian Sedimentary Basins Hydrogeology of the A.A. Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of the Russian Academy of Sciences (INGG SB RAS). The data were divided into homogeneous geochemical populations using the coefficients Ca/Na, Ca/Mg, Ca/Si, Mg/Si, Na/Si. The chemical composition of the studied objects was found to be highly diverse. The dominant waters have the chemical formula SO_4–HCO_3/Na–Mg–Ca with a TDS (total dissolved solids) of 400 to 700 mg/dm^3. Three geochemical groups of waters were identified. The first is represented by drainage waters of the developed rubble stone quarries, the second includes facilities of the Gorlovka coal basin, and the third refers to abandoned flooded quarries. The first group is characterized by oxidizing conditions with Eh varying over a wide range from +84.6 to +261.0 mV, pH from 6.9 to 8.6, and $O_{2dissolved}$ from 3.43 to 14.39 mg/dm^3. The radionuclide concentrations are (mg/dm^3): ^{238}U $9.30 \cdot 10^{-3}$ – 1,40; ^{232}Th $1,00 \cdot 10^{-6}$ – $2,16 \cdot 10^{-3}$; ^{222}Rn activity varies from 1 to 572.5 Bq/dm^3. The ^{232}Th/^{238}U ratio ranges from $4.20 \cdot 10^{-5}$ to $2.69 \cdot 10^{-3}$ with an average of $8.40 \cdot 10^{-4}$. The second group has a smaller Eh variation range of +133.2 to +199.6 mV, pH from 7.5 to 8.5, and $O_{2dissolved}$ from 6.81 to 10.43 mg/dm^3. The radionuclide concentrations vary in the following ranges (mg/dm^3): ^{238}U $2.26 \cdot 10^{-3}$ – $2.90 \cdot 10^{-2}$; ^{232}Th $7.5 \cdot 10^{-6}$ – $5.57 \cdot 10^{-4}$. The ^{232}Th/^{238}U ratio ranges from $8.37 \cdot 10^{-4}$ to $4.80 \cdot 10^{-2}$ at an average of $9.54 \cdot 10^{-3}$. The third group is also characterized by an oxidizingizing geochemical environment with Eh +131.3 – +250.0 mV, pH from 6.9 to 8.8 and $O_{2dissolved}$ from 4.00 to 16.59 mg/dm^3. The radionuclide concentrations are (mg/dm^3): ^{238}U $3.00 \cdot 10^{-4}$ – $2.74 \cdot 10^{-2}$; ^{232}Th $1.65 \cdot 10^{-6}$ – $1.15 \cdot 10^{-5}$; ^{222}Rn activity varies from 2 to 31 Bq/dm^3. The ^{232}Th/^{238}U ratio ranges from $2.36 \cdot 10^{-4}$ to $1.02 \cdot 10^{-3}$ at an average of $6.25 \cdot 10^{-4}$. Overall, the ^{232}Th/^{238}U ratio of the studied waters indicates their uranium nature of radioactivity. The data obtained indicate a slight impact of the drainage water discharge from the abandoned quarries on the environment.

Keywords

drainage waters, geochemistry, radionuclides, quarries, Novosibirsk Region, Western Siberia

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ТЕХНОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ В МИНЕРАЛЬНО-СЫРЬЕВОМ КОМПЛЕКСЕ И ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ

Научная статья

Природа радиоактивности дренажных вод карьеров Новосибирской области

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Аннотация

Актуальность исследования заключается в получении первых геохимических данных (включая информацию о радионуклидах) о дренажных водах разрабатываемых и затопленных карьеров в пределах восточных районов Новосибирской области. Целью исследования является выявление особенностей химического состава дренажных вод (широкого спектра химических элементов от Li до U). Лабораторное изучение химического состава методами титриметрии, ионной хроматографии, масс-спектрометрии с индуктивно связанной плазмой проводилось в Проблемной научно-исследовательской лаборатории гидрогеохимии (ПНИЛ ГГХ) Инженерной школы природных ресурсов Томского политехнического университета (ИШПР ТПУ). Измерение содержаний ^{222}Rn в водах проводилось на комплексе «Альфарад плюс» в лаборатории гидрогеологии осадочных бассейнов Сибири Института нефтегазовой геологии и геофизики им. А.А. Трофимука Сибирского отделения Российской академии наук (ИНГГ СО РАН). Разделение данных на однородные геохимические совокупности выполнено с помощью коэффициентов Ca/Na, Ca/Mg, Ca/Si, Mg/Si, Na/Si. Установлено, что химический состав изученных объектов весьма разнообразен. Доминируют воды SO_4–HCO_3 Na–Mg–Ca состава с величиной общей минерализации от 400 до 700 мг/дм^3. Выявлены три геохимические группы вод. Первая представлена дренажными водами разрабатываемых карьеров бутового камня, вторая включает в себя объекты Горловского угольного бассейна и третья – отработанные затопленные карьеры. Первая группа характеризуется окислительными параметрами геохимической среды с Eh, изменяющимся в широком диапазоне от +84,6 до +261,0 мВ, pH от 6,9 до 8,6 и $O_{2\,раств.}$ от 3,43 до 14,39 мг/дм^3. Содержания радионуклидов составляют (мг/дм^3): ^{238}U $9{,}30\cdot10^{-3}$ – 1,40; ^{232}Th $1{,}00\cdot10^{-6}$ – $2{,}16\cdot10^{-3}$; активность ^{222}Rn изменяется от 1 до 572,5 Бк/дм^3. Отношение ^{232}Th/^{238}U находится в диапазоне от $4{,}20\cdot10^{-5}$ до $2{,}69\cdot10^{-3}$ при среднем $8{,}40\cdot10^{-4}$. Вторая группа отличается меньшей вариацией Eh от +133,2 до +199,6 мВ, pH от 7,5 до 8,5 и $O_{2раств.}$ от 6,81 до 10,43 мг/дм^3. Концентрации радионуклидов изменяются (мг/дм^3): ^{238}U $2{,}26\cdot10^{-3}$ – $2{,}90\cdot10^{-2}$; ^{232}Th $7{,}15\cdot10^{-6}$ – $5{,}57\cdot10^{-4}$. Отношение ^{232}Th/^{238}U находится в диапазоне от $8{,}37\cdot10^{-4}$ до $4{,}80\cdot10^{-2}$ при среднем $9{,}54\cdot10^{-3}$. Третья группа также характеризуется окислительной геохимической обстановкой с Eh +131,3– +250,0 мВ, pH от 6,9 до 8,8 и $O_{2раств.}$ от 4,00 до 16,59 мг/дм^3. Содержания радионуклидов составляют (мг/дм^3): ^{238}U $3{,}00\cdot10^{-4}$ – $2{,}74\cdot10^{-2}$; ^{232}Th $1{,}65\cdot10^{-6}$ – $1{,}15\cdot10^{-5}$; активность ^{222}Rn изменяется от 2 до 31 Бк/дм^3. Отношение ^{232}Th/^{238}U находится в диапазоне от $2{,}36\cdot10^{-4}$ до $1{,}02\cdot10^{-3}$ при среднем $6{,}25\cdot10^{-4}$. В целом ^{232}Th/^{238}U отношение изученных вод свидетельствует об их урановой природе радиоактивности. Полученные данные говорят о незначительном влиянии сброса дренажных вод разрабатываемых месторождений полезных ископаемых на окружающую среду.

Ключевые слова

дренажные воды, геохимия, радионуклиды, карьеры, Новосибирская область, Западная Сибирь

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Для цитирования

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Introduction

Novosibirsk is the only major city in Russia in the vicinity of which the Prigorodnoye uranium deposit has been discovered, therefore making the presence of radionuclides in its local waters a rather natural phenomenon. The elevated radionuclide concentrations are due to the presence of scattered radioactive minerals in the granitoids of the large Novosibirsk massif. In the 1980s and 1990s, more than ten deposits of radon water were discovered in the Novosibirsk Region that were used for medicinal purposes (the most famous were the Zaeltsovsky Bor sanatorium, Gorvodolechenitsa, and the Khimkoncentraty plant dispensary). The deposits were practically not described in scientific literature until the 2010s [1–3].

The majority of studies in world scientific literatureis devoted to research on geological [4–6], hydrogeological [7, 8], and geochemical [9–11] factors affecting the distribution of natural radionuclides in waters of various isotopic-hydrogeochemical compositions. In Russia, research work to study various aspects of the radiochemistry of natural waters and simulation of geological processes in aquatic environments has been going on for a long time. Some of the latest works in this area are notably the studies on the geochemistry of bottom sediments [12, 13], the techniques for extracting radionuclides from natural waters [14, 15], the geochemical features of different types of natural waters [16–18] and their isotopic composition [19–22], and issues related to mineral deposit development [23, 24].

The situation with studies conducted on the na-tural waters of the Novosibirsk Region has begun to change for the better in recent years. This is largely associated with the work of the Laboratory of Hydrogeology of Siberian Sedimentary Basins of the INGG SB RAS on studying the hydrogeological conditions of radon water deposits [25], their isotopic and geochemical features [26], their composition formation mechanisms [27], and radionuclide monitoring [28]. Exhausted and flooded quarries (for excavating building crushed stone, coal, marble, sand) are of special importance in these studies. There has been significant attention paid to studying a wide range of chemical elements (from Li to U) in connection with the development of hydrogeochemical prospecting. An important factor here is assessing the environmental impact of drainage water discharge, primarily its radioactive hazard, which was performed in this study.

Research Method and Subject

pH, Eh, temperature, and the dissolved O_2, HCO_3^- concentrations were determined using special apparatus (Hanna HI9125, AKPM-1-02L oxygen meter) directly at the facilities and at a field hydrogeochemical laboratory. Measurements of the ^{222}Rn concentration in the waters were carried out at the Alfarad Plus facility of the Laboratory of Siberian Sedimentary Basins Hydrogeology of INGG SB RAS. The subsequent study of the chemical composition of 31 water samples by titrimetry, ion chromatography and inductively coupled plasma (ICP) mass spectrometry was carried out at the PNIL Instituteof Hydrogeochemistry of IShPR TPU (analysts O.V. Chebotarev, N.V. Bublii, A.S. Pogutsa, V.V. Kurovskaya, K.B. Krivtsova, L.A. Rakul).

The designation of the chemical type is given according to S.A. Shchukarev's classification (macrocomponents of concentrations >10%-eq are added to the formula) according to the hue principle from smallest to largest.

The division of data into homogeneous geochemical sets according to the composition formation processes with an assessment of their manifestation intensity was carried out based on the ratio of chemical elements in the waters. The coefficients Ca/Na, Ca/Mg, Ca/Si, Mg/Si, Na/Si were used to assess the characteristics of water enrichment due to the hydrolysis of aluminosilicates and the congruent dissolution of carbonates; $SO_4/Cl >> 1$ and $rNa/rCl >> 1$ – hydrolysis of aluminosilicates and oxidation of sulfide minerals; proportional increase in $SO_4/Cl = 1$, $rNa/rCl \geqslant 1$, $Ca/Na > 0$ – evaporative concentration.

Hydrogeological Structure

The studied quarries are distributed over a large territory, with the distance between the most remote facilities exceeding 200 km. The studied facilities include both active and mined out, currently flooded. The list of the studied ones is dominated by granite quarries. Coal, sand and one marble quarry were also considered. The most numerous granite quarry group is represented by the currently-operating Borok, Novobibeyevsky, Skalinsky; and the flooded Tulinsky, Kamensky and Gorsky. The group of operating quarries of the Gorlovka coal basin (Urgunsky, Gorlovka, and Kolyvansky) is located in the Iskitimsky district of the Novosibirsk Region. Sand quarries are represented by the flooded Kirov and Podgorny. The marble quarry group includes one facility – the Abrashinsky quarry in the Ordynsky district of the Novosibirsk Region. Overall, the studied quarries have similar hydrogeological conditions. There are two distinct hydrogeological complexes: the upper one is a Cenozoic-age sedimentary cover and the lower one consists of consolidated rocks of a Paleozoic foundation broken through by late Paleozoic granitoid intrusions. Cenozoic sediments are typically represented by alluvial sediments of the Ob River and its tributaries of various orders, as well as rocks of the Kochkovskaya (Q_{EI} $k\check{c}_1$) and Krasnodubrovskaya (*sa* $Q_{I\text{-}II}$ *kd*) suites.

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We starts our analysis with the most representative granite quarry group. It is important to note that they are located within various granitoid massifs. Thus, the Borok, Tulinsky, Kamensky and Gorsky quarries extract granites of the Novosibirsk granitoid massif and Novobibeyevsky of the Ob massif. Both these massifs belong to the Priobsky monzodiorite-granosyenite-granitic mesoabyssal complex (P_3–T_1p). The Skalinsky quarry extracts granites from the Kolyvansky granitoid massif that belongs to the Barlak granite-leucogranite mesoabyssal complex (T_{1-2}b) [29].

The Ob massif is petrotypic. The first intrusion phase has a very limited distribution and is not considered in this work. The second and main phase is composed of biotite and hornblende-biotite monzogranite, less often granosienite, granite and granodio-

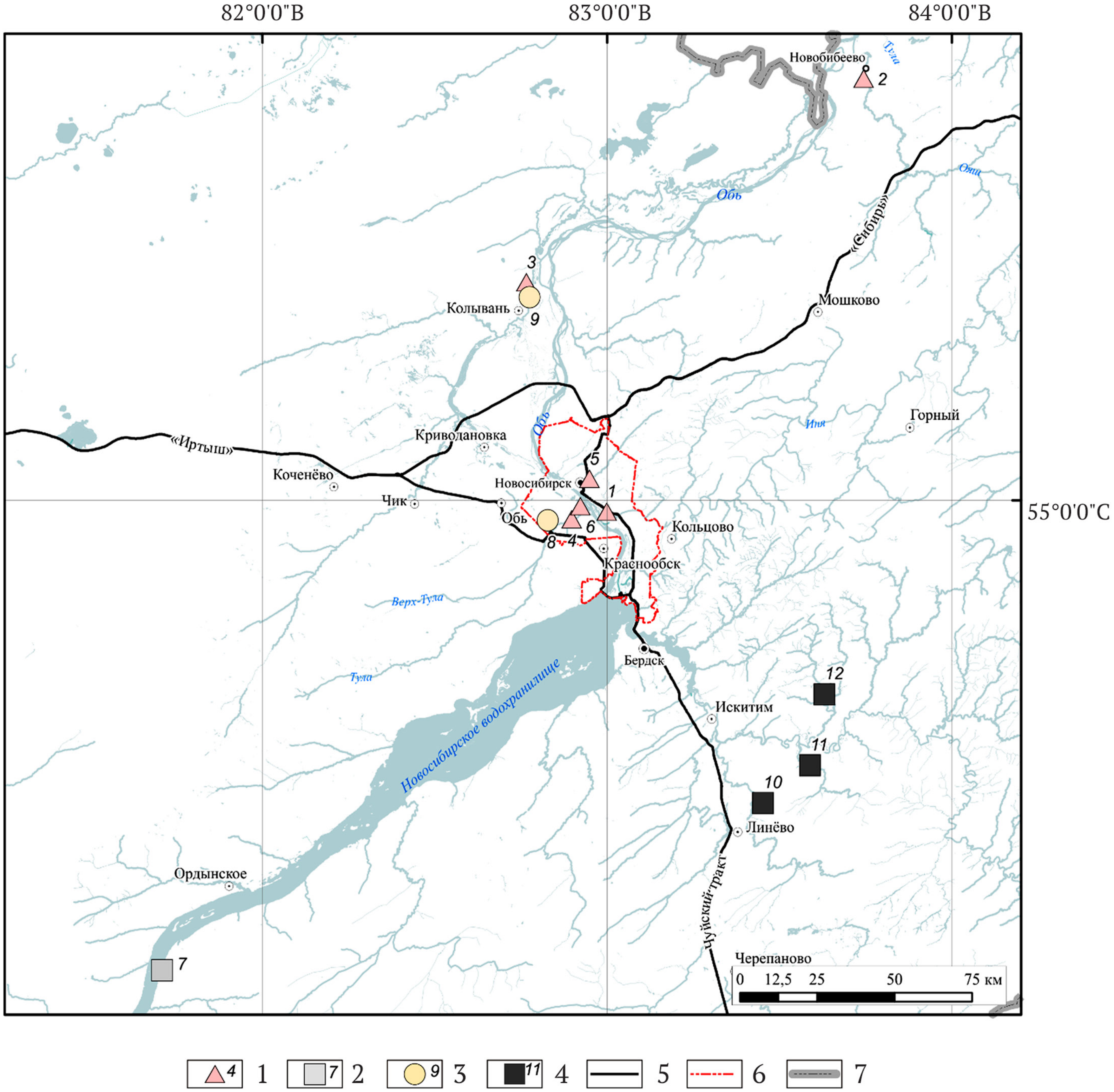

Fig. 1. Location of the studied quarries
1–4 – quarries: *1* – granite; *2* – marble; *3* – sandy; *4* – coal; *5* – federal highways; *6* – Novosibirsk Region border; *7* – Novosibirsk Region border; *1–3, 10–12* – operating: *1* – Borok; *2* – Novobibeyevsky; *3* – Skalinsky; *4–9* – flooded: *4* – Tulinsky; *5* – Kamensky; *6* – Gorsky; *7* – Abrashinsky; *8* – Kirovsky; *9* – Podgorny; *10* – Urgunsky; *11* – Gorlovka; *12* – Kolyvansky

rite. Moderately felsic granitoids gravitate to the endocontact zones of the massif. The third phase includes rare dykes of fine-grained monzogranite, monzoleucogranite, monzogranite porphyry, monzoleucogranite porphyry, and veins of aplite and pegmatite. In the Novobibeyevsky quarry and the bedrock outcrops along the bank of the Ob River, large and small xenoliths of quartz monzodiorite and quartz diorite in granite were identified. The Novosibirsk massif also includes the second and third phases. The second one is represented by hornblende-biotite monzogranite, granosyenite, normally alkaline granite and granodiorite. The rocks contain green hornblende and brown biotite. The biotite ferruginosity is 40–55 [30].

The list of accessory minerals includes sphene, zircon, apatite, magnetite, ilmenite and fluorite [29]. The third phase is represented by small bodies of inclined stocks of the north-eastern extension and dykes up to 15 m thick. The composition of the stocks is represented by monzogranite-porphyry and the dykes by monzogranite-porphyry, fine-grained monzoleucogranite, quartz monzodiorite-porphyry and spessartite. The monzogranite-porphyry has a similar composition to the fine-grained monzoleucogranite, and the porphyric inclusions are composed of feldspar. The content of quartz and K-Na feldspar is higher in the monzoleucogranite than in the monzogranite, while the Ca-Na-plagioclase content is respectively lower. The Borok quarry is located in the contact zone of the Novosibirsk massif. Here, the contact is sharp, dipping towards the host rocks, and is often represented by veins and leucogranite and aplite dykes.

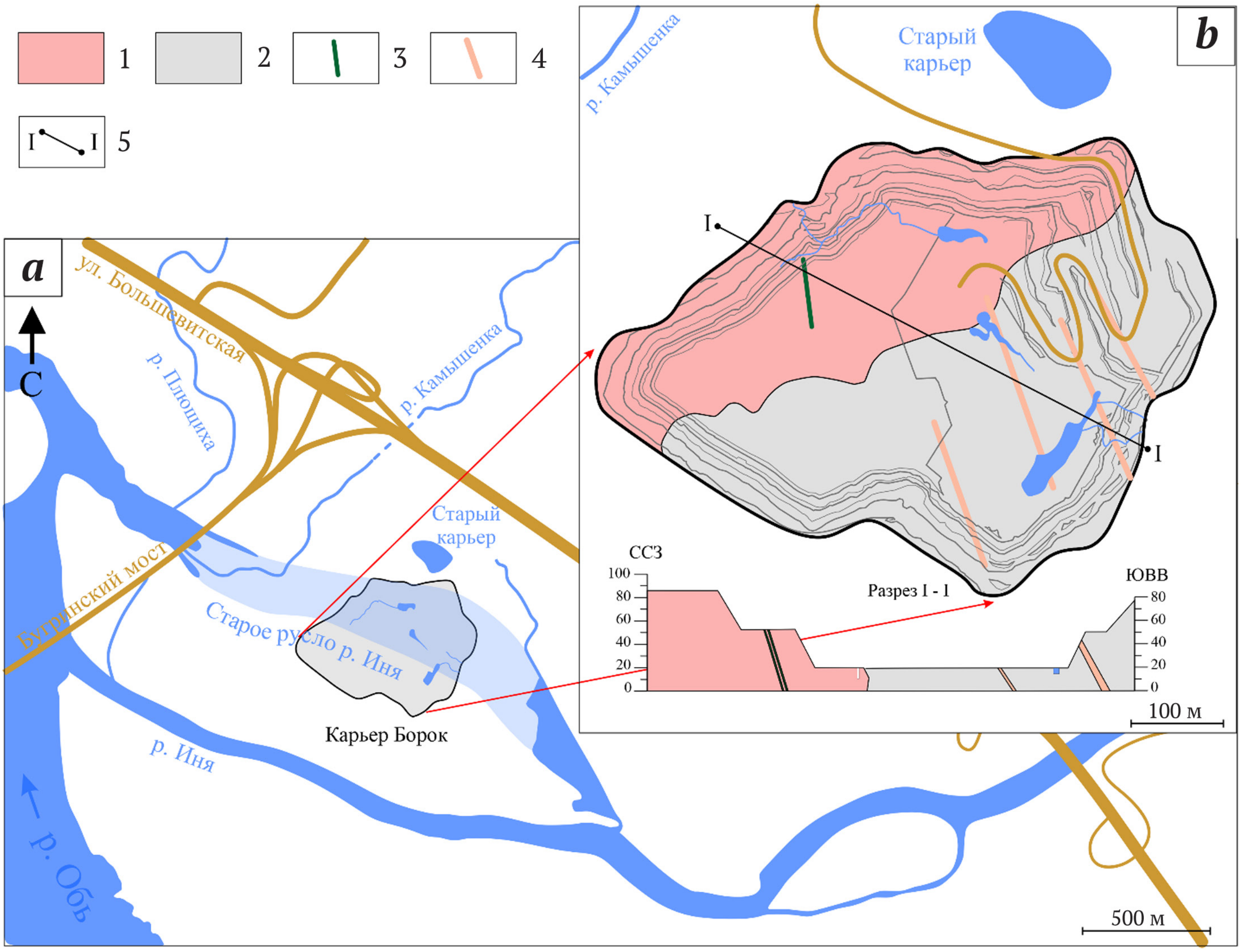

Fig. 2. Borok quarry location (*a*) and geological structure schematics (*b*):
1 – granitoids; *2* – hornfels; *3* – lamprophyre; *4* – granodiorite; *5* – cross-section line

The host rocks are represented by sandy-clayey shales of the Upper Devonian Pacha Formation that were transformed into hornfels by contact metamorphism. The Kolyvansky massif is composed of medium-grained granitoids that are predominated by monzoleucogranite. Second-phase rocks are represented by fine-grained monzoleucogranite dykes up to 3 m thick of a sublatitudinal/NE-SW strike. Pegmatite veins, lenses and nodes are observed

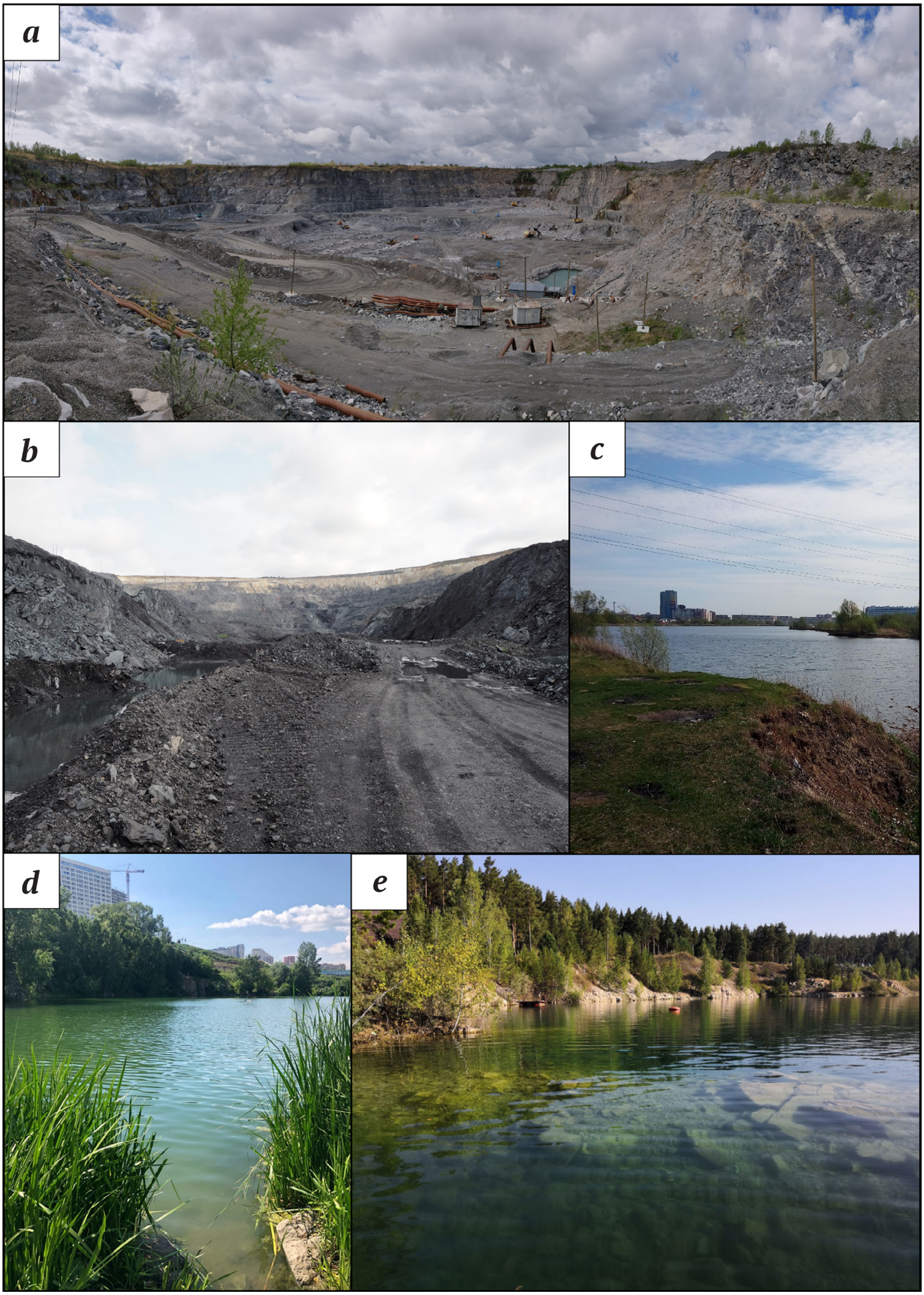

Fig. 3. Studied facilities. Quarries: Borok (*a*); Kolyvansky (*b*); Kirovsky (*c*); Gorsky (*d*); Abrashinskiy (*e*)

The studied coal quarries correspond to the similar-named deposits located within the Gorlovka coal basin. The latter has a highly complex geological structure, and is a narrow (4–8 km) graben-syncline that is elongated from northwest to southeast and sandwiched between the Kolyvan-Tomsk folded zone in the northwest and the Salair Ridge in the east. This basin is characterized by a single waterlogged fractured zone in sedimentary-terrigenous Upper Paleozoic rocks: medium- and fine-grained coal-bearing sandstone, siltstone, mudstone, carbonaceous mudstone and coal seams.

The studied construction sand quarries are characterized by a different position relative to granitoid massifs: the Podgorny quarry is located in the inner part of the Kolyvansky granitoid massif, while the Kirovsky sand quarry is located in the exocontact zone of the Novosibirsk granitoid massif. The latter was focused on the extraction of fine-grained sands from alluvial deposits of the second terrace above the Ob River floodplain. In the Podgorny quarry, sands were excavated from the sediments of the first terrace above the Ob River floodplain.

The Abrashinsky marble quarry is located within Bugotagsky suite (D_2*bg*). In addition to effusive, volcanogenic-sedimentary, and sedimentary rocks, as well as subvolcanic formations, this stratigraphic unit includes layers of marbled limestone. This geological situation therefore suggests that the formation of the Abrashinsky deposit marble occurred due to the impact of a magmatic body on the limestone of the Bugotagsky suite. Such a plutonic body could be a gabbro-dolerite stock, located no further than 3 km west of the quarry. The quarry is also located within a tectonic block, so metamorphosed rocks and a heat source could be spaced along the tectonic boundary.

Geochemical Features

Analysis of available data on drainage water composition allowed identifying three geochemical populations based on coefficients (Ca/Na, Ca/Mg, Ca/Si, Mg/Si, Na/Si, Si/Na, rNa/rCl и SO_4/Cl). The first one includes drainage waters of the developed granite quarries (Novobibeyevsky, Skalinsky, Borok). They have the following coefficient values: Ca/Si 17.61; Mg/Si 4.17; Na/Si 6.73; Mg/Na 4.17; Si/Na 0.25; Ca/Na 2.84; Ca/Mg 4.23; rNa/rCl 5.24; SO_4/Cl 9.14. The second population is represented by the waters of coal quarries (Urgunsky, Gorsky, Kolyvansky). They differ from the first in the increased ratios of Ca/Si 21.49; Mg/Si 9.78; Na/Si 14.89; Mg/Na 9.78; rNa/rCl 7.38; SO_4/Cl 24.91 and decreased Si/Na 0.10; Ca/Na 2.36; Ca/Mg 2.26. The third population includes the flooded quarry waters (granite: Gorsky, Tulinsky; sandy: Kirovsky, Podgorny; marble: Abrashinsky), which differ from the Gorlovka coal basin facilities in terms of their geochemical coefficients by increased Ca/Si 95.84; Mg/Si 51.02; Na/Si 58.82; Mg/Na 50.58; Ca/Mg 3.88 and decreased Si/Na 0.05; Ca/Na 1.75; rNa/rCl 1.77; SO_4/Cl 1.79. The waters of the flooded quarries compared to the first population are characterized by increased ratios of Ca/Si 95.84; Mg/Si 51.02; Na/Si 58.82; Mg/Na 50.58 and decreased Ca/Mg 3.88; Si/Na 0.05; Ca/Na 1.75; rNa/rCl 1.77; SO_4/Cl 1.79.

In this study, drainage waters of the Borok, Kamensky, Tulinsky and Gorsky quarries located within the Novosibirsk Region (similar-named massif) were analyzed. The *Borok* quarry waters are characterized by SO_4–HCO_3 Na–Mg–Ca, Cl–SO_4–HCO_3 Mg–Na–Ca and Cl–SO_4–HCO_3 Na–Mg–Ca compositions (Fig. 4, Table 1) with a total salinity of 583–697 mg/dm^3 and a silicon concentration of 0,89–10,53 mg/dm^3. The geochemical parameters of the geological environment correspond to the oxidizing conditions with Eh +150,2 – +261,0 mV, pH 7,6–8,5 and $O_{2dissolved}$ 3.43–11.43 mg/dm^3. The average values of the geochemical coefficients (ratios) are as follows: Ca/Si 23.54; Mg/Si 5.32; Na/Si 9.64; Mg/Na 0.53; Si/Na 1.15; Ca/Na 2.34; Ca/Mg 4.49; rNa/rCl 2.67; SO_4/Cl 3.63 (Figure 5).

Kamensky quarry waters are characterised by SO_4–Cl–HCO_3/Ca–Na composition with a total salinity of 166–349 mg/dm^3 and a silicon concentration of 1.87–4.21 mg/dm^3. The waters are characterized by a slightly alkaline pH of 7.6–8.5 and an $O_{2dissolved}$ concentration of 4.00 mg/dm^3. The average geochemical coefficients are increased in Ca/Mg (8.68) and decreased in Mg/Na (0.24); Ca/Na (1.52); rNa/rCl (1.19); SO_4/Cl (0.76). *Tulinsky* quarry waters are haracterised by Cl–SO_4–HCO_3/Na–Ca–Mg and SO_4–Cl–HCO_3/Ca–Mg–Na composition with a total salinity of 454–541 mg/dm^3 and a silicon concentration of 0.32–0.78 mg/dm^3. The geological environment geochemical parameters correspond to oxidizingizing conditions with Eh +131.3 – +250.0 mV, pH 8.7–8.8 and $O_{2dissolved}$ 8.58–11.30 mg/dm^3. The average geochemical coefficients are as follows: Ca/Si, 88.39; Mg/Si, 60.92; Na/Si, 103.45; Mg/Na, 0.66; Si/Na, 0.01; Ca/Na, 0.92; Ca/Mg, 1.43; rNa/rCl, 2.06; SO_4/Cl, 1.51. *Gorsky* quarry waters are characterized by a Cl–SO_4–HCO_3/Na–Mg–Ca and SO_4–Cl–HCO_3/Na–Mg–Ca composition with a total salinity of 403 mg/dm^3 and a silicon concentration of 0.25–0.40 mg/dm^3. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +139.3 – +250.0 mV, pH 8.5–8.7 and $O_{2dissolved}$ 8.20–16.59 mg/dm^3. The average geochemical coefficients are increased for Ca/Si, 154.83; Mg/Si, 81.38; Mg/Na, 1.13; Ca/Na, 2.17; Ca/Mg, 1.91, and decreased for Na/Si, 74.32; rNa/rCl, 1.05; SO_4/Cl, 1.33, while comparable values are characteristic for Si/Na (0.02). Overall, the values of the geochemical coefficients for all quarries are characteristic of sulfide oxidation, which is pronounced in the values of the ratios SO_4/Cl (0.67–11.51) and rNa/rCl (0.53–9.19).

Novobibeyevsky quarry waters drain the Ob massif granitoids and are characterized by a SO_4–HCO_3/Na–Mg–Ca composition with a total a salinity of 385–461 mg/dm^3 and a silicon concentration of 5.02–9.60 mg/dm^3. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +107.8 – +145.6 mV, pH 7.8–8.6 and $O_{2dissolved}$ 6.50–14.38 mg/dm^3. The averaged geochemical coefficients are as follows: Ca/Si, 9.55; Mg/Si, 3.07; Na/Si, 2.97; Mg/Na, 1.08; Si/Na, 0.39; Ca/Na, 3.51; Ca/Mg, 3.33; rNa/rCl, 9.46; SO_4/Cl, 11.49. *Skalinsky* quarry waters correlate with the Barlak granite-leucogranite mesoabyssal complex. They belong to the chemical types HCO_3–SO_4/Na–Mg–Ca and SO_4–HCO_3/Na–Mg–Ca with a total salinity of 279–787 mg/dm^3 and a silicon concentration of 8.22–10.21 mg/dm^3. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +84.6 – +167.0 mV, pH 6.9–7.0 and

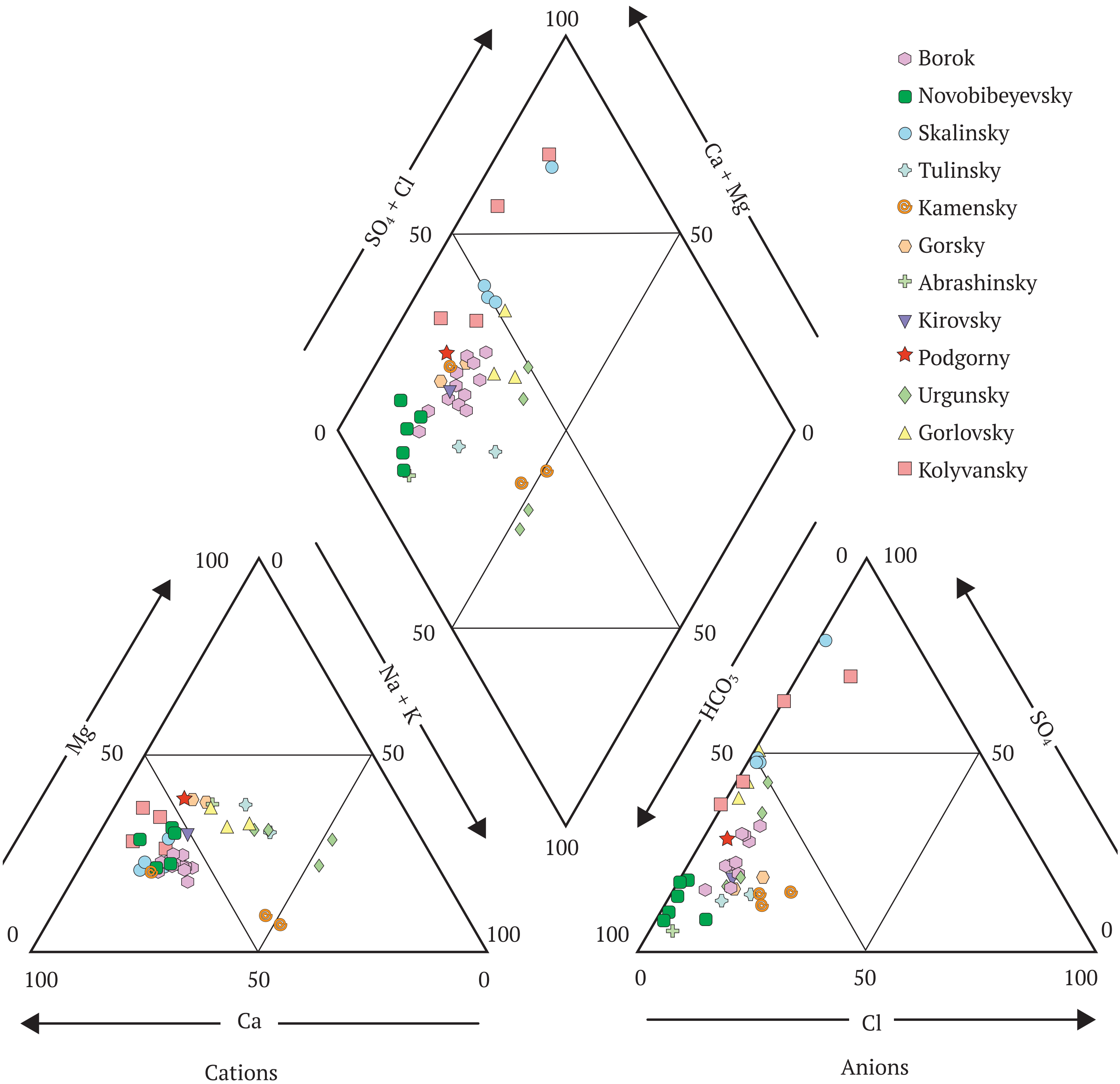

Fig. 4. Drainage water chemistry Piper diagram

Table 1

Chemical composition of drainage waters of the Novosibirsk Region quarries

No. in Fig. 1	pH	Eh, mV	O_2, mg/dm³	^{222}Rn, Bq/dm³	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	M	Si	Th	U	Th/U	Chemical type
					mg/dm³												
1	8.3	261.0	9.30	17	378	96	38	101	22	50	4.2	697	6.98	$5.10 \cdot 10^{-5}$	$9.26 \cdot 10^{-2}$	$5.51 \cdot 10^{-4}$	$Cl–SO_4–HCO_3$ Mg–Na–Ca
1	8.1	225.0	10.58	19	371	107	32	109	25	41	4.0	696	0.89	$1.24 \cdot 10^{-5}$	$1.08 \cdot 10^{-2}$	$1.15 \cdot 10^{-3}$	$SO_4–HCO_3$ Na–Mg–Ca
1	8.3	256.3	10.90	4	378	90	34	102	19	54	3.9	687	7.07	$9.90 \cdot 10^{-6}$	$8.00 \cdot 10^{-2}$	$1.24 \cdot 10^{-4}$	$Cl–SO_4–HCO_3$ Mg–Na–Ca
1	8.3	246.5	11.21	1	348	82	28	90	21	45	3.6	619	6.70	$5.40 \cdot 10^{-6}$	$2.96 \cdot 10^{-2}$	$1.82 \cdot 10^{-4}$	$SO_4–HCO_3$ Mg–Na–Ca
1	8.3	244.7	11.43	8	388	58	25	99	22	35	2.7	630	5.96	$6.50 \cdot 10^{-6}$	$9.30 \cdot 10^{-3}$	$6.99 \cdot 10^{-4}$	$SO_4–HCO_3$ Na–Mg–Ca
1	8.5	215.8	11.10	16	386	61	5	95	18	32	5.0	603	5.03	$1.00 \cdot 10^{-6}$	$1.03 \cdot 10^{-2}$	$9.71 \cdot 10^{-5}$	$SO_4–HCO_3$ Na–Mg–Ca
1	7.6	194.3	3.61	45	319	111	36	97	26	44	4.7	660	7.74	$1.39 \cdot 10^{-5}$	1.16E-01	$1.20 \cdot 10^{-4}$	$Cl–SO_4–HCO_3$ Na–Mg–Ca
1	8.2	195.1	8.55	38	308	113	29	94	24	37	3.9	619	6.70	–	$1.19 \cdot 10^{-2}$	–	$SO_4–HCO_3$ Na–Mg–Ca
1	7.6	184.7	3.43	88	320	118	28	95	22	50	6.2	663	10.53	$5.48 \cdot 10^{-5}$	$2.13 \cdot 10^{-1}$	$2.57 \cdot 10^{-4}$	$SO_4–HCO_3$ Mg–Na–Ca
1	8.2	209.7	8.98	89	331	56	37	89	21	36	4.7	583	4.85	$1.54 \cdot 10^{-5}$	$1.03 \cdot 10^{-2}$	$1.49 \cdot 10^{-3}$	$Cl–SO_4–HCO_3$ Na–Mg–Ca
1	7.9	201.7	7.52	51	352	77	41	101	22	41	4.5	652	6.56	$9.62 \cdot 10^{-5}$	$9.15 \cdot 10^{-2}$	$1.05 \cdot 10^{-3}$	$Cl–SO_4–HCO_3$ Na–Mg–Ca
1	8.0	150.2	7.11	57	272	116	34	91	21	43	3.9	605	7.11	$4.62 \cdot 10^{-5}$	$7.95 \cdot 10^{-2}$	$5.81 \cdot 10^{-4}$	$Cl–SO_4–HCO_3$ Mg–Na–Ca
2	7.8	107.8	6.49	25	224	20	3	55	15	20	3.3	385	7.00	$2.60 \cdot 10^{-6}$	$1.07 \cdot 10^{-2}$	$2.43 \cdot 10^{-4}$	$SO_4–HCO_3$ Na–Mg–Ca
2	8.0	111.0	7.91	15	248	28	3	65	16	20	3.0	434	6.49	–	$1.02 \cdot 10^{-2}$	–	$SO_4–HCO_3$ Na–Mg–Ca
2	8.6	121.7	14.39	6	232	48	3	58	22	20	2.3	433	5.02	$1.76 \cdot 10^{-5}$	$1.02 \cdot 10^{-2}$	$1.72 \cdot 10^{-3}$	$SO_4–HCO_3$ Na–Mg–Ca
2	7.9	139.7	7.88	39	256	40	3	62	25	20	2.9	461	5.72	$2.90 \cdot 10^{-5}$	$1.08 \cdot 10^{-2}$	$2.69 \cdot 10^{-3}$	$SO_4–HCO_3$ Na–Mg–Ca
2	8.1	145.6	7.44	2	268	43	3	72	20	13	4.5	423	9.60	$3.10 \cdot 10^{-5}$	$1.16 \cdot 10^{-2}$	$2.67 \cdot 10^{-3}$	$SO_4–HCO_3$ Mg–Ca
3	6.9	84.6	4.58	573	67.1	215	6	120	22	29	5.1	787	8.34	$2.96 \cdot 10^{-4}$	1.40	$2.12 \cdot 10^{-4}$	$HCO_3–SO_4$ Na–Mg–Ca
3	6.9	153.6	4.60	495	140	106	7	105	22	27	4.1	773	8.22	$3.93 \cdot 10^{-5}$	$9.38 \cdot 10^{-1}$	$4.20 \cdot 10^{-5}$	$SO_4–HCO_3$ Na–Mg–Ca
3	7.0	167.0	4.49	154	98	73	4	63	19	20	4.5	282	10.21	$3.90 \cdot 10^{-4}$	1.16	$3.35 \cdot 10^{-4}$	$HCO_3–SO_4$ Na–Mg–Ca
3	7.0	164.5	3.75	259	98	77	4	62	13	21	4.5	279	9.96	$2.16 \cdot 10^{-3}$	1.21	$1.78 \cdot 10^{-3}$	$SO_4–HCO_3$ Na–Mg–Ca
4	8.8	250.0	11.30	2	325	53	31	46	35	43	7.8	541	0.78	$3.20 \cdot 10^{-6}$	$1.21 \cdot 10^{-2}$	$2.64 \cdot 10^{-4}$	$Cl–SO_4–HCO_3$ Na–Ca–Mg
4	8.7	131.3	8.58	–	244	49	38	37	24	48	8.6	454	0.32	$7.08 \cdot 10^{-6}$	$1.23 \cdot 10^{-2}$	$5.77 \cdot 10^{-4}$	$SO_4–Cl–HCO_3$ Ca–Mg–Na
5	7.5	–	–	–	109	18	20	–	–	–	–	166	3.27	–	–	–	–
5	6.9	–	4.00	–	183	24	36	59	11	19		349	4.21	–	–	–	$SO_4–Cl–HCO_3$ Na–Mg–Ca
5		–	–	–	146	28	39	35	3	51		316	1.87	–	–	–	$SO_4–Cl–HCO_3$ Ca–Na
5	7.5	–	–	–	109	18	20	27	3	35		231	3.27	–	–	–	$SO_4–Cl–HCO_3$ Ca–Na
5		–	–	–	146	28	39					228	1.87	–	–	–	–
6	8.7	250.0	16.59	–	239	40	29	48	24	20	3.7	403	0.40	$1.00 \cdot 10^{-5}$	$9.80 \cdot 10^{-3}$	$1.02 \cdot 10^{-3}$	$Cl–SO_4–HCO_3$ Na–Mg–Ca
6	8.5	139.3	8.21	–	207	47	37	48	26	25	4.5	403	0.25	$1.15 \cdot 10^{-5}$	$1.24 \cdot 10^{-2}$	$9.30 \cdot 10^{-4}$	$SO_4–Cl–HCO_3$ Na–Mg–Ca
7	8.6	144.0	5.42	31	239	16	8	36	22	22	1.4	353	0.29	$1.65 \cdot 10^{-6}$	$2.28 \cdot 10^{-3}$	$7.24 \cdot 10^{-4}$	HCO_3 Na–Ca–Mg
8	8.7	205.0	15.50	2	449	107	45	100	41	45	2.0	789	1.29	–	$3.00 \cdot 10^{-4}$	–	$Cl–SO_4–HCO_3$ Na–Mg–Ca
9	8.4	186.5	9.34	–	177	59	11	42	21	15	3.2	330	0.18	$6.47 \cdot 10^{-6}$	$2.74 \cdot 10^{-2}$	$2.36 \cdot 10^{-4}$	$SO_4–HCO_3$ Na–Mg–Ca
10	8.3	145.6	7.70	–	561	96	57	65	33	158	2.5	973	6.55	$1.92 \cdot 10^{-5}$	$5.97 \cdot 10^{-3}$	$3.22 \cdot 10^{-3}$	$Cl–SO_4–HCO_3$ Mg–Ca–Na
10	8.2	160.4	8.16	–	378	186	44	72	42	97	3.9	823	3.68	$1.40 \cdot 10^{-5}$	$1.67 \cdot 10^{-2}$	$8.37 \cdot 10^{-4}$	$Cl–SO_4–HCO_3$ Mg–Ca–Na
10	7.5	148.8	6.81	–	360	240	36	83	43	94	4.4	860	5.24	$3.78 \cdot 10^{-5}$	$1.30 \cdot 10^{-2}$	$2.91 \cdot 10^{-3}$	$SO_4–HCO_3$ Mg–Na–Ca
10	8.5	133.2	8.26	–	344	71	43	32	28	102	2.5	625	6.59	$2.68 \cdot 10^{-5}$	$7.86 \cdot 10^{-3}$	$3.41 \cdot 10^{-3}$	$Cl–SO_4–HCO_3$ Ca–Mg–Na
11	8.1	174.7	8.58	–	315	289	4	90	53	54	2.9	808	4.15	$7.15 \cdot 10^{-6}$	$3.41 \cdot 10^{-3}$	$2.10 \cdot 10^{-3}$	$HCO_3–SO_4$ Na–Mg–Ca
11	7.7	185.2	7.44	–	421	243	12	96	51	77	3.2	907	4.19	$1.59 \cdot 10^{-5}$	$2.26 \cdot 10^{-3}$	$7.02 \cdot 10^{-3}$	$SO_4–HCO_3$ Na–Mg–Ca
11	7.8	190.4	7.61	–	414	285	11	88	54	94	4.4	950	4.15	$4.68 \cdot 10^{-5}$	$4.02 \cdot 10^{-3}$	$1.17 \cdot 10^{-2}$	$SO_4–HCO_3$ Na–Ca–Mg
12	7.8	190.7	7.65	–	302	182	9	104	28	36	3.0	673	5.25	–	$9.16 \cdot 10^{-3}$	–	$SO_4–HCO_3$ Na–Mg–Ca
12	7.5	198.8	8.40	–	153	456	65	150	56	40	1.7	922	4.62	$5.57 \cdot 10^{-4}$	$1.16 \cdot 10^{-2}$	$4.80 \cdot 10^{-2}$	$Cl–HCO_3–SO_4$ Na–Mg–Ca
12	8.0	194.8	10.43	–	257	118	2	84	22	13	3.3	500	3.80	$9.32 \cdot 10^{-6}$	$1.11 \cdot 10^{-2}$	$8.39 \cdot 10^{-4}$	$SO_4–HCO_3$ Mg–Ca
12	8.0	199.6	9.18	–	366	502	9	190	72	28	4.1	1171	4.13	$4.47 \cdot 10^{-4}$	$2.90 \cdot 10^{-2}$	$1.54 \cdot 10^{-2}$	$HCO_3–SO_4$ Mg–Ca

Note: "–" – data are not available; M is total salinity.

$O_{2dissolved}$ 3.75–4.60 mg/dm³. Compared to the *Novobibeyevsky* quarry waters, the average values of the geochemical coefficients are almost similar, and are as follows: Ca/Si, 9.89; Mg/Si, 2.12; Na/Si, 2.71; Mg/Na, 0.78; Si/Na, 0.39; Ca/Na, 3.52; Ca/Mg, 4.59; rNa/rCl, 7.65; SO_4/Cl, 22.76.

The Gorlovka coal basin drainage waters have been studied in several quarries. Thus, *Gorlovka* quarry waters are characterized by a HCO_3–SO_4/Na–Mg–Ca and SO_4–HCO_3/Na–Mg–Ca composition with a total salinity of 808–950 mg/dm³ and a silicon concentration of 8.22–10.21 mg/dm³. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +174.7 – +190.4 mV, pH 7.7–8.1 and $O_{2dissolved}$ 7.44–8.58 mg/dm³. The averaged values of geochemical coefficients are as follows: Ca/Si, 21.95; Mg/Si, 12.70; Na/Si, 18.01; Mg/Na, 0.74; Si/Na, 0.06; Ca/Na, 1.28; Ca/Mg, 1.73; rNa/rCl, 14.36; SO_4/Cl, 38.19. *Urgunsky* quarry waters are characterized by a Cl–SO_4–HCO_3/Mg–Ca–Na composition with a total salinity of 625–973 mg/dm³ and a silicon concentration of 3.68–6.59 mg/dm³. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +133.2 – +160.4 mV, pH 7.5–8.5 and $O_{2dissolved}$ 6.81–8.26 mg/dm³. The average values of the geochemical coefficients compared to those de-

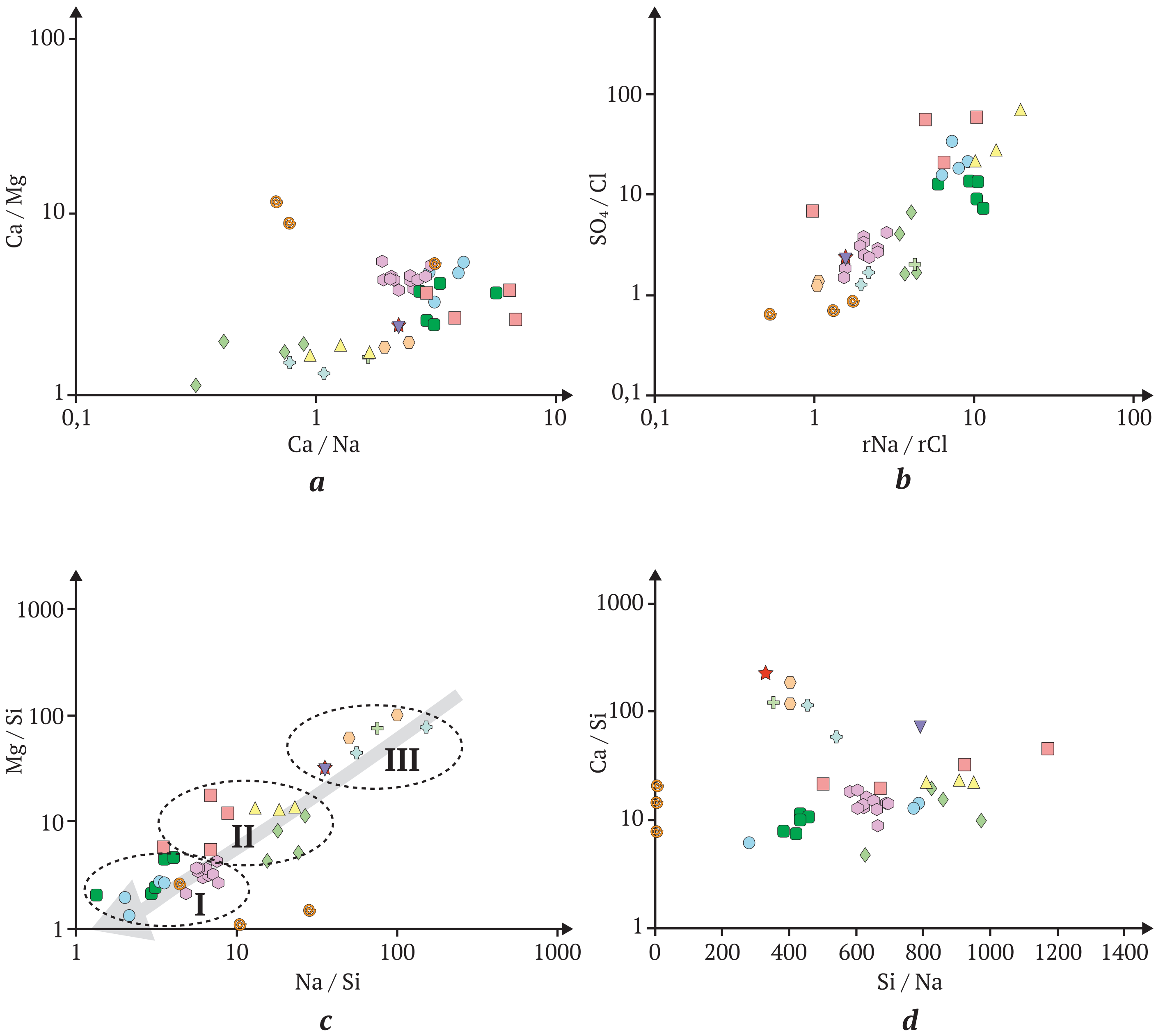

Fig. 5. Geochemical types of drainage water based on the relationship of the coefficients Ca/Mg – Ca/Na (*a*), SO_4/Cl – rNa/rCl (*b*), Mg/Si – Na/Si (*c*), Ca/Si – Si/Na (*d*). The arrow indicates an increase in the silicon concentration. See Legend in Fig. 4

scribed above are higher for Na/Si, 20.99 and lower for Ca/Si, 12.55; Mg/Si, 7.21; Mg/Na, 0.34; Si/Na, 0.05; Ca/Na, 0.59; Ca/Mg, 1.69; rNa/rCl, 3.84; SO_4/Cl, 3.56. *Kolyvansky* quarry waters are characterized by a Cl–HCO_3–SO_4/Na–Mg–Ca and SO_4–HCO_3/Mg–Ca composition with a total salinity of 500–1171 mg/dm³ and a silicon concentration of 3.80–5.25 mg/dm³. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +190.7 – +199.6 mV, pH 7.5–8.0 and an $O_{2dissolved}$ concentration of 7.65–10.43 mg/dm³. Compared to the Gorlovka quarrywaters, these waters are characterized by increased Ca/Si, 30.10; Si/Na, 0.17; Ca/Na, 4.93; Ca/Mg, 3.21 and decreased Mg/Si, 10.17; Na/Si, 6.46; Mg/Na, 1.60; rNa/rCl, 5.69; SO_4/Cl, 36.28. Drainage waters of the Gorlovka coal basin are characterized by high concentrations of sulfates (71–502 mg/dm³) and sodium (13–158 mg/dm³), as well as increased Na/Si, rNa/rCl, SO_4/Cl ratios, which indicate sulfide oxidation processes.

Abrashinsky marble quarry drainage waters are characterized by a HCO_3/Na–Ca–Mg composition with a total salinity of 500–1171 mg/dm³ and a silicon concentration of 3.80–5.25 mg/dm³. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +190.7 – +199.6 mV, pH 7.5–8.0 and $O_{2dissolved}$ 7.65 – 10.43 mg/dm³. The average values of the geochemical coefficients are: Ca/Si, 123.50; Mg/Si, 75.47; Na/Si, 74.95; Mg/Na, 1.01; Si/Na, 0.01; Ca/Na, 1.65; Ca/Mg, 1.64; rNa/rCl, 4.24; SO_4/Cl, 2.03. Abrashinsky quarry waters accumulate magnesium, sodium and calcium that is expressed in high Ca/Si, Mg/Si and Na/Si ratios.

Kirovsky sand quarry waters are characterized by a Cl–SO_4–HCO_3/Na–Mg–Ca composition with a total salinity of 789 mg/dm³ and a silicon concentration of 1.29 mg/dm³. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +205.0 mV, pH 8.7 and an $O_{2dissolved}$ concentration of 15.50–3 mg/dm³. The average values of the geochemical coefficients are as follows: Ca/Si, 77.52; Mg/Si, 31.71; Na/Si, 35.09; Mg/Na, 0.90; Si/Na, 0.03; Ca/Na, 2.21; Ca/Mg, 2.44; rNa/rCl, 1.55; SO_4/Cl, 2.38. *Podgorny* sand quarry waters are characterized by a SO_4–HCO_3/Na–Mg–Ca composition with a total salinity of 330 mg/dm³ and a silicon concentration of 0.18 mg/dm³. The geological environment geochemical parameters correspond to oxidizing conditions with Eh +186.5 mV, pH 8.4 and O2dissolved 9.34 mg/dm³. The average values of the geochemical coefficients are increased for Ca/Si, 229.91; Mg/Si, 113.31; Na/Si, 80.12; Mg/Na, 1.41; Ca/Na, 2.87; rNa/rCl, 2.11; SO_4/Cl, 5.51 and decreased for Si/Na, 0.01; Ca/Mg, 2.03. The geochemical coefficients indicate that the Podgorny quarry waters are enriched with calcium, magnesium and sodium.

Types of Radionuclides

The development of solid mineral (ore and non-metallic) deposits carries a significant threat to the environment. This primarily applies to the elements of the first hazard class, which include beryllium, arsenic, mercury and thallium[1]. The influence of radionuclides on ecosystems is also extremely dangerous, despite the fact that uranium now belongs to the second hazard class (MPC of 15 μg/dm³). The applicable regulatory documents of the Russian Federation indicate that there are no approved MPCs (maximum permissible concentrations) for thorium. The natural radioactivity of natural waters of various isotopic-geochemical compositions attracts genuine interest in the world. In this regard, in this work, for the first time, studies were carried out to assess the distribution of uranium and thorium in drainage waters, given that the studied region is characterized by an increased natural background radiation due to the presence of scattered radioactive minerals in granite and granodiorite. The features of the distribution of uranium, thorium and radon in the waters of the studied quarries are considered below.

The current concentrations of natural radionuclides in the *Borok* quarry waters are within the following limits (mg/dm³): ^{238}U from 0.009 to 0.213 and ^{232}Th from $1.00 \cdot 10^{-6}$ to $9.62 \cdot 10^{-5}$. The ^{232}Th/^{238}U ratio in the waters ranges from $9.71 \cdot 10^{-5}$ to $1.49 \cdot 10^{-3}$ (Fig. 6). The ^{222}Rn activity ranges from 1 to 89 Bq/dm³, which allows referring them to the class of very low- radon waters (according to the classification of N.I. Tolstikhin) [1]. The concentration of natural radionuclides in the Tulinsky quarry waters varies in the following ranges (mg/dm³): ^{238}U from 0.0121 to 0.0123 and ^{232}Th from $3.20 \cdot 10^{-6}$ to $7.08 \cdot 10^{-6}$. The ^{232}Th/^{238}U ratio in the waters varies in the range from $2.4 \cdot 10^{-4}$ to $5.77 \cdot 10^{-4}$, and the ^{222}Rn activity does not exceed 2 Bq/dm³. The concentration of natural radionuclides in the *Gorsky* quarry waters ranges as follows (mg/dm³): ^{238}U from 0.010 to 0.012 and ^{232}Th from $1.00 \cdot 10^{-5}$ to $1.15 \cdot 10^{-5}$. ^{232}Th/^{238}U ratio in the waters ranges from $9.30 \cdot 10^{-4}$ to $1.02 \cdot 10^{-3}$.

Novobibeyevsky quarry waters contain natural radionuclides within the following limits (mg/dm³): 238U from 0.010 to 0.012 and ^{232}Th from $2.60 \cdot 10^{-6}$ to $3.10 \cdot 10^{-5}$. ^{232}Th/^{238}U ratio in the waters ranges from $2.43 \cdot 10^{-4}$ to $2.69 \cdot 10^{-3}$. The ^{222}Rn activity varies from 2 to 39 Bq/dm³, which allows classifying them as very low-radon. *Skalinsky* quarry waters contain natural radionuclides within the following limits (mg/dm³): ^{238}U from 0.940 to 1.400 and ^{232}Th from $3.93 \cdot 10^{-5}$ to

[1] GOST R 58573-2019 "The nature conservancy. Hydrosphere. Water quality. Risk-based control"; GOST R 58556-2019 "Assessment of water quality of water bodies from ecological view points".

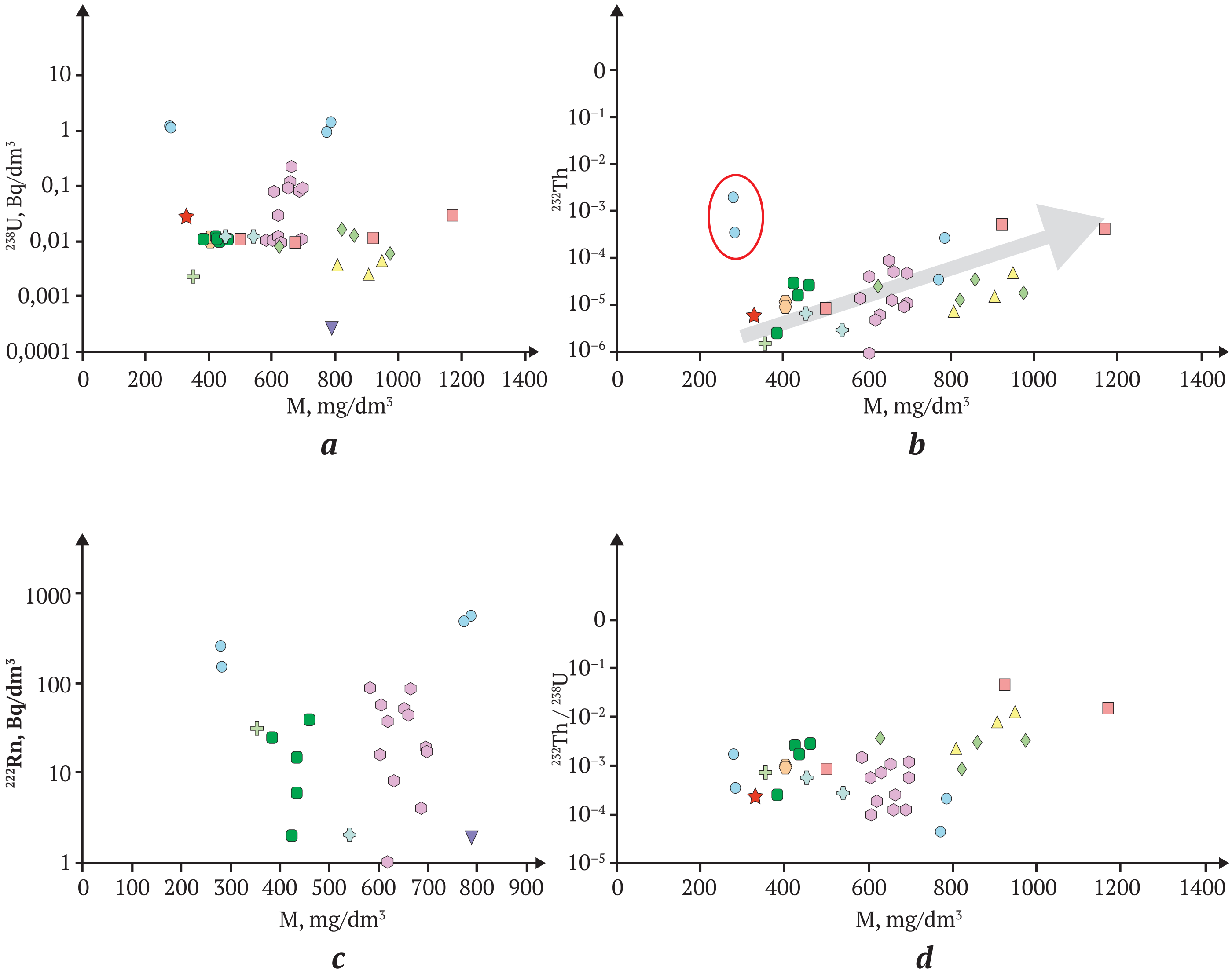

Fig. 6. Radionuclide composition as a function of the total salinity of drainage waters

$2.16 \cdot 10^{-5}$. $^{232}Th/^{238}U$ ratio in the waters ranges from $4.20 \cdot 10^{-5}$ to $1.78 \cdot 10^{-3}$. The ^{222}Rn activity ranges from 154 to 573 Bq/dm³, which allows classifying the waters as low-radon and moderately-radon waters.

The concentration of natural radionuclides in the *Gorlovka* quarry waters are as follows (mg/dm³): ^{238}U from 0.002 to 0.004 and ^{232}Th from $7.15 \cdot 10^{-6}$ to $4.68 \cdot 10^{-5}$. The $^{232}Th/^{238}U$ ratio in the waters ranges from $2.10 \cdot 10^{-3}$ to $1.17 \cdot 10^{-2}$. The radionuclide concentrations in the *Urgunsky* quarry waters are as follows (mg/dm³): ^{238}U from 0.006 to 0.017 and ^{232}Th from $1.40 \cdot 10^{-5}$ to $3.78 \cdot 10^{-5}$. $^{232}Th/^{238}U$ ratio in the waters ranges from $8.37 \cdot 10^{-4}$ to $3.41 \cdot 10^{-3}$. The concentration of ^{238}U in the *Kolyvansky* quarry watersvaries from 0.009 to 0.029 and that of ^{232}Th from $9.32 \cdot 10^{-6}$ to $5.57 \cdot 10^{-4}$, while the $^{232}Th/^{238}U$ ratio ranges from $8.39 \cdot 10^{-4}$ to $4.80 \cdot 10^{-2}$.

The radionuclide concentrations in the *Abrashinsky* quarry waters do not exceed the following levels (mg/dm³): ^{238}U, 0.002 and ^{232}Th, $1.65 \cdot 10^{-6}$. $^{232}Th/^{238}U$ ratio in the waters is $7.24 \cdot 10^{-4}$, the ^{222}Rn activity is 31 Bq/dm³.

The thorium concentration in the *Kirovsky* quarry watersis $3.00 \cdot 10^{-4}$ mg/dm³, and the ^{222}Rn activity does not exceed 2 Bq/dm³. The concentration of natural radionuclides in the *Podgorny* quarry waters is as follows (mg/dm³): ^{238}U, 0.027 and ^{232}Th, $6.47 \cdot 10^{-6}$, and the $^{232}Th/^{238}U$ ratio is $2.36 \cdot 10^{-4}$.

This paper assesses the environmental impact of the drainage water discharge from minedquarries (on non-metal deposits) in the eastern districts of the Novosibirsk Region. The volumes of radionuclides carried by drainage waters was assessed using the example of the Borok quarry. The automaticaccounting indicate an average drainage water volume of 2.3 million m³ per year. The average concentrations of uranium and thorium are $6.58 \cdot 10^{-2}$ mg/dm³ and $2.67 \cdot 10{-}5$ mg/dm³, respectively, based on the data of the geochemical studies of the waters. Thus, the annual uranium and thorium discharge volumes are 151.4 and 61.4 kg, respectively. It is important to note that radioactive element contamination of the Inya River into which the waters are discharged is not observed. Due to the mixing of river waters with drainage waters, the concentrations (mg/dm^3) in the river water are as follows: the concentrations of ^{238}U range from $2.32 \cdot 10^{-3}$ to $2.40 \cdot 10^{-3}$ and those of ^{232}Th from $3.08 \cdot 10^{-6}$ to $1.39 \cdot 10^{-5}$. Similar assessments were carried out for the Oyash, Chaus, and Elbash rivers into which the drainage waters are discharged from the Novobibeyevsky and Skalinsky quarries and the Gorlovka coal basin quarries, respectively. Thus, the radionuclide concentrations in the Oyash river are as follows (mg/dm^3): 238U, $2.36 \cdot 10^{-3}$; ^{232}Th, $5.85 \cdot 10^{-6}$, in the Chaus river U, $3.55 \cdot 10^{-3}$; Th, $4.09 \cdot 10^{-6}$, and in the Elbash river $2.46 \cdot 10^{-3}$ and $4.54 \cdot 10^{-6}$, respectively. The identified radionuclide concentrations in the river waters are correlated with radiochemical background values for surface waters in the Novosibirsk Region.

Conclusion

The study findings can be summarized briefly as follows.

Geological and hydrogeological conditions directly influence the geochemical parameters of the surveyed waters. As such, granite and coal quarry waters are characterized by a neutral pH, while sand and marble quarries are mainly characterized by alkaline conditions (pH > 7). Coal quarries are also observed to generate greater quantities of mineralized waters with a total salinity of up to 1,171 mg/dm^3, which corresponds to the low-salinity water category, while the other studied quarry drainage waters are ultra-fresh/actually fresh waters. This fact is not surprising, since the Gorlovka coal basin is hosted by sedimentary strata containing more ancient and salty waters not occurring in granite massifs. The calculated geochemical coefficients (Ca / Na, Ca / Mg, Ca / Si, Mg / Si, Na / Si, Si / Na, rNa / rCl, and SO_4 / Cl) allow concluding that the waters of the sand and marble quarries accumulate sodium, calcium and magnesium to a greater extent, while the granite and coal quarry waters accumulate silicon. The growth of the sodium concentration in quarry waters is also due to anthropogenic pollution. The highest radionuclide concentrations were detected in the waters of granite massif quarries, where uranium and thorium concentrations reached 1.40 mg/dm^3 and $2.16 \cdot 10^{-3}$ mg/dm^3, respectively, since the rocks contain increased radionuclide concentrations. The studies indicate that the development of industrial mineral and coal deposits does not pose a danger to the environment in terms of water pollution. The discharge of drainage water into the river system of the eastern districts of the Novosibirsk Region does not affect the quality of surface water.

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Theoretical studies on the nature and conditions of interaction of heel and peripheral nose cones of offset roller cone bits with a bottom hole

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Abstract
An offset of roller cone rotation centerlines is used to increase the mechanical penetration rate while drilling in soft rocks. This enables increasing the area of a cutting structure teeth contact with a bottom hole. The analysis of offset cone drill bit (cutting structure) teeth wear showed that particularly significant wear is characteristic of the transition zone from the heel cone to the nose cone, which leads to significant reduction in the mechanical rate of penetration and a rapid decrease in the hole diameter. The purpose of this paper is to conduct a theoretical research on the nature and conditions of interaction between heel and peripheral nose cones of offset roller cone bits with a bottom hole, which is aimed at improving the efficiency of rock cutting by offset roller cone bits. To achieve the purpose, the authors analyzed data on the nature and causes of wear of existing offset roller cone bit cutting structure (teeth); developed a mathematical model in a cylindrical coordinate system allowing to determine the location and geometric parameters of the gage cone contact area with the hole wall for different roller cone bits sizes; developed a computer solid model for checking the adequacy of the mathematical model by comparing these two models; prepared recommendations for further improvement of the design of existing offset roller cone bit cutting structure (teeth). The research was carried out by the method of mathematical simulation of geometric figures and bodies corresponding to roller cones and a hole. The research has revealed that significant adjustments need to be made to the geometry of the roller cone teeth (currently being patented). This would allow decreasing the areas of cone heel blunting by 15–20 % as well as providing more prolonged contact of base and gage cones with bottom hole and wall surfaces. This allows to reduce wear of teeth in the transition zone of the generatrix from the peripheral nose cone to the gage (heel) cone of the roller cone and to maintain the required specific pressure on the cut rock for a longer period of time and, as a result, to increase both the mechanical penetration rate and the service life of the drilling tools.

Keywords
drill bit, roller cone, hole, roller-bit drilling, mathematical simulation, rock destruction, tool

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ГОРНЫЕ МАШИНЫ, ТРАНСПОРТ И МАШИНОСТРОЕНИЕ

Научная статья

Теоретические исследования характера и условий взаимодействия с забоем тыльных и периферийных конусов шарошек бурового долота со смещенными осями вращения

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Аннотация
Для увеличения механической скорости бурения при бурении мягких пород используют смещение осей вращения шарошек, которое позволяет увеличить проскальзывание зубьев вооружения по всей площади забоя. Анализ износа зубчатого вооружения бурового инструмента со смещёнными осями

вращения шарошек показал, что происходит существенное изнашивание («зализывание») переходной зоны от тыльного конуса к основному, и это приводит к существенному снижению механической скорости бурения и быстрому уменьшению диаметра скважины. Целью работы является проведение теоретических исследований характера и условий взаимодействия с забоем тыльных и периферийных конусов шарошек данного вида бурового инструмента для повышения эффективности разрушения породы забоя шарошечным буровым инструментом со смещенными осями вращения шарошек. Для достижения поставленной цели в работе проведён анализ характера износа зубчатого вооружения и причин его возникновения у существующих конструкций шарошечного бурового инструмента; разработана математическая модель в цилиндрической системе координат, позволяющая определять расположение и геометрические параметры зоны контакта калибрующего конуса со стенкой скважины для различных типоразмеров шарошечных буровых долот; разработана компьютерная твердотельная модель для проверки адекватности работы математической модели путём их сравнения; разработаны рекомендации по дальнейшему совершенствованию конструкции зубчатого вооружения шарошечного бурового инструмента со смещёнными осями вращения шарошек. Исследования были проведены методом математического моделирования геометрических фигур и тел, соответствующих шарошкам и скважине. В результате исследований определено, что необходимо внести существенные коррективы в геометрию зубчатого вооружения шарошек (на данный момент патентуется), позволяющие на 15–20 % уменьшить площади площадок притупления периферийных венцов шарошек, а также обеспечить более длительный контакт основных и калибрующих конусов шарошек с поверхностью забоя и стенки скважины. Это позволит снизить повышенный износ зубьев вооружения в зоне перехода образующей от периферийного основного к калибрующему конусу шарошек и даст возможность зубчатому вооружению шарошек более длительный период времени сохранять требуемое удельное давление на разрушаемую породу, диаметр долота и, как следствие, обеспечит увеличение как механической скорости бурения, так и ресурса бурового инструмента.

Ключевые слова
буровое долото, шарошка, скважина, шарошечное бурение, математическое моделирование, разрушение породы, инструмент

Для цитирования
Boreiko D.A., Lutoev A.A., Serikov D.Yu. Theoretical studies on the nature and conditions of interaction of heel and peripheral nose cones of offset roller cone bits with a bottom hole. *Mining Science and Technology* (*Russia*). 2022;7(3):231–239. https://doi.org/10.17073/2500-0632-2022-3-231-239

Introduction

At present, different approaches are known for estimating the drilling efficiency of a roller-bit, which depends on a large number of diverse factors. They can be divided into process and design ones.

In terms of design, a roller cone bit is a rock destruction tool equipped with toothed wheels (roller cones or cones) capable of rotating around their own centerlines [1, 2]. In most cases, the bit designs do not provide for offset of a roller cone rotation centerline relative to a bit rotation centerline. This allows reducing the wear of the bits when drilling hard rocks (of high and medium hardness), as well as rocks of increased abrasiveness [3]. Figure 1 shows examples of tricone and two-cone drill bits without the cone rotation centerline offset. Particular emphasis in the Figure is made on the transition of a cone generatrix from peripheral nose teeth rows to heel cones (teeth rows), which are gage cones and form a hole diameter and walls.

But such bits cannot provide the highest mechanical penetration rate and specific penetration rate (per bit) when drilling through soft rocks. To increase mechanical penetration rate while drilling soft rocks, parallel offset of roller cones rotation centerlines is applied, allowing to increase the area of roller cone teeth contact with a bottom hole [4]. In contrast, most foreign companies primarily use angular offset of roller cone centerlines, which results in a smaller teeth contact area but allows to increase the size of roller cones [5–7].

However, the analysis of offset roller cone bit wear after running in the field drilling of oil and gas holes allowed establishing some important features of this process [8]. The main feature is the “licking” (wear) of the angle formed by the intersection of a peripheral nose cone (teeth row) and a gage cone of a roller cone (Fig. 2). This leads to an increase in the area of the peripheral nose teeth rows “blunting area” that inevitably leads to the reduction of the specific pressure on a bottom hole surface and, as a consequence, to a reduction in the destructive capacity of the roller cone [9].

Analysis of drill bit cutting structure (teeth) wear in the case, when the rotation centerlines of roller cones are offset relatively to the rotation centerline of the drill bit, showed that the wear of the transition zone from a heel cone to a nose cone was rather intensive. An intensive wear of this surface leads to increasing the “blunting area” of the roller cone peripheral teeth, the most energy-consuming zone working simultaneously both for gauging and destruction of the peripheral area of a bottom hole, since this part of a roller cone comprises the largest teeth forming the hole diameter and, respectively, experiencing the highest impact and abrasion loads [10]. Moreover, this leads to a rapid loss in the bit diameter and, correspondingly, in the diameter of the hole itself.

As a rule, an increase in the performance of a roller cone drilling tool derives from reduced energy consumption during the drilling by aligning the geometry of the roller cone with the operating conditions of each of the roller cone teeth rows in the annular sections of the bottom hole and the physical and mechanical properties of the drilled rock. Thus, the task of improving the design of roller cone drilling tools is still quite urgent at present [11, 12]. Therefore, it is necessary to examine the reasons for the aforementioned adverse processes occurring during drilling with offset roller cone bits.

Research tasks and objectives

The main objective of this study is to increase the performance of bottom hole rock destruction using offset roller cone bits by means of theoretical research of the nature and conditions of interaction between the roller cone heel and peripheral nose cones with the bottom hole.

a ***b***

Fig. 1. Options of new (unused) bit designs: *a* – tricone bit; *b* – two-cone bit

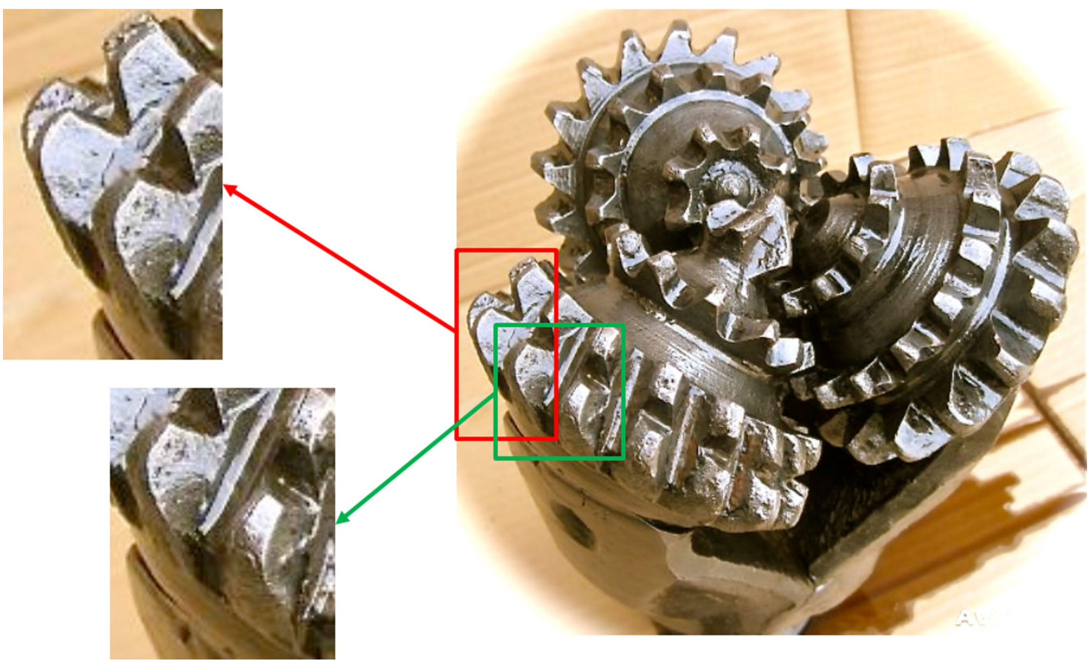

Fig. 2. Wear (“licking”) of peripheral nose and heel cone teeth rows of offset roller cones

In order to achieve this objective, the study addressed the following tasks:

1. Analysis of the nature of existing roller cone cutting structure (teeth) wear and its causes.
2. Development of a mathematical model in cylindrical coordinate system, allowing to determine the location and the geometry of the contact area of a gage cone with a hole wall for different types of roller cone bits.
3. Development of a computer-assisted solid model to check the adequacy of the mathematical model by comparing these models.
4. Development of recommendations on further improvement of the design of teeth of offset roller cone bits.

Research techniques

The studies on determining the position of the contact area between the large base of a gage cone and a hole wall were performed by the method of mathematical simulation of geometric figures and bodies, corresponding to the roller cones and the hole, taking into account a number of simplifications and assumptions [13]. For example, it is known that structurally all drill bit roller cones consist of a roller cone body and the cutting structure, which are milled or tungsten carbide teeth. In its turn, a roller cone body consists of several interconnected cones, which in general can be split into two bodies: the nose cone and the gage cone, as shown in Fig. 3. Thus, structurally, a standard roller cone design is a twin cone (nose cone + gage cone). An important feature of this design is that the transition zone is formed at an angle of $\gamma = 90°$ between the generatrixes of the base and gage cones.

Another simplification in the model is the form of the modeled body itself – it is the nose cone and the transition plane θ, which is common to both the nose cone and the gage cone. This plane is of particular scientific interest for the research since the contact area with a hole wall belongs to it.

The mathematical simulation was based on the methods of coordinate transformation, the system of equations of the cylinder, the inclined cone and the transition plane θ passing through their contact point (Fig. 4). For this purpose, at the first stage, we have created a geometric description of the examined bodies in the cylindrical coordinate system for a roller cone without its centerline offset relative to a hole centerline.

As can be seen from Fig. 4, the point M of the contact of the cone and the hole belongs to both the hole cylinder wall and the base (bottom) of the hole. This position provides perfect contact of lateral surface of a gage cone with hole wall allowing minimizing the wear of peripheral teeth rows. Fig. 2 demonstrates unfavorable position and contact.

Then, the centerline of the cone geometric model is offset along *X* and *Y* axes relative to the centerline of geometric model of the hole by distances *dx* and *dy*, respectively. At this offset of the cone centerline, the point *M* changes its spatial position, moving up the wall of the hole cylinder, and "overhanging" over the bottom hole, losing contact with it. In this position, sharp indentation of the peripheral teeth rows

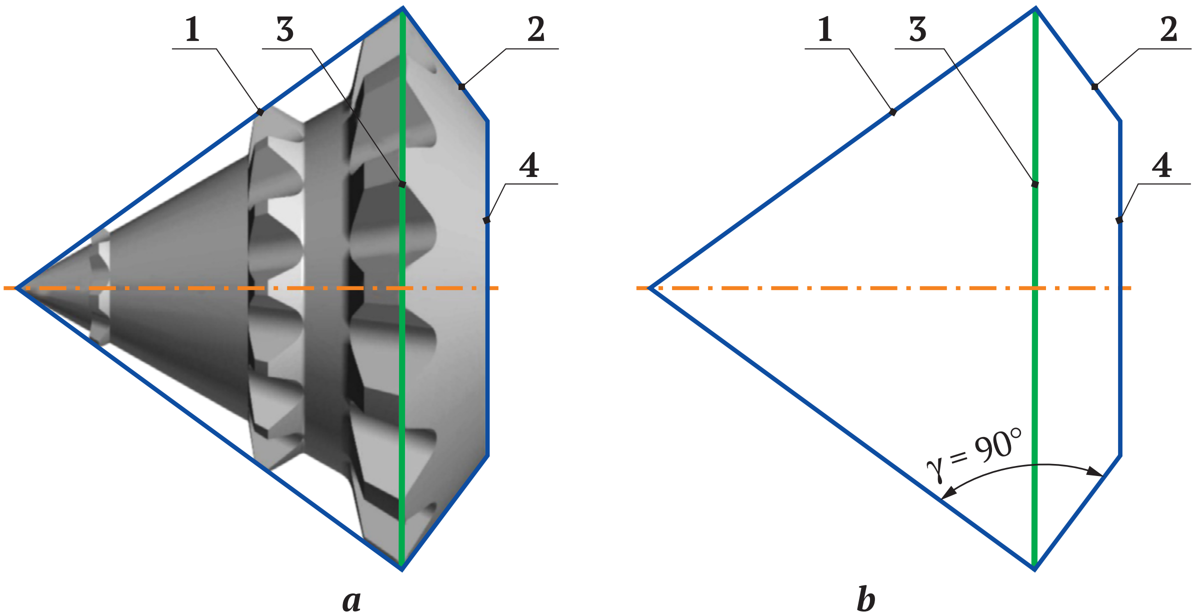

Fig. 3. Simplification of roller cone geometry before simulation:
a – model of a roller cone with milled teeth; *b* – sketch of a longitudinal section of cones of a roller cone; *1* – nose cone; *2* – gage cone; *3* – rib of transition surface θ (large base of gage cone); *4* – rib of small base of gage cone; γ – angle between the generatrixes of the nose and gage cones

into a rock takes place, resulting in their increased wear and formation of a rounded transition zone. Let us introduce two coordinate systems *OXYZ* and *O′X′Y′Z′* (Fig. 5) in the considered geometrical model to define the equation of cone and the equation of cylinder.

Taking into account the parallel translation of *dx* and *dy* and the rotation of the system *O′X′Y′Z′* relative to *OXYZ* through the angle β, we obtain:

$$\begin{cases} x' = (x - dx)\cos\beta + z\sin\beta; \\ y' = y - dy; \\ z' = z\cos\beta - x\sin\beta. \end{cases} \quad (1)$$

The problem of finding the coordinates of point *M* was converted to finding the point of contact of a cylinder given by the corresponding equation and a cone "angled" at the angle β with the base given by the plane θ.

The equation of cylinder has the following form:

$$x^2 + y^2 = R^2. \quad (2)$$

The equation of cone in canonical form in the *O′X′Y′Z′* coordinate system is written as follows:

$$x'^2 + y'^2 = \frac{z'^2}{c^2}, \quad (3)$$

where *c* is a cone constant (angular coefficient).

The section of a cone by the plane *OY′Z′* is given by the following equation: $z = \pm cy$. Then the angular coefficient of the straight line of section c (Fig. 6, *a*) is written as follows:

$$c = \mathrm{tg}(90 - \alpha) = \mathrm{ctg}\,\alpha. \quad (4)$$

Equation (3) will take the following form:

$$x'^2 + y'^2 = \frac{z'^2}{\mathrm{ctg}^2\,\alpha}. \quad (5)$$

Bearing in mind that:

$$\frac{1}{\mathrm{ctg}\,\alpha} = \mathrm{tg}\,\alpha, \quad (6)$$

$$\alpha = 90° - \beta \Rightarrow \mathrm{tg}(90° - \beta) = \mathrm{ctg}\,\beta, \quad (7)$$

and the transformation (1) of translation and rotation, we obtained the equation of cone in the *OXYZ* coordinate system:

$$((x - dx)\cos\beta + z\sin\beta)^2 + (y - dy)^2 = = (z\cos\beta - x\sin\beta)^2\,\mathrm{ctg}^2\,\beta. \quad (8)$$

The plane θ passing through point M_0 perpendicularly to the normal vector $\bar{N}(A;B;C)$, in a general way, is given by the following equation:

$$A(x - x_0) + B(y - y_0) + C(z - z_0) = 0. \quad (9)$$

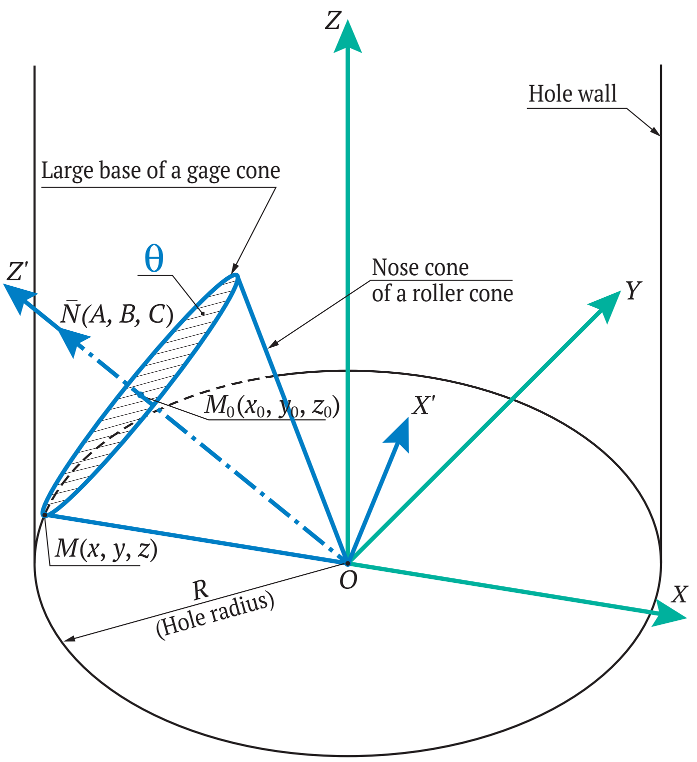

Fig. 4. Geometric model of a roller cone without centerline offset:
M – point of contact of the large base of a cone and a hole;
M_0 – center of the large (transitional) base of the cone

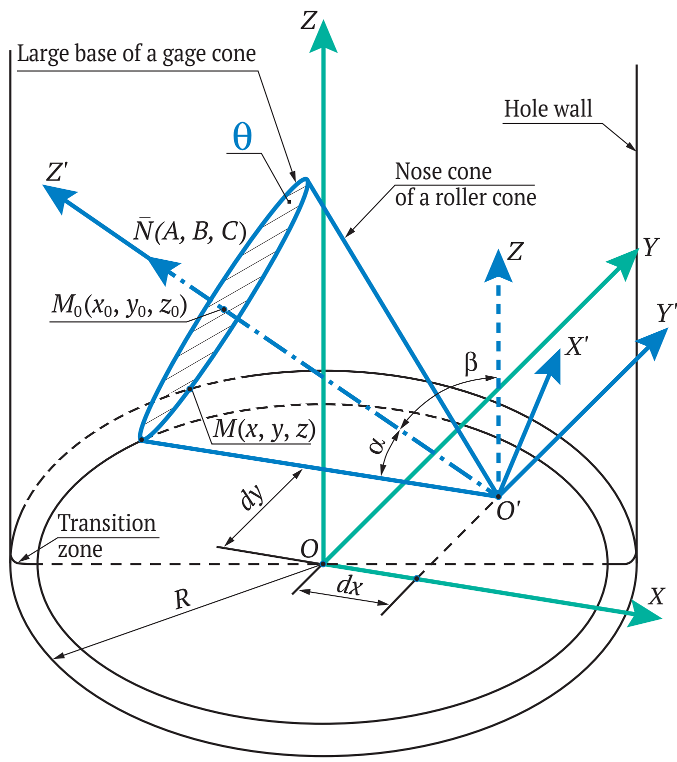

Fig. 5. Geometric model of offset roller cone:
α – angle between *O′Z′* and cone generatrix;
β – angle of cone centerline rotation relative to *OZ*;
dx – offset of cone centerline relative to *OX*;
dy – offset of cone centerline relative to *OY*

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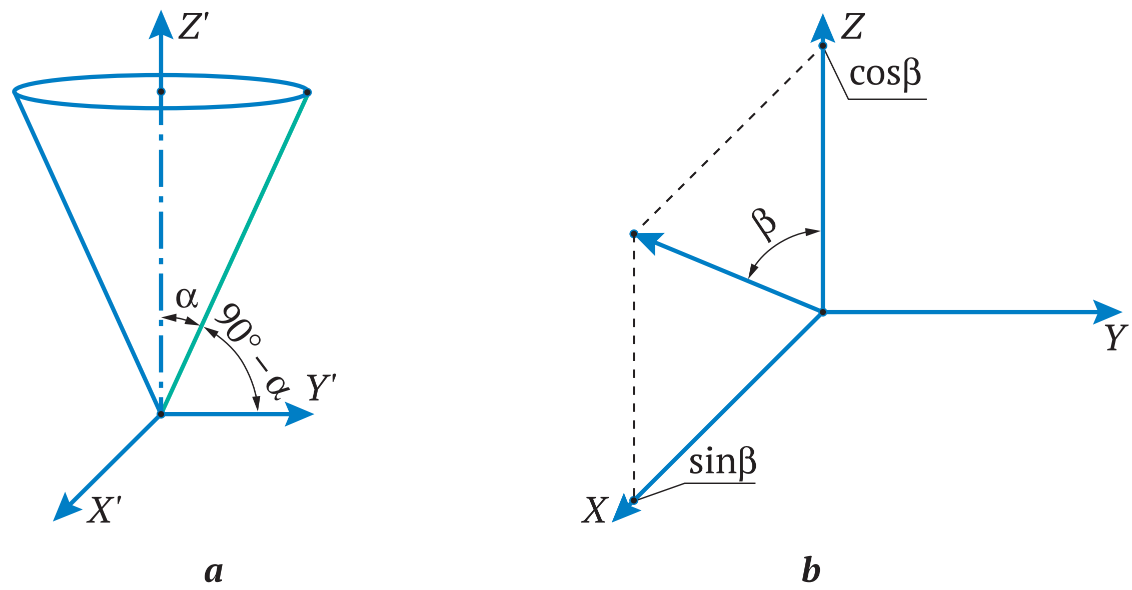

Fig. 6. *O'X'Y'Z'*cone geometric model:
a – *O'X'Y'Z'* cone geometric model; *б* – determination of the coordinates of the plane θ normal vector; α – cone angle

Taking into account that the normal vector of the plane θ is the centerline of cone obtained by the rotation relative to *OY* axis by the angle β (Fig. 6, *b*), we obtain $\bar{N}(\sin\beta;\ 0;\ \cos\beta)$.

Then the equation of the plane θ is written as follows:

$$\sin\beta(x - x_0) + \cos\beta(z - z_0) = 0. \qquad (10)$$

Research Findings

Thus, to find the point *M*, it is necessary to solve a system of nonlinear equations:

$$\begin{cases} x^2 + y^2 = R^2; \\ (x - dx)(\cos\beta + z\sin\beta)^2 + (y - dy)^2 = \\ = (z\cos\beta - x\sin\beta)^2 \operatorname{ctg}^2\beta; \\ \sin\beta(x - x_0) + \cos\beta(z - z_0) = 0. \end{cases} \qquad (11)$$

The resulting system of equations (11) will make it possible to determine the coordinates of point *M* for different bit sizes when drilling holes of different diameters.

After mathematic simulation, a computer-generated solid model of the roller cone, similar to its geometric model, and a model of a hole cylinder were built to check the coincidence of the results and visualise the desired contact area. Fig. 7 shows the models of roller cones and a hole created in the domestic computer-aided design system KOMPAS-3D.

The Figure shows that in the solid model, the gage cone contact area is defined in the same area as in the mathematical model. This testifies to the adequacy of both models and the correctness of the obtained results.

To minimize fast wear and formation of "blunting area" in an offset roller cone bit, it is necessary to achieve full contact of lateral surface of a gage cone with a hole wall, as is the case in standard bits with no offset [14]. To ensure such contact, it is necessary to increase the angle γ between the generatrixes of the nose and gage cones until the small base of the gage cone touches the hole wall in the same way and simultaneously with its transition plane θ. We obtained such position iteratively in the computer-assisted solid model presented in Fig. 7, *d*.

To achieve this result, several successive iterations were simulated to increase the angle γ to a value that ended up being 97.7913°. The longitudinal dx and transverse dy offsets according to the scheme (Fig. 7, *b*) amounted to +5.4839 mm and +11.8789 mm, respectively, and were also determined iteratively. According to the simulation result, the required geometry of the gage cone can be determined mathematically, similarly to the mathematical model of the transition plane contact area with the hole wall.

Due to this roller cone design, it will be possible to maintain the required specific contact pressure for the efficient destruction of a rock for a longer period of time [15]. This all will allow increasing mechanical penetration rate and keeping hole diameter for the whole period of the drilling tool operation.

Areas of further research

To finally meet the purpose of this research, it is necessary to determine the full geometry of a gage cone, at which the contact of its surface with a hole wall will be along the line connecting the point *M* belonging to the transition plane θ and a similar point

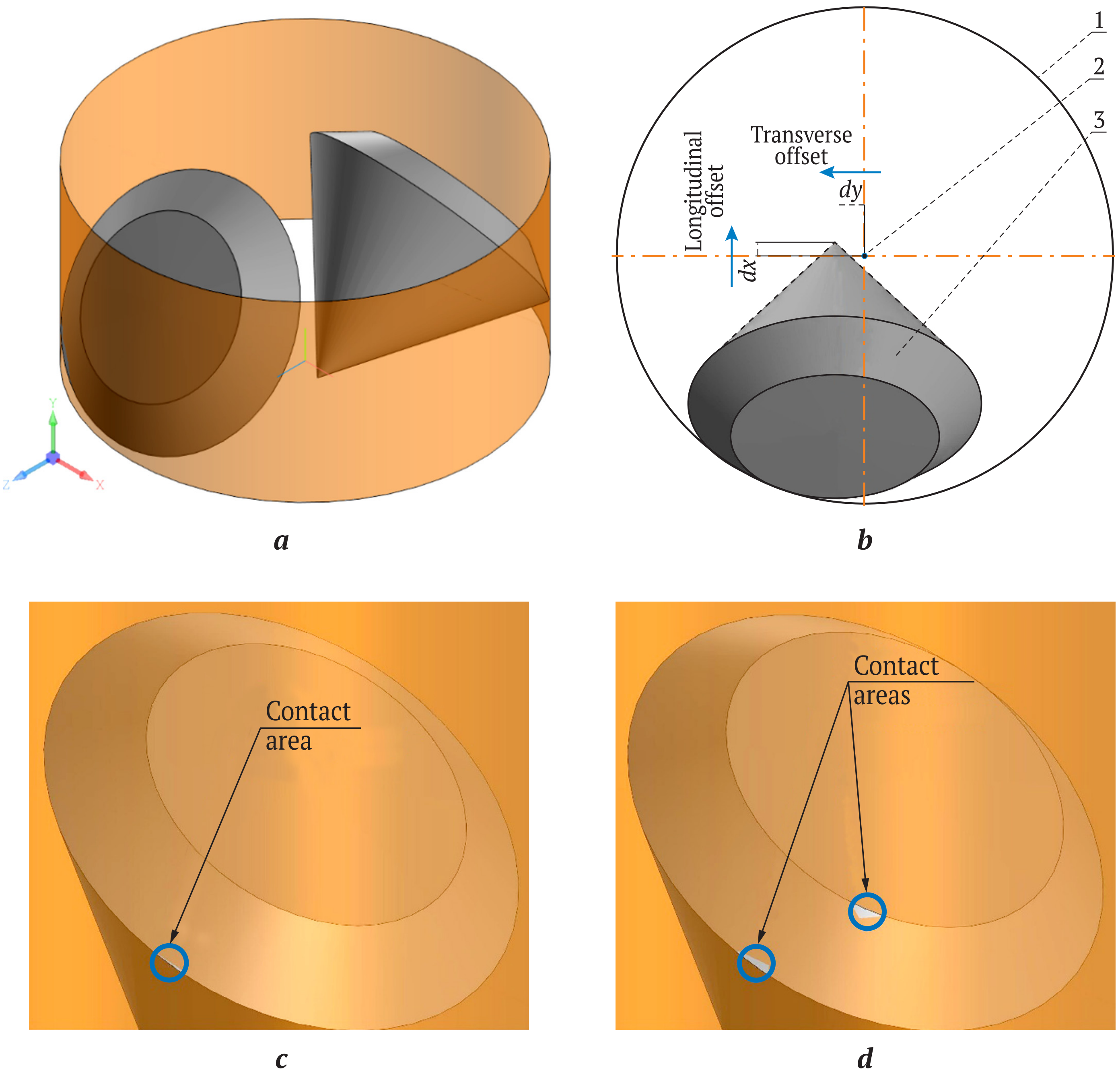

Fig. 7. The result of 3D simulation of the contact area of plane θ with a hole:
a is a model of the location of the cone models inside the hole cylinder model; *b* is a scheme of the offset of the roller cone model rotation centerline; *c* is the result of the contact area simulation; *d* is the result of 3D simulation of the areas of simultaneous contact of the gage cone two bases with the hole wall; *1* – hole model wall; *2* – hole model centerline; *3* – roller cone model

belonging to the small base, the coordinates of which are determined on the basis of the developed mathematical model, taking into account the angle of inclination γ. For this purpose, a mathematical model will be developed describing the specified line, which belongs to both the inner side surface of the hole cylinder and the lateral surface of the gage cone, which provides a uniform "contact spot" (this model is currently being patented).

Conclusion

1. The performed theoretical studies made it possible to establish the causes of uneven wear of cutting structures (teeth) of offset roller cone bits: this is an inconsistency between the geometry/position of the cutting structures (teeth) and the curvature of a hole wall in the transition zone of the generatrix of a nose cone to a gage one, as well as the kinematic features of offset roller cone bits.

2. A mathematical model of the intersection of the plane θ of the roller cone model transitional base in the area of its contact with the cylinder of a hole model was developed. The model provides the possibility of creating the geometry of roller cone cutting structure (teeth) which can significantly reduce the uneven wear of the cone heel teeth and their gauging surfaces in such a way that when the teeth are subject to wear, the teeth "blunting area" is 15–20% smaller than that of similar standard roller cones. The mathematical model was verified by its comparison with the results of solid-state computer simulations, which showed good correlation of the model and simulation results.

3. The researches showed that it is necessary to make significant adjustment to the geometry of roller cone cutting structure (teeth) (at the moment they are being patented). This would allow decreasing the areas of cone heel blunting by 15–20% as well as providing more prolonged contact of nose and gage cones with bottom hole and wall surfaces. This allows reducing the teeth wear in the area of the transition of generatrix from a peripheral nose cone to a gage cone of a roller cone and enables keeping the required specific pressure on the cut rock for a longer time and as a result increasing both the mechanical penetration rate and the life time of the drilling tools.

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PROFESSIONAL PERSONNEL TRAINING

Review paper

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Analytical review of the training system for mining engineers in Russia

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Abstract
Personnel training for the mineral resources sector in Russia has always been one of the most relevant topics for discussion in academic and professional mining community, including the international context. Experts from many countries regularly present their research on the state and achievements of higher education in mining in the national training systems for mining engineers. The purpose of this paper is to analyze and quantify the system of training for mining engineers in Russia. To assess the quantitative characteristics of the training of mining engineers in Russia, the research used methods of analysis based on the objective data of state statistics on the graduation of mining engineers in all universities, as well as admission to the corresponding professions and training programs. Thus, 5,031 mining engineers were trained in Russia in the specialties "Applied Geology"; "Geological Exploration"; "Mining"; "Physical Processes of Mining and Oil and Gas Production" in 2021. 10,789 bachelors and masters were trained under oil and gas directions of training. The results of the analysis are presented in the paper in the context of particular universities, specializations and directions of training of Federal Districts and the country as a whole. The quantitative parameters of personnel training for the mineral resource sector at Russian universities indicate the opportunity for the formation of human resources potential within the higher education system of the industry exclusively at the expense of their own academic schools.

Keywords
mining engineer, mineral resource sector, oil and gas, mining, applied geology, higher education in mining, mining universities, regions of Russia, training, mining professions, prestige, university admission, admission statistics, quality, analysis

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ПОДГОТОВКА ПРОФЕССИОНАЛЬНЫХ КАДРОВ. ОРГАНИЗАЦИЯ ИССЛЕДОВАНИЙ

Обзорная статья

Аналитический обзор системы подготовки горных инженеров в России

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Аннотация
Подготовка специалистов для минерально-сырьевого комплекса в России является всегда одной из самых актуальных тем для дискуссий в академическом и профессиональном горном сообществе, в том числе и в международном контексте. Эксперты из многих стран регулярно представляют свои исследования о состоянии и достижениях высшего горного образования в национальных системах подготовки горных инженеров. Целью публикации являются анализ и количественная оценка системы подготовки горных инженеров в России. Для оценки количественных характеристик подготовки горных инженеров в России в исследовании использовались методы анализа, основанные на объективных данных государственной статистики выпуска горных инженеров во всех университетах, а также приема на соответствующие специальности и направления подготовки. Так, по специальностям «Прикладная геология»; «Технология геологической разведки»; «Горное дело»; «Физические процессы горного или нефтегазового производства» в 2021 г. в России был подготовлен 5031 горный инженер. По специальностям нефтегазового профиля – 10 789 бакалавров и магистров. Результаты анализа представлены в статье в разрезе конкретных университетов, специальностей и направлений подготовки, федеральных округов и страны в целом. Количественные параметры подготовки кадров для минерально-сырьевого комплекса в университетах России свидетельствуют о возможности формирования кадрового потенциала в системе высшего образования отрасли только за счет собственных научно-педагогических школ.

Ключевые слова
горный инженер, минерально-сырьевой комплекс, нефтегазовое дело, горное дело, прикладная геология, высшее горное образование, горные университеты, регионы России, обучение, горные специальности, престиж, прием в университет, статистика приема, качество, анализ

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Introduction

Personnel training for the mineral resources sector in Russia is always one of the most relevant topics for discussion in the academic and professional communities [1–3], including in the international context [1, 4, 5]. International experts regularly present their research on the state and achievements of higher mining education in Australia [4, 6], Ukraine [7], South Africa [8], Romania [9], Turkey [10], Slovakia [11], as well as in some other countries. Active public discussions are held on such authoritative platforms as, for example, the Society of Mining Professors (SOMP), at international conferences of mining and mining-geological profile, as well as within the framework of the International Mining Congress. Collections of the works of the mentioned scientific events give an insight into progressive solutions in various areas of the development of training systems for the mining engineers implemented in universities and countries, an opportunity to learn about the objective crises faced by certain countries, by developing their national training systems for the mineral resource sector [9]. Indeed, higher mining education has to address extremely serious challenges, which are determined by the following factors:

- mining industry is often in decline in some regions and countries, the industry of solid commercial minerals is being wound down and is becoming unpopular. This objectively reduces the demand for specialists and causes the stagnation of mining academic schools;
- it is difficult for mining programs at universities to compete with many other training programs, for example, IT specialties, in attracting talented young people to their mining and geological profile programs;
- the new technological order changes the profession and role of a mining engineer significantly. The high speed of these changes does not always allow universities to respond to them in their training programs flexibly, resulting in a gap between the requirements for training specialists from the mining business and the capacity of universities to meet these requirements.

The author makes no pretense to a detailed analysis of all the factors that reduce the prestige of higher mining education and its attractiveness, the article presents only the main self-explanatory reasons of this situation. Perhaps the analysis of these factors will grab the attention of other experts who will express their opinion on this issue.

Advanced universities that implement educational programs based on their academic schools are trying to meet the increasing needs of the mining industry in terms of quantitative and qualitative indicators, by taking the leading positions in terms of timely response to new challenges. We see that advanced technologies based on new digital solutions, including VR [12–15] and AR technologies [16], are being actively introduced into the educational process. Traditionally and almost everywhere, special attention is paid to the formation of competencies of a mining engineer related to technological safety [17–19], as well as practical training [20, 21]. It should be noted that methodological aspects of on-line training in higher mining education were discussed by experts long before the start of Covid-19 pandemic [22].

By assessing the aspects of the development in the part of the mineral resource sector, which is associated with the extraction and primary processing of solid minerals (mining), it is impossible not to touch on the oil and gas industry.

The problems of higher mining and oil and gas education are mostly very similar. However, it should be noted that the oil and gas in Russia is more attractive as a field of professional activity, which creates conditions for the intensive development of oil and gas education system [23–25].

Public, academic, and professional institutes play an important role in the development and harmonization of the global system of personnel training for mineral resource sector [26, 27]. Among the international ones, it is necessary to note Society of Mining Professors in the field of mining, the subject of whose work is closely related not only to the concepts of mining education development, but also to its content, with the development of common approaches the implementation of educational programs.

In the Russian Federation, the state has established a special public-state institute in the higher education system – Federal Academic Methodological Association in educational fields, among which there is also a Federal Academic Methodological Association in the higher education system “Applied Geology, Mining, Oil and Gas, and Geodesics”. This public association is responsible for the development of scientific and methodological support for the relevant field of education, including the development of federal educational standards, as well as participation in the formation and implementation of state policy in the field of higher education.

Quantitative indicators for assessing graduation of mining engineers in Russia

Issues related to the assessment of quantitative indicators of personnel training for the industry have always attracted the interest of the expert community. Industry representatives often claim a shortage of mining engineers in the industry. Universities did their best to increase their graduation, trying not to reduce training quality. Nevertheless, there are not so many expert analytical materials related to quantitative assessments of the need for training of mining engineers. The last such information in Russia was presented in the author's research in 2017 [3, 28]. The same materials formed the basis of the author's report on higher mining education in Russia within the framework of the 28th conference of the International Society of Mining Professors (SOMP), which was held in Turin (Italy) in 2017.

Quite interesting data on quantitative estimates of the need for mining engineers are given in the study [29]. This is one of the few studies that gives an assessment of the need for mining engineers not in Russia. The study provides an example of formation of a personnel engineering corps of the mining industry in Australia, where the shortage in mining engineers is covered by specialists from other countries, such as Poland, Russia, Ukraine, Peru, etc.

In Russia, quantitative assessments of the training of mining engineers have been presented in the public field since 2005 and are the subject of discussion on the pages of many publications [3, 28]. The same issues are regularly discussed at public events, councils of the Federal Academic Methodological Association in the higher education system "Applied Geology, Mining, Oil and Gas, and Geodesics", the Supreme Mining Council of Russia.

When presenting analytical materials, the authors of this paper took into account the interests of international experts who, in order to form a complete picture of the Russian system of personnel training for the mineral resource sector, need to get a general idea of some of the features of the higher education system in Russia (admission to universities, lists of directions and specializations of training, etc.). Overall, the system of state regulation in terms of the implementation of educational programs in different countries has much in common, but each of them, including Russia, has its own nuances.

This research reveals updated data and takes into account the latest trends in the development of higher engineering education in Russia.

Features of admission to higher educational institutions of Russia

Higher educational institutions of Russia plan the number of citizens admitted to study 8–9 months before the start of the basic procedures. In many respects this planning is undertaken at the level of universities, which independently determine the competitive groups of training programs, the list of entrance tests, etc. The key parameter in this planning process is the number of state-funded places that are allocated to the university for training citizens at the expense of the federal budget. The allocation of budget places is based on the competitive procedures between universities, taking into account the need for specialists at the federal and regional levels, as well as objective performance indicators of the universities themselves. According to the results of these competitive procedures, universities are granted "admission quotas" to study at the expense of the federal budget directions of training, specializations of training or group of directions and specializations of training (analogous to personal state grants, which are often used in international systems of higher education) for admission to the first year.

Admission to higher education programs in the Russian Federation is based on the results of a specialized national exam, which is called the "Unified State Exam" (USE). About six months before the end of secondary school, its graduate must plan which subjects in the framework of the Unified State Exam he/she will take after graduation (June of the year of graduation), in order to enter the university (July, August of the year of admission to the university). The results of the Unified State Exam are valid for four years and can be improved in the following years (can be combined with the best results by year).

The state determines the mandatory disciplines that an applicant must pass when entering certain directions or specializations of training. Thus, for programs related to mining and geology, it is Russian language and mathematics. Universities can also establish additional subjects or combinations of subjects at their discretion. In some universities, incoming applicants are invited to submit the results of the Unified State Exam in physics, chemistry or computer science (optional).

The procedures and technologies of the Unified State Exam in Russian society are the source of the most heated discussions, which are not inferior in intensity to such aspects of public life, for example, as pension reform or employment. But this mechanism has been working for more than 20 years, and it allows for admission to universities on the basis of uniform national criteria for assessing the knowledge of graduates of secondary schools in subject areas.

Certain exceptions refer to graduates of specialized secondary schools who have completed secondary vocational education programs (the level of vocational education in Russia, which is before higher education).

Graduates of these secondary schools can choose the trajectory of admission to the university: according to the results of the Unified State Exam or according to the results of the university entrance tests. Most of them, if they wish, can enter the university, having passed the university entrance tests (not the Unified State Exam). According to the results of university entrance tests, persons who have received secondary general education abroad, including foreign citizens, can enter as well.

All applicants to the university are ranked according to a list, in which almost all applicants are on an equal basis before being enrolled in the first year. Only those persons who have positive results of entrance tests or corresponding results of the Unified State Exam take part in the competition.

A small category of citizens (orphans, disabled people, etc.) have non-competitive benefits or preferential rights, and the winners of All-Russian and international subject school specialized Olympiads can enter in universities without exams. The number of persons who use such exceptions in the implementation of competitive procedures for directions and specializations of training in personnel training for the mineral resource sector is insignificant, and in general they do not play a big role in increasing competitive indicators.

If a particular person did not pass the competition, he has the opportunity to study at his own expense or at the expense of legal entities (paid tuition) by signing a contract with the university. The university also plans this quantitative indicator, by announcing passing score and the number of places, conducting separate competitive procedures for these places.

Specializations and directions of training for personnel of the mineral resource sector of Russia

The Russian Federation has its own system of classification of specializations and directions of training in higher education. At the federal level, a list specializations and directions of training is approved, which is fixed in the administrative act of the department that forms and implements state policy in the country's higher education system (the Ministry of Science and Higher Education of the Russian Federation). It should be noted that Russia has a tiered system of higher education, but it has certain specifics.

The following levels of higher education are fixed by federal law:

- higher education – bachelor's degree (4 years of study);
- higher education – specialist's degree (5–5.5 years of study);
- higher education – master's degree (2 years of study), which is possible to obtain only after any previously obtained level of higher education, usually bachelor's degree);
- higher education – training of highly qualified personnel (postgraduate studies).

Bachelor's and master's degree programs are implemented on program tracks, while specialist's degree programs, on specialties. The pattern of classification of program tracks (training programs) and specialties in higher education in Russia is presented in Fig. 1.

Specialist's programs (training is conducted in specializations of training) and master's degree programs belong to the programs of the second level of higher education. Specialist's programs are implemented not after the bachelor's degree, like the master's degree, but simultaneously with it.

An applicant entering higher education programs can choose where to enroll: for a bachelor's degree or for a specialist's. After a bachelor's degree, he can continue his studies in a master's degree, and then in a postgraduate course. After the specialist's degree, you can immediately enroll in postgraduate school. Bachelor's and master's degree programs are implemented in the directions of trai-ning, specialist's degree – in specializations of training (see Fig. 1).

Universities develop and implement the main professional educational programs of higher education in the directions and specializations of training, by for-ming their own profile (name of the program) (see Fig. 1). For example, within the framework of the specialization "Mining", universities often adhere to the classical names of the programs "Open-pit mining", "Underground mining of mineral deposits", "Surveying", "Mineral enrichment", "Mining machines", "Technological safety and mine rescue", "Mine and underground construction", "Blasting work", "Electrification of mining industry", etc. In the last 10 years, under the influence of various factors, new names of programs have begun to appear, such as: "Mining and geological information systems", "Mining ecology", etc. Thus, universities, using their freedom in terms of forming new training programs for specialists, can look to the future and try to foresee new professions of a mining engineer.

Personnel training for the mineral resource sector in Russian universities is currently carried out in the following main specializations of training:

- "Applied Geology" with the qualification of mining engineer (5 years of training);
- "Geological Exploration" with the qualification of mining engineer (5 years of training);
- "Mining" with the qualification of mining engineer (5.5 years of training);
- "Physical Processes in Mining or Oil and Gas Production" with the qualification of mining engineer (5.5 years of training);
- "Oil and Gas Engineering and Technologies" with the qualification of mining engineer (5.5 years of training).

Within the bachelor's and master's degree programs, the main program is "Oil and Gas" (4 years of bachelor's degree and 2 years of master's degree).

The names of the main directions and specializations of training are similar to the names of professional activities – geological exploration, mining, and processing of mineral raw materials, etc.

However, this does not mean that graduates of only the main directions and specializations of training can engage in engineering activities in the mineral resource sector. Certainly, companies in this sector of the economy need engineers from related industries – power engineers, economists, specialists in the field of information systems and technologies, technological machines, transport, and many others who want to realize themselves in the field of geology, mining or oil and gas.

In some sectors of the mineral resource complex, for example, the extraction of solid minerals, in order to perform official duties related to the management and conduct of mining operations, the management and conduct of blasting, personnel must meet the requirements of the The Federal Service for the Supervision of Environment, Technology and Nuclear Management (Rostekhnadzor). This department imposes special requirements on the basic higher education of such specialists. In particular, for the above-described case, people, who manage mining operations, must have a basic higher mining education – a diploma of a mining engineer in the specialization "Mining". It is precisely such features that limit the activities of specialists at mining enterprises, even from very close areas. For example, a bachelor or master who has completed training program "Geology" within the framework of classical education (without the qualification of a mining engineer or a mining engineer-geologist) will not be able to manage mining operations, but will certainly be in demand as a specialist, an expert whose activities may be related to analysis, testing, prospecting, design engineering, etc. Similar situations can be observed in the oil and gas field.

Universities, by using their freedoms in terms of forming profiles of educational programs, create and implement programs focused on the mineral resource sector on the basis of non-core directions and specializations of training. This process is especially typical for regions with a dominant mining sector of the economy. For example, within the framework of the master's degree program "Informatics and Computer Science", a program called "Mining and geological information systems" is being created and implemented in universities (an analogue of the profession or profile in the specialist's degree, which was written above). This approach makes it possible to attract additional personnel to the industry, by using graduates of various training programs, and also enables universities to quickly respond to the needs of companies when implementing projects related to the development and exploration of the mineral resource base in the regions.

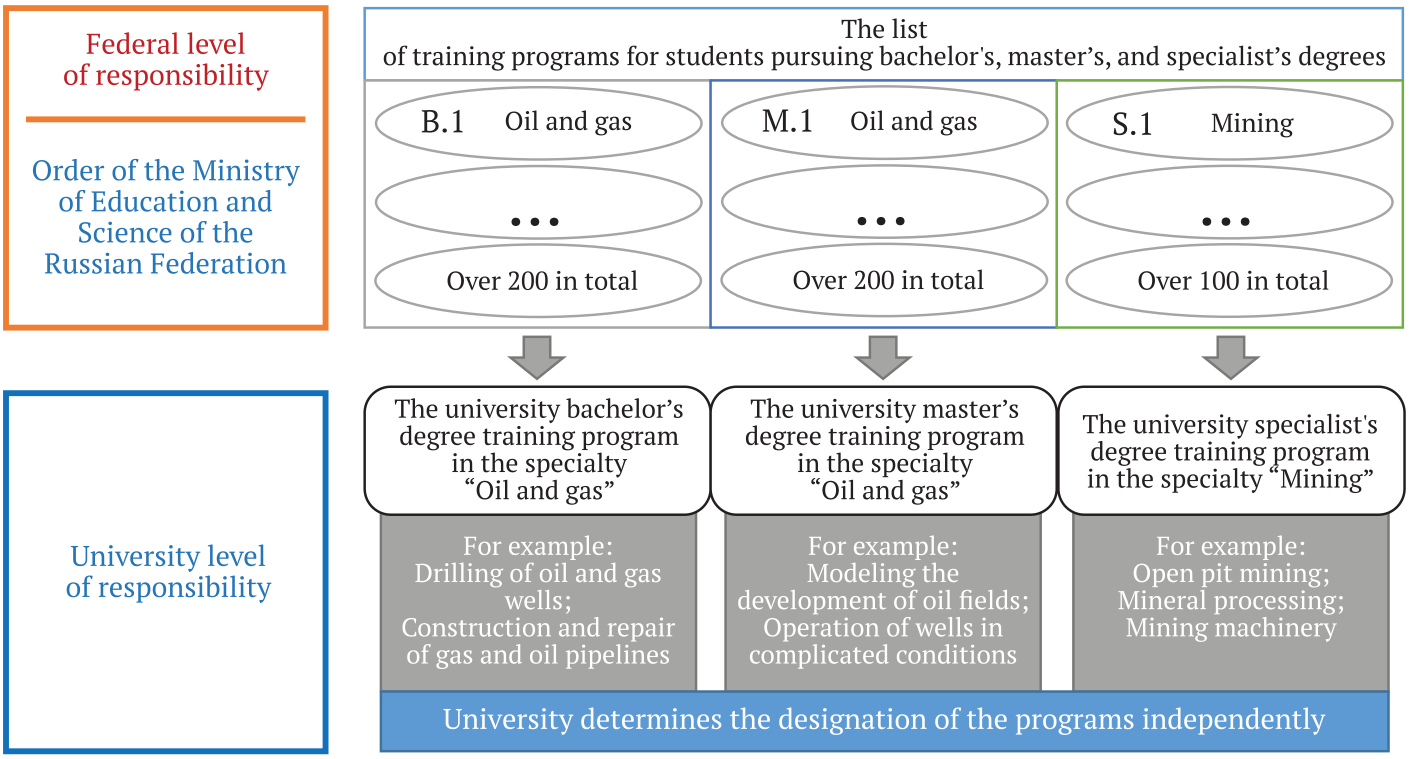

Fig. 1. The pattern of classification of program tracks (training programs) and specialties in higher education in Russia

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Universities that train personnel for the mineral resource sector. Analysis of quantitative characteristics of personnel training

Over the past 15 years, the development of universities in Russia has been carried out on the basis of special government programs, the purpose of which was to increase the competitiveness of both universities and the country's higher education system in general. As a result, a national network of universities was formed, based on federal universities, national research universities [16].

Federal universities are organized in federal districts, usually one university per federal district. However, in the Far Eastern Federal District, taking into account its scale and the special attention of the state to the development of this region, two federal universities were established: in Yakutsk (North-Eastern Federal University) and in Vladivostok (Far Eastern Federal University). There are a total of 10 federal universities in the Russian Federation. They are established to provide training for the integrated socio-economic development of the subjects of the Russian Federation.

The activities of national research universities are aimed at staffing priority areas of development of science, technology, engineering, economic sectors, social sphere, for development and introduction of "high" technologies into production. There are a total of 29 such universities in the Russian Federation.

All federal and national research universities are developing on the basis of development programs that are approved for federal universities by the government of the country, and for national research – by relevant ministries. The development of these universities is carried out under conditions of additional funding. Unfortunately, there are no universities in the Russian Far East that have the status of national research ones.

Under the Russian federal legislation, national research universities have more academic freedoms.or example, they are able to develop and implement their educational programmes based on their own educational standards, while other universities must strictly follow the Federal State Educational Standards of Higher Education (FSES HE). This allows them to respond to the demands of the labor market in a more flexible and creative way, to create programs that can constitute an integral part of large industrial projects, and to "look beyond" some of the constraints that hold back the development of innovative education due to the bureaucratic formal requirements of certain documents. It is fair to note that over the past ten years, federal regulatory documents, including the Federal State Educational Standard of Higher Education itself, have evolved greatly in the direction of transferring significant powers to universities, developing their freedoms, including academic ones, which allows universities to respond more flexibly to new challenges.

This study presents the results of the data analysis of state statistics of the Russian Federation in the higher education system. Universities provide data on the main statistical indicators in the relevant directions and specializations of training annually. The author of the article obtained these data from the Ministry of Science and Higher Education of the Russian Federation. In this publication, they are presented for public discussion (data are given for 2021). Tables 1 and 2 provide information about universities and the number of graduates in training programs and professions for the mineral resource sector in 2021. Statistical data are presented with an accuracy of one accounting unit (one graduate) and are given in tables without rounding, as they reflect the absolute values of indicators from the system of state statistics of the Russian Federation. Table does not provide data on the graduation of mining engineers in the training program "Oil and Gas Engineering and Technology", which is due to the fact that this specialization is new. Training on it was started only five years ago, and the first graduation in specialized Russian universities will take place in 2022 only. An analytical review of the training of mining engineers in this profession will be presented by the Federal Academic Methodological Association in the coming publications. The data is grouped by federal districts of Russia.

Table 1

Number of graduates by specializations of training: "Applied Geology"; "Geological Exploration"; "Mining"; "Physical Processes in Mining or Oil and Gas Production" in 2021

	University	Specialization of training							
		Mining		Applied Geology		Geological Exploration		Physical Processes in Mining or Oil and Gas Production	
		admission	graduation	admission	graduation	admission	graduation	admission	graduation
Central Federal District									
1	National Research University "Belgorod State University", Belgorod	52	17	22	7	–	–	–	–
2	Belgorod State Technological University named after V. G. Shukhov, Belgorod; Gubkin branch, Belgorod region	22	43	–	–	–	–	–	–

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Table 1 continued

	University	Mining admission	Mining graduation	Applied Geology admission	Applied Geology graduation	Geological Exploration admission	Geological Exploration graduation	Physical Processes in Mining or Oil and Gas Production admission	Physical Processes in Mining or Oil and Gas Production graduation
3	Voronezh State University, Voronezh	–	–	9	–	–	–	–	–
4	Moscow Polytechnic University, Moscow	49	92	–	47	–	17	–	–
5	Sergo Ordzhonikidze Russian State University for Geological Prospecting, Moscow; branch in Stary Oskol, Belgorod Region	117	52	203	95	77	74	20	9
6	Peoples' Friendship University of Russia, Moscow	24	15	23	22	–	–	–	–
7	Gubkin Russian State University of Oil and Gas (National Research University), Moscow	–	–	79	54 (84*)	49 (75*)	49	25	21
8	Tver State Technical University, Tver	16	10	–	–	–	–	–	–
9	Tula State University, Tula	44	27	–	–	–	–	–	–
10	Dubna University, Dubna, Moscow region	–	–	–	–	19	17	–	–
11	University of Science and Technology MISIS, Moscow; branch – Technological Institute named after A.A. Ugarov in Stary Oskol; branch in Gubkin, Belgorod region	303 (408**)	260	–	–	–	–	26	22
12	Southwest State University, Kursk	29	24	–	–	–	–	–	–
	Итого	**656**	**540**	**336**	**225**	**150**	**157**	**71**	**52**
	Total: 12 universities are training in the Central Federal District								
	Southern Federal District								
1	Astrakhan State Technical University, Astrakhan	–	–	29	16	–	–	–	–
2	Astrakhan State University, Astrakhan	–	–	–	–	–	–	–	–
3	Kuban State University, Krasnodar	–	–	–	–	23	–	–	–
4	Platov South-Russian State Polytechnic University (NPI), Novocherkassk; branch – Shakhty Highway Institute in Shakhty, Rostov region	79	106	58	62	–	–	–	–
5	Southern Federal University, Rostov-on-Don	–	–	23	15	–	–	–	–
	Total	**79**	**106**	**110**	**93**	**23**	**–**	**–**	**–**
	Total: 5 universities are training in the Southern Federal District								
	North-Western Federal District								
1	Murmansk Arctic State University, Murmansk, branch in Apatity, Murmansk region	53	36	–	–	–	–	10	–

* Gubkin Russian State University of Oil and Gas (National Research University) trains specialists in the field of Geological Exploration at the branch in Tashkent, Republic of Uzbekistan. In 2021, the admission to this specialization course amounted to 30 persons, while the number of graduates was 26. These figures are not included in the overall statistics for the Russian Federation.

** University of Science and Technology MISIS trains specialists in the field of Mining at the branch in Almalyk, Republic of Uzbekistan. In 2021, the admission to this specialization course amounted to 105 persons. The first graduation in the branch is planned for 2023. These figures are not included in the overall statistics for the Russian Federation.

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Table 1 continued

University		Mining		Applied Geology		Geological Exploration		Physical Processes in Mining or Oil and Gas Production	
		admission	graduation	admission	graduation	admission	graduation	admission	graduation
2	Murmansk State Technical University, Murmansk	–	–	–	–	–	–	22	3
3	Petrozavodsk State University, Petrozavodsk, Republic of Karelia	37	38	–	–	–	–	–	–
4	Saint Petersburg Mining University (National Research University), Saint Petersburg	392	296	129	88	52	47	–	–
5	Northern (Arctic) Federal University named after M. V. Lomonosov, Arkhangelsk,	19	11	15	10	–	–	–	–
6	Ukhta State Technical University, Ukhta, Komi Republic; branch in Vorkuta	38	15	18	20	–	11	–	–
	Total	**539**	**396**	**162**	**118**	**52**	**58**	**32**	**3**
Total: 6 universities are training in the North-Western Federal District									
Far Eastern Federal District									
1	Amur State University, Blagoveshchensk, Amur region	–	7	35	31	–	–	–	–
2	East Siberia State University of Technology and Management, Ulan-Ude, Republic of Buryatia	8	–	–	–	–	–	–	–
3	Far Eastern Federal University, Vladivostok	–	68	–	–	–	–	–	–
4	North-Eastern State University, Magadan	78	43	24	7	–	–	–	–
5	Ammosov North-Eastern Federal University, Yakutsk, Republic of Sakha-Yakutia; branch in Mirny, branch in Neryungri	212	179	46	24	46	23	–	–
6	Pacific National University, Khabarovsk	27	14	–	–	–	–	–	–
	Total	**325**	**311**	**105**	**62**	**46**	**23**	**–**	**–**
Total: 6 universities are training in the Far Eastern Federal District									
Siberian Federal District									
1	T. F. Gorbachev State Technical University, Kemerovo, Kuzbass; branch in Prokopyevsk; branch in Mezhdurechensk; branch in Novokuznetsk; branch in Belov, Kemerovo region	591	402	–	8	–	–	19	17
2	Siberian Federal University, Krasnoyarsk	158	136	70	44	75	32	–	–
3	Siberian State Industrial University, Novokuznetsk, Kemerovo region	261	140	20	14	–	–	–	–
4	Irkutsk National Research Technical University, Irkutsk	366	147	25	18	27	21	–	–
5	Irkutsk National Research State University, Irkutsk	–	–	24	26	–	–	–	–
6	N. M. Fedorovsky Polar State University, Norilsk, Krasnoyarsk krai	66	37	–	–	–	–	–	–

End of Table 1

University		Mining		Applied Geology		Geological Exploration		Physical Processes in Mining or Oil and Gas Production	
		admission	graduation	admission	graduation	admission	graduation	admission	graduation
7	Siberian State University of Geosystems and Technologies, Novosibirsk	117	29	–	–	–	–	–	–
8	National Research Tomsk Polytechnic University, Tomsk; branch – Yurginsky Technology Institute, Yurga, Kemerovo region	–	8	83	57	51	30	–	–
9	National Research Tomsk State University, Tomsk	–	–	–	9	–	–	–	–
10	Tuvan State University, Kyzyl, Republic of Tuva	38	–	–	–	–	–	–	–
11	Novosibirsk State University of Architecture and Civil Engineering (SIBSTRIN), Novosibirsk[1]	–	–	–	–	–	–	–	–
12	Transbaikal State University, Chita	169	158	40	7	–	8	–	–
	Total	**1766**	**1057**	**262**	**183**	**153**	**91**	**19**	**17**
Total: 12 universities are training in the Siberian Federal District									
Ural Federal District									
1	Nosov Magnitogorsk State Technical University, Chelyabinsk region	247	140	–	–	–	–	–	–
2	Technical University of UMMC, Verkhnyaya Pyshma, Sverdlovsk region	30	20	–	–	–	–	–	–
3	Tyumen Industrial University, Tyumen	44	–	88	107	54	35	–	–
4	Ural State Mining University, Yekaterinburg, Sverdlovsk region	626	350	91	89	109	86	–	–
5	Yugra State University, Khanty-Mansiysk, Khanty-Mansi autonomous district	–	–	25	22	–	–	–	–
6	South Ural State University (National Research University), branch in Miass, Chelyabinsk region	–	–	9	–	–	–	–	–
	Total	**947**	**510**	**213**	**218**	**163**	**121**	**–**	**–**
Total: 6 universities are training in the Ural Federal District									
Volga Federal District									
1	Bashkir State University, Republic of Bashkortostan, Ufa, Sterlitamak branch	–	–	–	–	34	49	18	–
2	Kazan National Research Technological University, Kazan, Republic of Tatarstan	25	14	–	–	–	–	–	–
3	Orenburg State University, Orenburg	–	–	103	96	–	–	–	–
4	Perm State National Research University, Perm	–	–	–	–	16	–	–	–

Note: the header "Specialization of training" spans the Mining, Applied Geology, Geological Exploration and Physical Processes columns.

[1] The university had no admission and graduation in 2021, but has license and accreditation for the Mining specialty. According to the information from the University, the RF Ministry of Education and Science has allocated 10 state-financed openings for the enrollment of students in 2023.

University		Specialization of training							
		Mining		Applied Geology		Geological Exploration		Physical Processes in Mining or Oil and Gas Production	
		admission	graduation	admission	graduation	admission	graduation	admission	graduation
5	Perm National Research Polytechnic University, Perm, branch in Berezniki, Perm Krai	106	72	94	35	–	–	19	12
6	Samara State Technical University, Samara	–	–	23	40	–	–	22	19
7	Saratov (Chernyshevsky) State University, Saratov	–	–	76	41	–	–	–	–
8	Udmurt State University, Izhevsk, Republic of Udmurtia	–	–	22	15	–	–	–	–
9	Ufa State Petroleum Technical University, Ufa, Republic of Bashkortostan	–	–	34	62	17	34	–	–
	Total	**131**	**86**	**352**	**289**	**67**	**83**	**59**	**31**
Total: 9 universities are training in Volga Federal District									
North Caucasus Federal District									
1	Grozny State Oil Technical University, Grozny, Chechen Republic	–	–	23	26	31	23	–	–
2	North Caucasus Mining and Metallurgical Institute (State Technological University), Vladikavkaz, Republic of North Ossetia	106	69	27	17	–	–	–	–
3	North Caucasus Federal University, Stavropol	–	–	49	31	12	35	–	–
	Total	**106**	**69**	**99**	**74**	**43**	**58**	**–**	**–**
Total: 3 universities are training in the North Caucasus Federal District									
Total: 59 universities are training in the Russian Federation									
	Summary total	**4549**	**3075**	**1639**	**1262**	**697**	**591**	**181**	**103**

Table 2

The number of graduates in the directions of training “Oil and Gas” (bachelor’s degree, master’s degree) and specialization “Oil and Gas Engineering and Technology” (specialist’s degree) in 2021

University		Directions and specialization of training					
		“Oil and Gas”, bachelor’s degree		“Oil and Gas Engineering and Technologies”, specialist’s degree		“Oil and Gas”, master’s degree	
		admission	graduation	admission	graduation	admission	graduation
Central Federal District							
1	Voronezh State Technical University, Voronezh	110	128	–	–	60	49
2	Moscow Polytechnic University, Moscow	10	63	–	–	–	–
3	Sergo Ordzhonikidze Russian State University for Geological Prospecting, Moscow; branch in Stary Oskol, Belgorod Region	36	54	–	–	42	69
4	Gubkin Russian State University of Oil and Gas (National Research University), Moscow	388 (604*)	329 (508*)	53	–	323	384
5	Peoples’ Friendship University of Russia, Moscow	83	56	–	–	17	7

* Gubkin Russian State University of Oil and Gas (National Research University) trains bachelors in the field of Oil and Gas at the branch in Tashkent, Republic of Uzbekistan. In 2021, the admission to this specialization course amounted to 216 persons, while the number of graduates was 179. These figures are not included in the overall statistics for the Russian Federation.

Table 2 continued

	University	Directions and specialization of training					
		"Oil and Gas", bachelor's degree		"Oil and Gas Engineering and Technologies", specialist's degree		"Oil and Gas", master's degree	
		admission	graduation	admission	graduation	admission	graduation
6	Skolkovo Institute of Science and Technology, Moscow	–	–	–	–	12	13
7	Tambov State Technical University, Tambov	3	11	–	–	2	2
	Total	**630**	**641**	**53**	**–**	**456**	**524**
Total: 7 universities are training in the Central Federal District							
Southern Federal District							
1	Astrakhan State Technical University, Astrakhan	109	132	–	–	52	108
2	Don State Agrarian University Novocherkassk Engineering and Reclamation Institute named after A. K. Kortunova – branch of Don State Agrarian University, Novocherkassk, Rostov region	29	–	–	–	–	–
3	Kuban State Technological University, Krasnodar, branch in Armavir, Krasnodar Krai	213	276	–	–	86	137
4	Maykop State Technological University, Maykop, branch in Yablonovsky, Republic of Adygea	115	136	–	–	19	–
5	Platov South-Russian State Polytechnic University (NPI), Novocherkassk, Rostov region	62	47	24	–	–	–
	Total	**528**	**591**	**24**	**–**	**157**	**245**
Total: 5 universities are training in the Southern Federal District							
North-Western Federal District							
1	Murmansk State Technical University, Murmansk	17	10	–	–	–	–
2	Saint Petersburg Mining University (National Research University), Saint Petersburg	317	227	92	–	137	109
3	Saint Petersburg State University, Saint Petersburg	16	8	–	–	9	13
4	Northern (Arctic) Federal University named after M. V. Lomonosov, Arkhangelsk	100	68	–	–	24	9
5	Ukhta State Technical University, Ukhta, Komi Republic; branch in Vorkuta, branch in Usinsk	263	287	69	–	75	44
	Total		**600**	**161**	**–**	**245**	**175**
Total: 5 universities are training in the North-Western Federal District							
Far Eastern Federal District							
1	Far Eastern State Transport, Khabarovsk, branch in Svobodny, Khabarovsk region	34	44	–	–	1	–
2	Far Eastern Federal University, Vladivostok, Far Eastern region	52	92	–	–	30	35
3	Maritime State University named after admiral G. I. Nevelskoy, Vladivostok, Far Eastern Region[2]	–	–	–	–	–	–
4	Sakhalin State University, Yuzhno-Sakhalinsk	39	60	–	–	–	–
5	Ammosov North-Eastern Federal University, Yakutsk, Republic of Sakha-Yakutia, branch in Mirny	42	49	33	–	–	–

[2] In 2021, the University did not have an admission and graduation on these specialties. However, there is a certain number of students enrolled in previous years (59 people at different study years).

Table 2 continued

	University	Directions and specialization of training					
		"Oil and Gas", bachelor's degree		"Oil and Gas Engineering and Technologies", specialist's degree		"Oil and Gas", master's degree	
		admission	graduation	admission	graduation	admission	graduation
6	Pacific National University, Khabarovsk	25	56	–	–	–	–
	Total	**192**	**301**	**33**	**–**	**31**	**35**
Total: 6 universities are training in the Far Eastern Federal District							
Siberian Federal District							
1	Irkutsk National Research Technical University, Irkutsk	112	292	107	–	37	4
2	National Research Tomsk Polytechnic University, Tomsk	182	205	–	–	125	99
3	Omsk State Technical University, Omsk	209	153	–	–	80	85
4	Siberian Federal University, Krasnoyarsk	33	88	–	–	–	–
5	Tomsk State University of Architecture and Building, Tomsk	81	34	–	–	–	–
	Total	**617**	**772**	**107**	**–**	**242**	**188**
Total: 5 universities are training in the Siberian Federal District							
Ural Federal District							
1	Nizhnevartovsk State University, Nizhnevartovsk, Khanty-Mansi autonomous district	62	122	–	–	–	–
2	Tyumen Industrial University, Tyumen, branch in Noyabrsk, branch in Surgut, branch in Nizhnevartovsk, Khanty-Mansi autonomous district	411	1137	493	–	216	669
3	Yugra State University, Yugra, Khanty-Mansi autonomous district	262	363	–	–	–	–
	Total	**735**	**1622**	**493**	**–**	**216**	**669**
Total: 3 universities are training in the Ural Federal District							
Volga Federal District							
1	Almetyevsk State Oil Institute, Almetyevsk, Republic of Tatarstan	135	176	–	–	60	73
2	Kalashnikov Izhevsk State Technical University, Udmurtia	22	–	–	–	8	–
3	Kazan (Volga Region) Federal University, Kazan, Republic of Tatarstan	102	57	–	–	52	38
4	Kazan National Research Technological University, Kazan, Republic of Tatarstan	51	78	–	–	–	–
5	Kamsky Institute of Humanitarian and Engineering Technologies, Izhevsk, Udmurtia	9	23	–	–	–	–
6	Nizhny Novgorod State Technical University named after R. E. Alekseev, Nizhny Novgorod	54	10	–	–	7	5
7	Perm National Research Polytechnic University, Perm	124	234	50	–	75	31
8	Volga State Technological University, Yoshkar-Ola, Republic of Mari El	43	9	–	–	–	–
9	Samara State Technical University, Samara	688	726	–	–	232	210
10	Yuri Gagarin State Technical University of Saratov, Saratov, branch in Engels, Saratov region	100	200	–	–	–	–
11	Saratov (Chernyshevsky) State University, Saratov	61	31	–	–	–	–

End of Table 2

University		Directions and specialization of training					
		"Oil and Gas", bachelor's degree		"Oil and Gas Engineering and Technologies", specialist's degree		"Oil and Gas", master's degree	
		admission	graduation	admission	graduation	admission	graduation
12	Udmurt State University, Izhevsk, Republic of Udmurtia, branch in Votkins	235	408	186	–	69	63
13	Ulyanovsk State Technical University, Ulyanovsk	18	16	–	–	14	3
14	Ulyanovsk State University, Ulyanovsk	38	68	–	–	14	–
15	Ufa State Petroleum Technical University, Ufa, Republic of Bashkortostan, Sterlitamak branch, Oktyabrsky branch, Salavat branch	475	732	805	–	367	495
16	Branch of Gubkin Russian State University of Oil and Gas (National Research University) in Orenburg	128	185	–	–	–	–
17	Cheboksary Institute (branch) of "Moscow Polytechnic University", Cheboksary, Chuvash Republic	45	–	–	–	–	–
	Total	**2328**	**2953**	**1041**	**–**	**898**	**918**
Total: 17 universities are training in the Volga Federal District							
North Caucasus Federal District							
1	Grozny State Oil Technical University, Chechen Republic	75	106	71	–	28	20
2	Dagestan State Technical University, Makhachkala, Republic of Dagestan	95	66	–	–	14	32
3	Ingush State University, Magas, Republic of Ingushetia	54	–	–	–	–	–
4	North Caucasus Mining and Metallurgical Institute (State Technological University), Vladikavkaz, Republic of North Ossetia[3]	–	–	–	–	–	–
5	North Caucasus Federal University, Stavropol	161	233	–	–	55	98
6	Kadyrov Chechen State University, Grozny, Chechen Republic	3	–	–	–	–	–
	Total	**388**	**405**	**71**	**–**	**97**	**150**
Total: 6 universities are training in the North Caucasus Federal District							
Total: 54 universities are training in the Russian Federation							
	Summary total	**6131**	**7885**	**1983**	**–**	**2342**	**2904**

[3] In 2021, the University did not have an admission and graduation on these specialties. However, there is a certain number of students enrolled in previous years (41 people at different study years).

Among the universities that train personnel for the mineral resource sector of the economy, different categories of universities can be determined. There are historical industry universities of mining, geological or oil and gas profile, for example, Saint Petersburg Mining University (National Research University); Gubkin Russian University of Oil and Gas (National Research University) (Moscow), University of Science and Technology MISIS (Moscow), Ural State Mining University, and also federal universities, such as North-Eastern Federal University (Yakutsk), Siberian Federal University (Krasnoyarsk), Far Eastern Federal University (Vladivostok), etc. There are universities in each federal district that train personnel for the country's mineral resource sector, which indicates the possibility of supporting the implementation of geological exploration projects and the development of new mineral deposits.

Based on the data provided in the table, the following conclusions can be drawn:

- In total, 85 universities in all federal districts are training specialists for the mineral resource sector in the Russian Federation.

● 36 universities in all federal districts are training specialists for the extraction and processing of solid minerals (Mining).

● 49 universities in all federal districts are training specialists for the extraction, primary processing, and transportation of liquid and gaseous minerals (Oil and gas).

● 37 universities in all federal districts are training specialists for geological exploration (applied geology, geological exploration).

● Among the universities that train specialists for the mineral resource sector, 7 are federal universities, 13 are national research universities of Russia.

● The largest number of universities that train personnel in the programs and professions of the mineral resource sector is concentrated in the Central Federal District – 15, which is determined by the concentration of large-scale enterprises of the industry that form tens of thousands of jobs, including for engineering personnel (Lebedinsky Mining and Processing Plant, Stoilensky Mining and Processing Plant, Mikhailovsky Mining and Processing Plant, and other enterprises).

Among the universities that make a significant contribution to the formation of quantitative characteristics of personnel training for the mineral resource sector, the following universities should be noted.

Mining: T.F. Gorbachev State Technical University (13.7 % of the total training of specialists); Ural State Mining University (11.38 %); Saint Petersburg Mining University (9.63 %); University of Science and Technology MISIS (8.46 %); Ammosov North-Eastern Federal University (5.82 %); Transbaikal State University (5.14 %); Irkutsk National Research Technical University (4.78 %); Siberian State Industrial University (4.55 %); Magnitogorsk State Technical University named after G.I. Nosov (4.55 %); Siberian Federal University (4.42 %); Platov South-Russian State Polytechnic University (NPI) (3.45 %), – providing training for more than 75 % of the total graduation of relevant personnel in the country.

Applied Geology: Tyumen Industrial University (8.48 %); Orenburg State University (7.61 %); Sergo Ordzhonikidze Russian State Geological Exploration University (7.53 %); Ural State Mining University (7.05 %); Saint Petersburg Mining University (6.97 %); Platov South-Russian State Polytechnic University (NPI) (4.91 %); Ufa State Petroleum Technical University (4.91 %); National Research Tomsk Polytechnic University (4.52 %); Gubkin Russian University of Oil and Gas – National Research University (4.28 %); Moscow Polytechnic University (3.72 %); Siberian Federal University (3.49 %); Saratov (Chernyshevsky) National Research State University (3.25 %); Samara State Technical University (3.17 %); Perm National Research Polytechnic University (2.77 %); Amur State University (2.46 %); North Caucasus Federal University (2.46 %), providing training for more than 75 % of the total graduation of relevant personnel in the country.

Geological Exploration: Ural State Mining University (14.55 %); Sergo Ordzhonikidze Russian State Geological Exploration University (12.52 %); Gubkin Russian University of Oil and Gas National Research University (8.29 %); Bashkir State University (8.29 %); Saint Petersburg Mining University (7.95 %); Tyumen Industrial University (5.92 %); North Caucasus Federal University (5.92 %); Ufa State Petroleum Technical University (5.75 %); Siberian Federal University (5.41 %); National Research Tomsk Polytechnic University (5.08 %); Grozny State Oil Technical University (3.89 %); Ammosov North-Eastern Federal University (3.89 %); Irkutsk National Research Technical University (3.55 %), providing training for more than 90 % of the total graduation of relevant personnel in the country.

Oil and Gas (bachelor's degree): Tyumen Industrial University (14.42 %); Ufa State Petroleum Technical University (9.28 %); Gubkin Russian State University of Oil and Gas – National Research University (6.52 %); Samara State Technical University (9.21 %); Udmurt State University (5.17 %); Yugra State University (4.60 %); Irkutsk National Research Technical University (3.70 %); Ukhta State Technical University (3.64 %); Kuban State Technological University (3.50 %); Perm National Research Polytechnic University (2.97 %); North Caucasus Federal University (2.95 %); Saint Petersburg Mining University (2.88 %); Tomsk National Research Polytechnic University (2.60 %); Yuri Gagarin State Technical University of Saratov (2.54 %); Almetyevsk State Petroleum Institute (2.23 %), providing training for more than 75 % of the total graduation of relevant personnel in the country.

Oil and Gas (master's degree): Tyumen Industrial University, Tyumen (23.04 %); Ufa State Petroleum Technical University (17.05 %); Samara State Technical University (13.22 %); Udmurt State University (7.23 %); Uygra State University (4.72 %); Gubkin Russian State University of Oil and Gas (National Research University (3.75 %); Irkutsk National Research Technical University (3.72 %); Ukhta State Technical University (3.41 %); Kuban State Technological University (3.37 %); Perm National Research Polytechnic University (2.93 %), providing training for more than 80 % of the total graduation of relevant personnel in the country.

The regional analytical section is of great importance in the study of the education system for mining engineers in the country. In the Russian Federation, regional analytics is presented at the level of the constituent subjects of the federation. Given that there are 89 such subjects in the country, it would be difficult to provide relevant research results on the training of mining engineers in all these regions. Therefore, we present these data at the level of federal districts. Grouped information on the graduation of personnel from universities for the mineral resource sector in the context of federal districts is presented in Table 3.

Quantitative characteristics of personnel training for the mineral resource sector in Russian universities in the context of federal districts demonstrate not only the ability of universities in the regions to train professional personnel, but also the demand for them in the respective regions. Thus, the oil and gas sector is concentrated in the large oil and gas regions of the country such as the Ural (20.57 %) and Volga (37.45 %) federal districts. Mining, respectively, in the Siberian Federal district (34.38 %). Professions related to geological exploration of minerals are in demand both in mining companies and oil and gas sector at the same time, which reflects a more uniform distribution of the training of relevant specialists across federal districts.

When assessing quantitative characteristics, analytical data reflecting the dynamics of personnel training over the years are of particular interest.

In the Federal Academic Methodological Association in the system of higher education, statistical accounting of quantitative characteristics of mining engineers graduation in mining specializations has been conducted since 1992 [28, 30]. Updated data on the dynamics of total graduation of mining engineers by year in the professions Mining and Physical Processes in Mining or Oil and Gas Production are presented in Fig. 2.

Similar data for the graduation of specialists in otherdirections and specializations of training of the mineral resource sector are presented in Figs. 3, 4.

The analysis of the presented data allows us to draw the following conclusions:

1. A tendency to decrease the graduation of mining engineers at Russian universities is observed in such specializations as Mining, Applied Geology, Geological Exploration. The reason for this are several factors, among which it should be noted:

- deterioration of reputation of the mining engineer and geologist profession, which affects the attractiveness of these programs at universities;
- relatively low quality indicators of students enrolled in the first year of mining and geological specializations, which is determined by the average indicators of the Unified State Exam. The value of this indicator determines to the greatest extent the student's ability to successfully master the educational program of higher education – its "academic survival".

2. There are fairly stable graduation rates for the oil and gas industry at almost all levels of higher education (bachelor's and master's degrees).

Table 3

Data on the graduation of mining engineers in the main specializations and directions of training of the mineral resource sector in the federal districts of Russia

Federal district	Oil and gas, bachelor's degree	Oil and gas, master's degree	Applied Geology, specialist's degree	Geological Exploration, specialist's degree	Mining, specialist's degree	Physical Processes in Mining or Oil and Gas Production, specialist's degree
Central Federal District	641 (8.13 %)	524 (18.04 %)	225 (17.83 %)	157 (26.57 %)	540 (17.56 %)	52 (50.49 %)
Southern Federal District	591 (7.50 %)	245 (8.44 %)	93 (7.37 %)	–	106 (3.45 %)	–
North-Western Federal District	600 (7.61 %)	175 (6.03 %)	118 (9.35 %)	58 (9.81 %)	396 (12.88 %)	3 (2.91 %)
Far Eastern Federal District	301 (3.82 %)	35 (1.21 %)	62 (4.91 %)	23 (3.89 %)	311 (10.12 %)	–
Siberian Federal District	772 (9.79 %)	188 (6.47 %)	183 (14.50 %)	91 (15.40 %)	1057 (34.37 %)	17 (16.50 %)
Ural Federal District	1622 (20.57 %)	669 (23.04 %)	218 (17.27 %)	121 (20.47 %)	510 (16.59 %)	–
Volga Federal District	2953 (37.45 %)	918 (31.61 %)	289 (22.90 %)	83 (14.04 %)	86 (2.80 %)	31 (30.10 %)
North Caucasus Federal District	405 (5.14 %)	150 (5.17 %)	74 (5.86 %)	58 (9.81 %)	69 (2.24 %)	–
Total	**7885 (100 %)**	**2904 (100 %)**	**1262 (100 %)**	**591 (100 %)**	**3075 (100 %)**	**103 (100 %)**

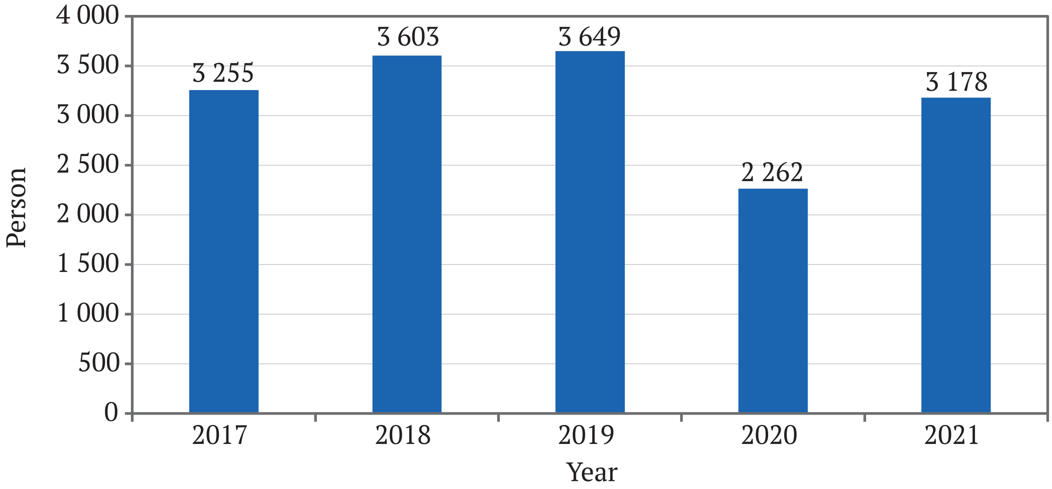

Fig. 2. Graduation of mining engineers in Russia in specializations "Mining" and "Physical Processes in Mining or Oil and Gas Production" from 2017 to 2021

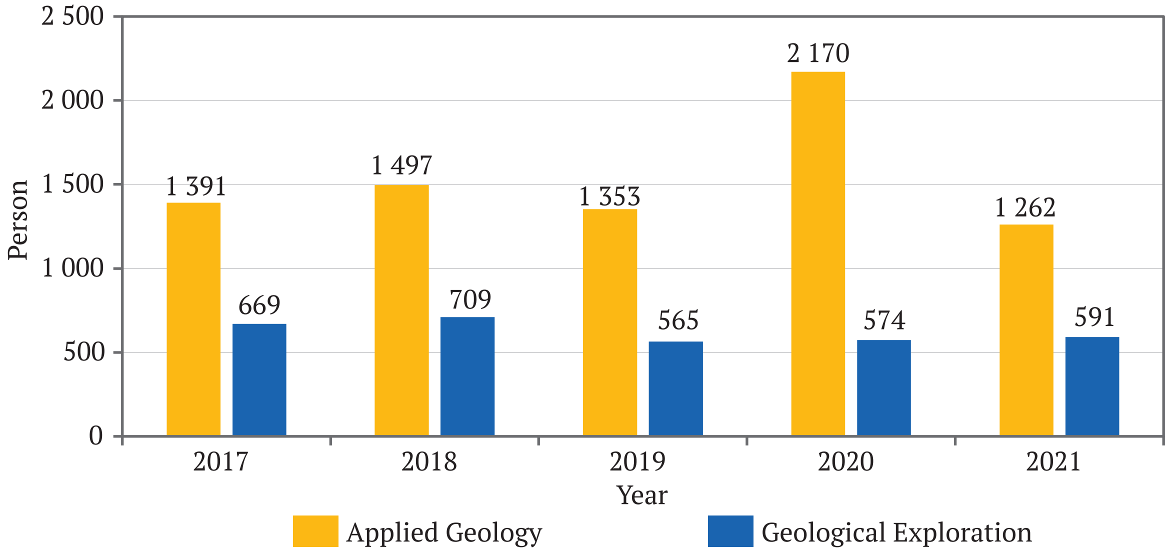

Fig. 3. Graduation of mining engineers in Russia in specializations "Applied Geology" and "Geological Exploration" from 2017 to 2021

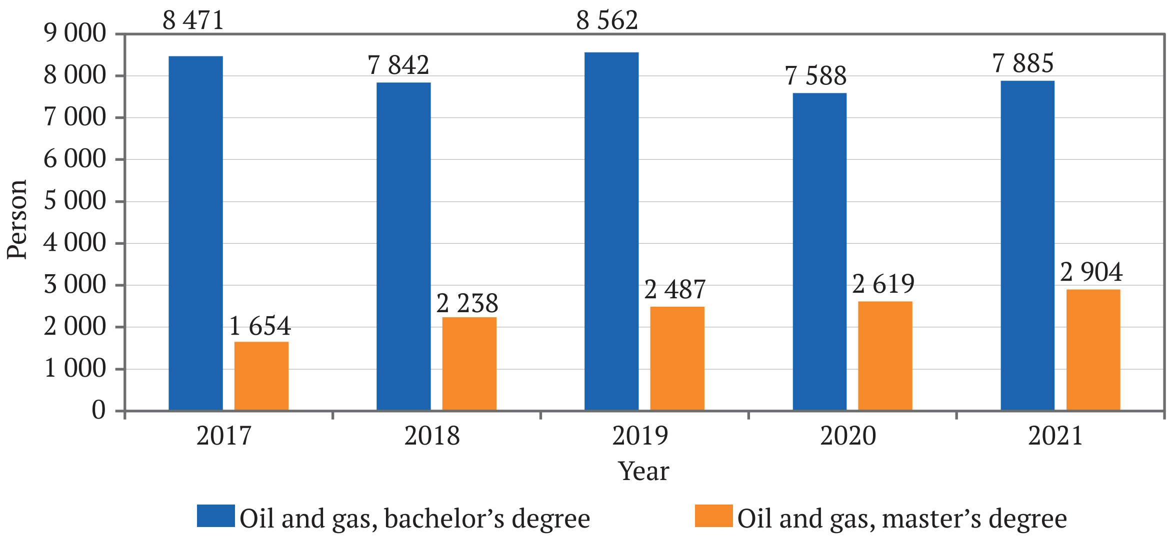

Fig. 4. Graduation of bachelors and masters in Russia in the program "Oil and gas" from 2017 to 2021

3. It is obvious that the indicators of personnel training for the mineral resource sector in the Far Eastern Federal district (see Table 3) do not correspond to its needs necessary to solve those tasks that are now being formalized at the level of the state vector of development of the country's economy. The Far Eastern Federal District occupies a dominant position in reserves and extraction of the main types of minerals among other regions of the Russian Federation. The region has large reserves of hydrocarbons, 49.1 % of coal reserves, 73.85 % of uranium reserves, almost all tin reserves (100 % of Russian production), 65.8 % of wolfram reserves (100 % of Russian production), 34.6 % of copper reserves, 54.3 % of lead reserves, 57.4 % of zinc reserves, 61.06 % of molybdenum reserves, 64.8 % of mercury reserves, 97 % of arsenic reserves (100 % of production in the Russian Federation), 87 % of antimony reserves, 62.7 % of bismuth reserves, 59.8 % of germanium reserves, 76.45 % of diamond reserves, 73.2 % of iron reserves, 99.68 % of boron reserves, 91.5 % of jade reserves, 97 % of perlite reserves, which forms a significant industrial and export potential of the territory [31]. A significant increase in the number of mining enterprises is expected in the segment of common minerals, which is associated with the development of the regional construction industry and the production of local building materials [31]. According to official data presented in the analytical note of the Ministry for Development of Russian Far East "Calculation of the personnel needs of key sectors of the economy of Far Eastern Federal District with distribution by region, taking into account the requirements for the education level 2020–2025 and proposals on the volume and structure of personnel training with higher education and secondary vocational education for 2020–2025", the need for specialists with higher education and work experience for the mining of coal, metal ores, and diamonds for 2020–2025 amounted to 1876 people. The Analytical Note of Russian Far East an Arctic Development Corporation on personnel needs in key sectors of the economy in Far East indicates that as of 01.01.2021, the average number of employees in the coal, metal ores, and diamonds mining industry was 114,112 people. Employment growth in the industry is expected to be the largest and will amount to 20–25 % by 2027. At the same time, the additional need will be from 30,000 employees [31].

It is noteworthy that the increase in demand for specialists in Russian Far East was predicted as early as 2005 [30]. Forecast justification was carried out at Moscow State Mining University (now, University of Science and Technology MISIS) and presented in a number of publications. Unfortunately, the situation has only worsened over the past time, the formed federal universities in Yakutsk and Vladivostok have not been able to increase the graduation of mining engineers, and targeted training for the needs of Far East in other regions does not work actually. The fragmentation of

Table 4

Admission to universities in the directions and specializations of training of the mineral resource sector

Directions and specializations of training	Admission in 2021/22		
	Total	Budget	The share of students accepted for the first year to study at the expense of the state budget of Russia, %
Oil and gas, bachelor's degree	6 131	3 138	51
Oil and gas, master's degree	2 342	1 247	53
Applied Geology, specialist's degree	1 639	1 252	76
Geological Exploration, specialist's degree	697	603	87
Mining, specialist's degree	4 549	2 781	61
Physical Processes in Mining or Oil and Gas Production, specialist's degree	181	160	88
Oil and Gas Engineering and Technologies, specialist's degree	1 983	444	22

Table 5

The average subject score of the Unified State Exam of an enrolled first-year mining and geology student

Form of training	Maximum value of the average subject score of the Unified State Exam in Russian universities when applying for mining and geological specializations	Minimum value of the average subject score of the Unified State Exam in Russian universities when applying for mining and geological specializations
Training at the expense of the Russian Federation (state grant)	84.7 out of 100 possible	47.4 out of 100 possible
Training at the expense of private and legal entities	72.9 out of 100 possible	48.2 out of 100 possible

country's regions, outflow of population to other regions, the weak attractiveness of jobs in the Far East for the younger generation is affected. It is to be hoped that the situation will change.

All these facts indicate the need for additional state measures related to planning the development of this segment of higher education in Russian Far East [30].

Analysis of admission to universities for directions and specializations of training of the mineral resource sector

The characteristics of graduation and admission to universities may differ significantly. It is due not only to the presence of a delay determined by the time of learning process itself (4–6 years), but also changes in management decisions at the federal and university levels. The analysis of the quantitative characteristics of admission makes it possible to predict the upcoming graduation, taking into account the likely "dropout" of students during learning process.

Table 4 shows data on admission to universities in training programs and professions of the mineral resource sector in 2021.

The data given in Table 4 reflect a higher level of extra-budgetary training in training programs related to oil and gas, which again indicates their higher attractiveness. The establishment of the Oil and Gas Engineering and Technology profession for training personnel in the oil and gas industry was justified, which reflects its popularity among university entrants. Most of the students enrolled in the first year of this profession study at the expense of individuals and legal entities (in fact, about 80 %). This does not mean that bachelor's degree programs in this field are not in demand. Most likely, specialized universities and companies have decided on the functionality and areas of responsibility of graduates of bachelor's and specialist's degree in employment, and effectively use both levels of higher education to form the human engineering potential of the industry.

Analysis of the data presented in Tables 2 and 4, indicates that graduation of bachelors in the program Oil and Gas is much higher than admission this year. This phenomenon is largely explained by the fact that at the federal level, within the framework of all directions and specializations of training in the field of oil and gas, a decision to terminate extra-mural education was made. Experts drew attention to the fact that personnel training in these directions and specializations of training using extra-mural programs has taken hypertrophied forms. This contingent of students began to dominate, which began to affect the overall quality of industry training. At the level of the Federal Academic Methodological Association, it was decided to exclude the possibility of extra-mural training in all areas of directions and specializations of training in the field of oil and gas business. The decision was made collectively and reflected in the requirements of federal state educational standards.

Express analysis of admission quality of higher education programs of mining and geological profile

When describing some of admission features to the university of Russia, the author noted the need for the results of the Unified State Exam (USE) for the applicant when entering the university. Universities are competing with each other to attract applicants with high USE scores or winners of Olympiads. Indicators that determine the average USE score of an enrolled student are included in the quality indicators of admission in the federal monitoring systems and the national university ranking systems.

Many processes and procedures for admission to the university are implemented on the basis of information platforms, which allows for the systematic collection of voluminous information and its analysis. Information reflecting the average score of the Unified State Exam in the disciplines of the enrolled applicant is also accumulated in information systems, grouped, and presented publicly (https://ege.hse.ru/rating).

Here are some data that will allow for an express assessment of the quality of admission to mining and geological professions in Russia.

Table 5 presents data on the average subject score of the Unified State Exam of an enrolled first-year mining and geology student in 2021.

Table 5 indicates that the specialized universities achieve different results in the qualitative characteristics of student enrolment in the first year of mining and geology. It is obvious that the universities of Moscow and Saint Petersburg win in this competition. The universities located in the capital city have always attracted gifted young people from the regions, while the specialized training in secondary schools is actually better in these regions.

At the same time, the status of universities does not always guarantee to win in the competition. Sometimes both federal and national research universities face significant difficulties in attracting well-trained applicants.

The situation in this regard is particularly difficult in remote mining and industrial regions and one-company towns – cities whose economy is dominated by the mining and industrial sector. Examples of such regions are Magadan, Murmansk region, Komi Republic, Krasnoyarsk Krai (Norilsk), etc. Universities and their branches have to do a lot of work to attract applicants with high USE scores. It should be taking into account that this problem also has a social connotation.

Conclusion

1. The system of personnel potential formation for the mineral resource sector of Russia is based on a national network of universities represented in virtually all regions with a developed mining complex.

2. In the specializations "Applied Geology", "Geological Exploration", "Mining", "Physical Processes in Mining or Oil and Gas Production" in 2021, 5,031 mining engineers were trained in Russia; in the programs of the oil and gas profile – 10,789 bachelors and masters.

3. Quantitative parameters of personnel training for the mineral resource sector at Russian universities indicate the opportunity of forming human resources of the industry only at the expense of their own academic schools in the higher education system.

4. The system of mining engineer training in Russia is developing in conditions of acute competition with other fields of higher education training in terms of attracting the most trained and talented young people to mining and geological programs who are able to master educational programs effectively and take jobs in the industry after graduation.

5. Universities and mining businesses should undertake significant efforts to improve the reputation of the mining engineer profession in society, including aspects of remuneration and social positioning within the community.

6. Particular attention should be paid to the development of the system to form human resources potential of the mineral resource sector in the Russian Far East, where large-scale projects for the extraction and processing of minerals are to be implemented, requiring new personnel trained at regional universities.

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