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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,

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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

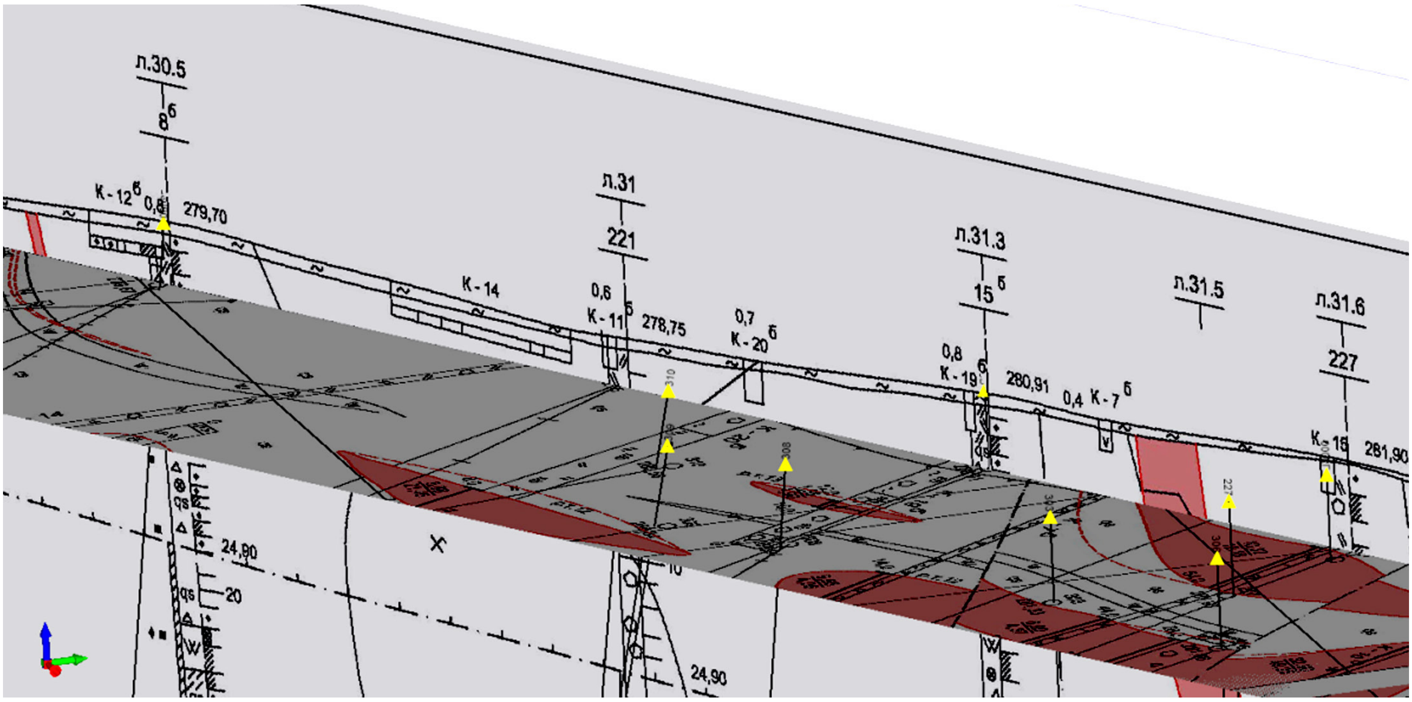

Fig. 1. Georeferenced plan and cross-section along line 128, Berezkinsky area with superimposed database of boreholes

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

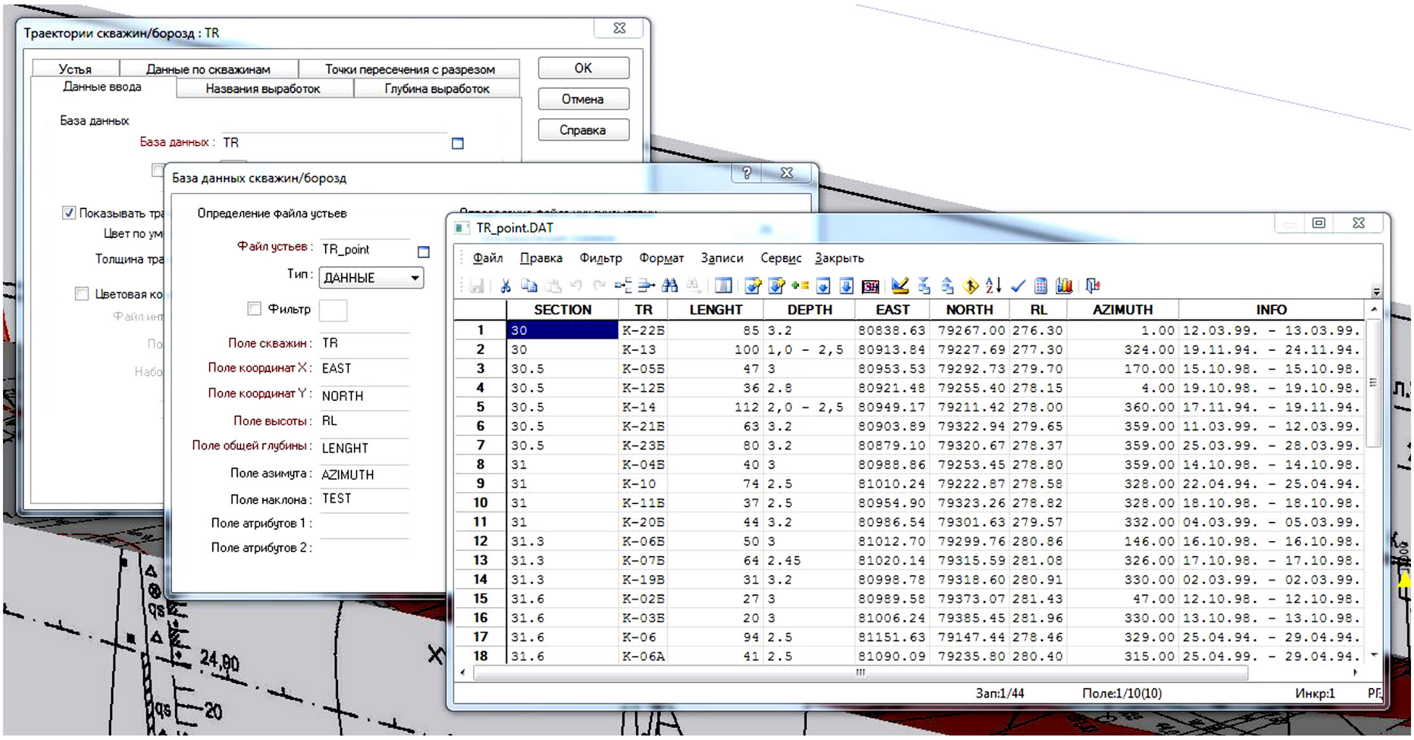

Fig. 2. Database of boreholes and trenches created with the use of the Micromine software

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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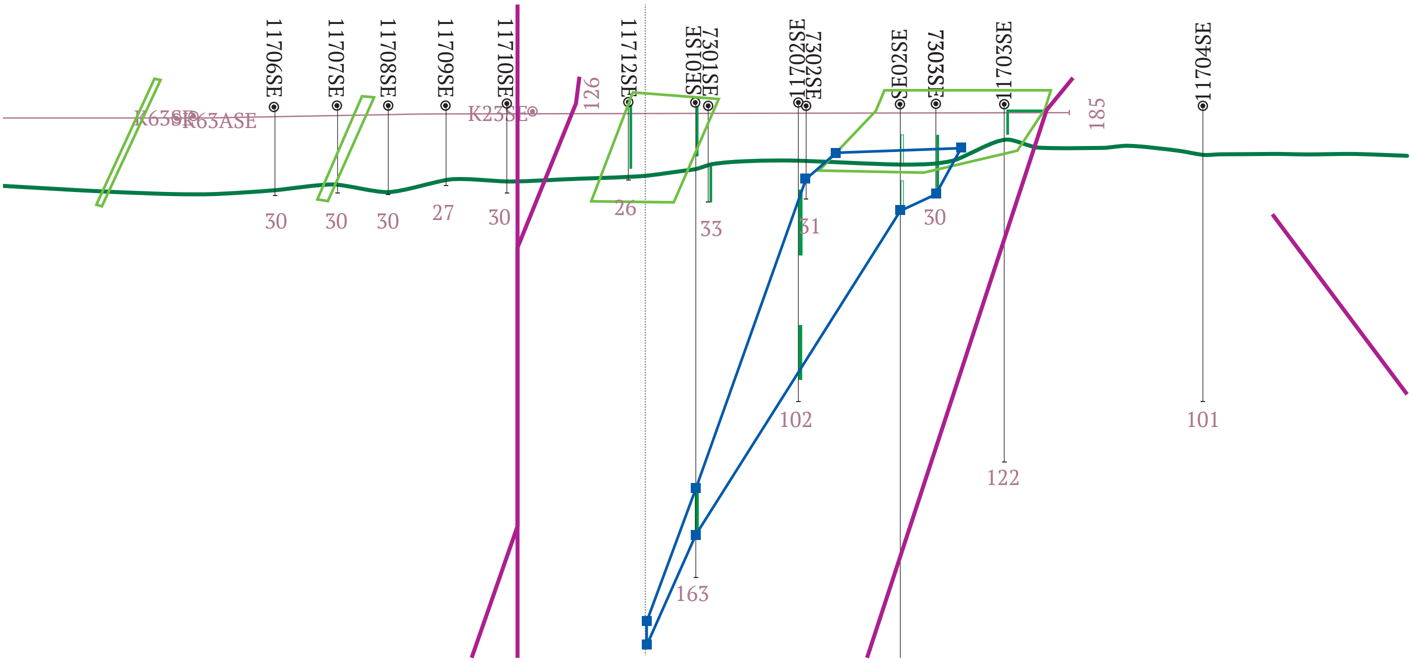

Fig. 3. Vectorization of ore zone outlines at cross-sections linked to composite intervals on P-15 line, the Berezkinsky area

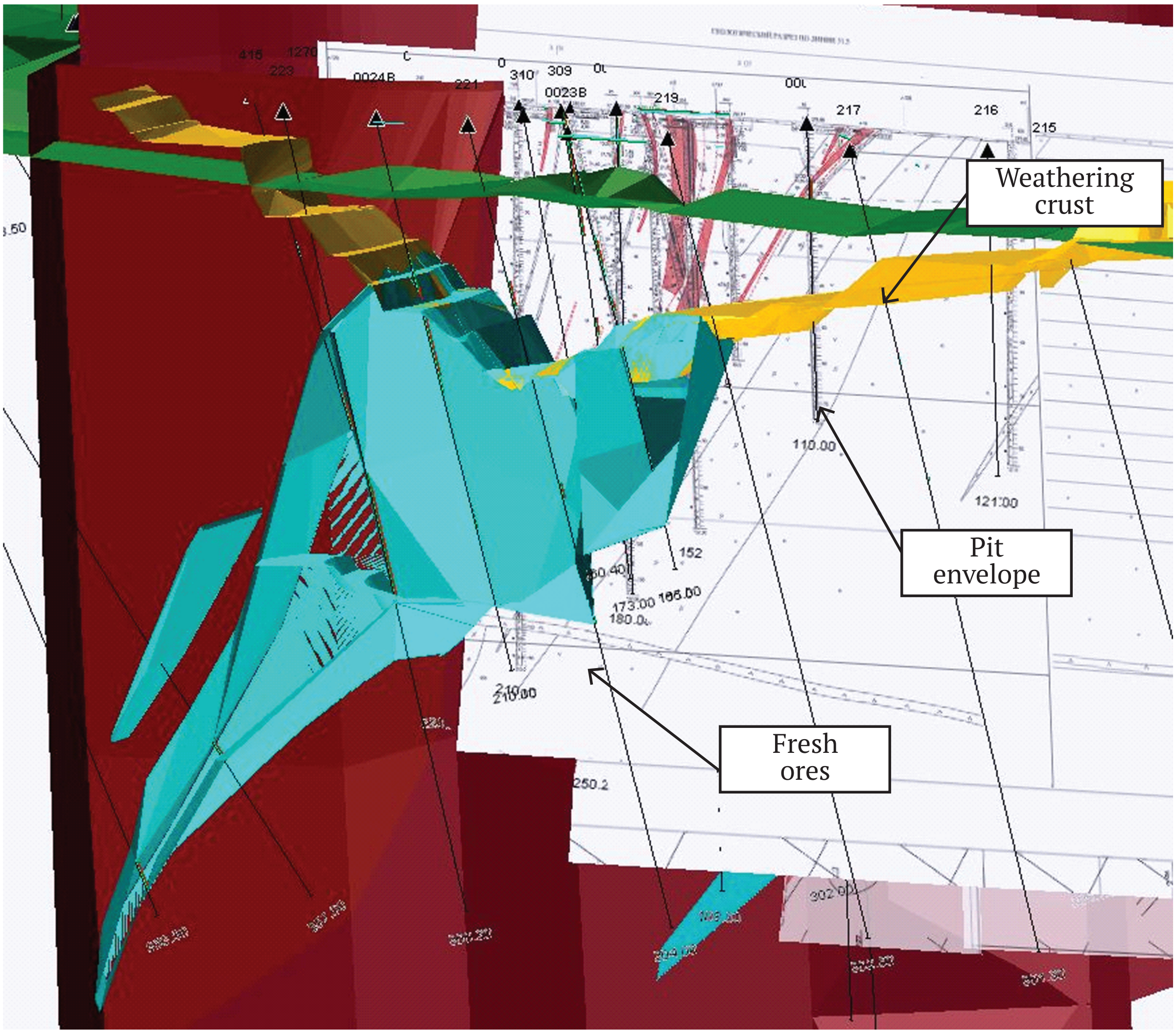

Fig. 4. Linking outlines between cross-sections taking into account weathering crust and current position of mining work. Construction of 3D wireframe model (cut-off grade of 28.3 g/ t, fresh ores) (lines P15, P57, Berezkinsky area)

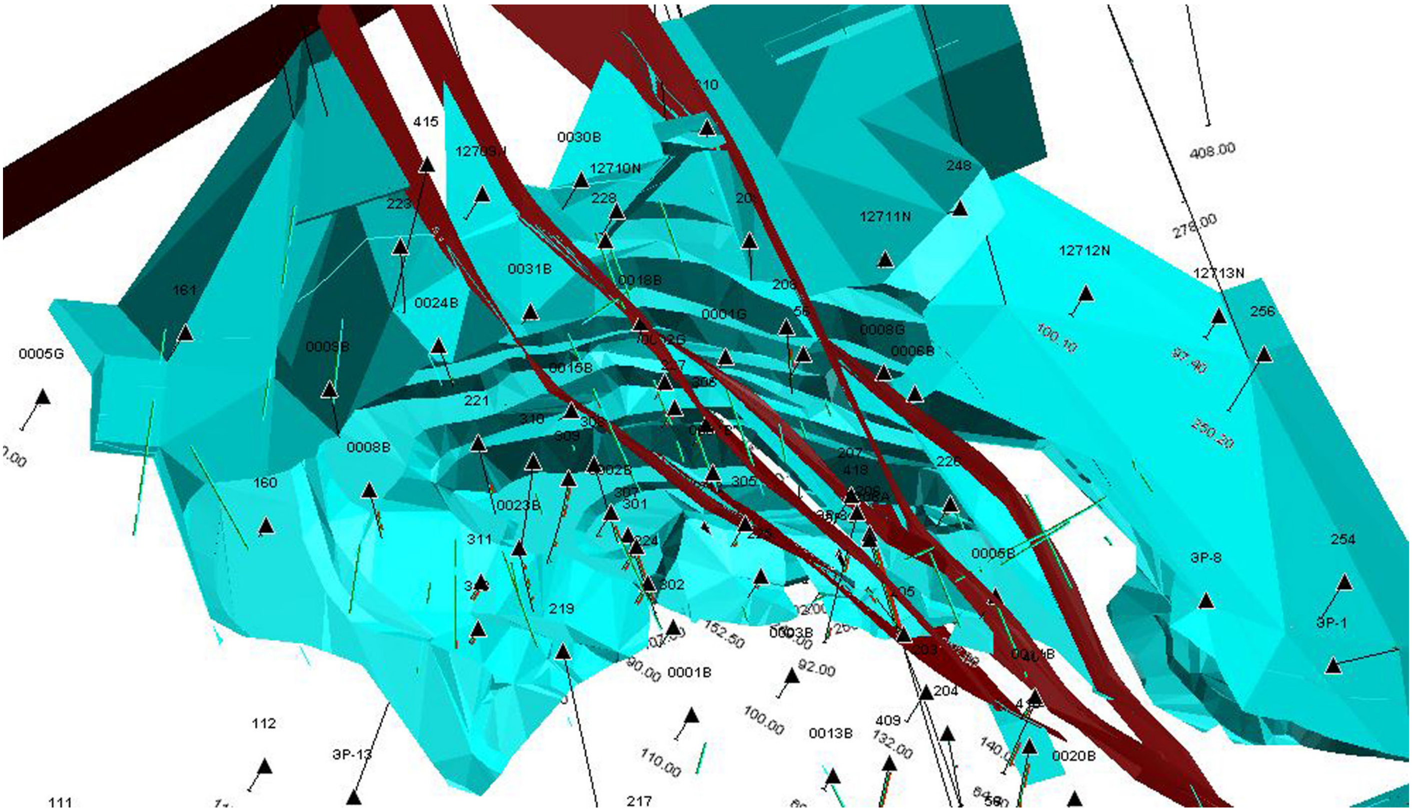

Fig. 5. Constructed wireframe model taking into account faults controlling plan, Berezkinsky area

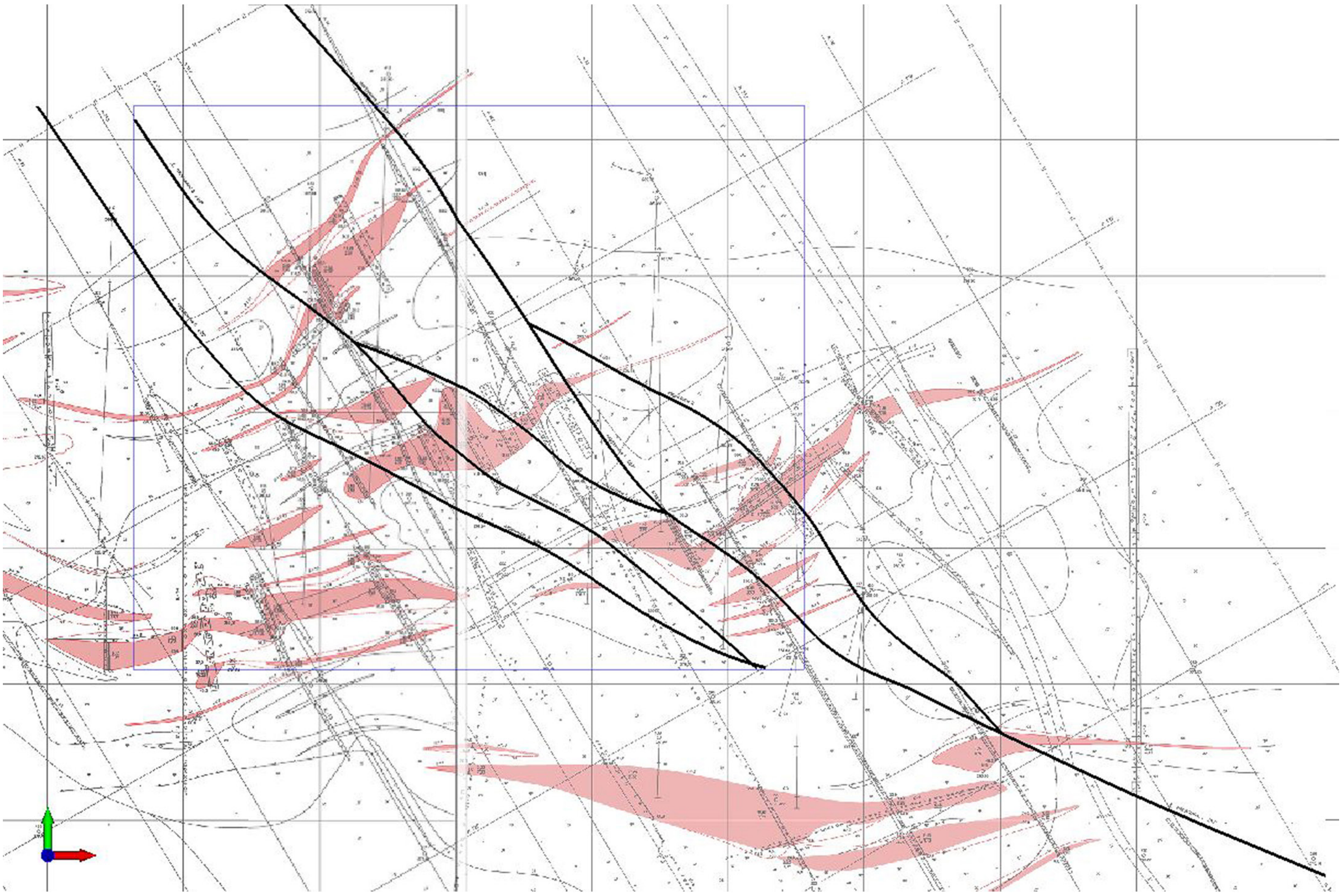

Fig. 6. Vectorization of faults in plan, Berezkinsky area

– 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.

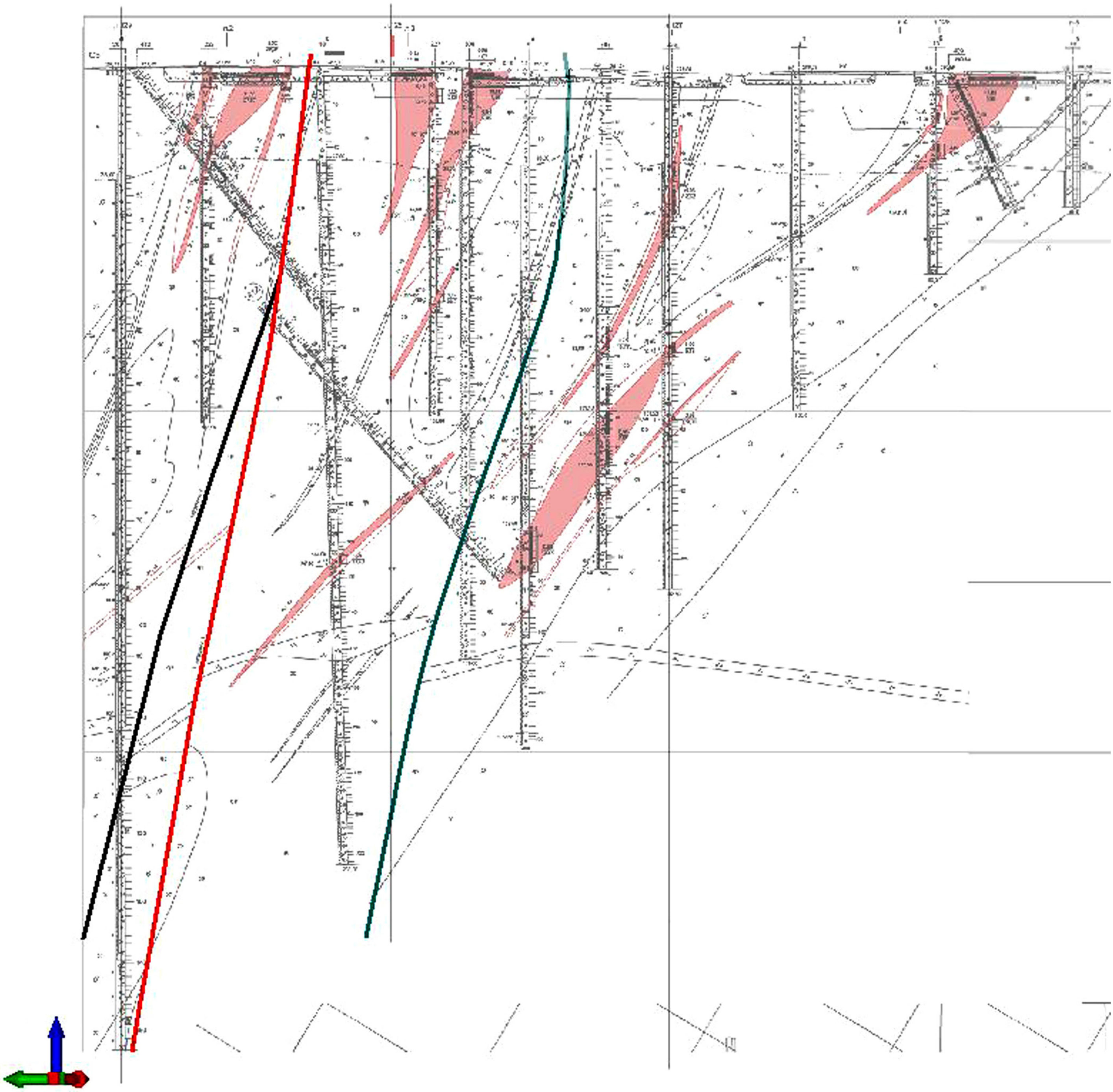

Fig. 7. Vectorization of faults in plan, Berezkinsky area

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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.

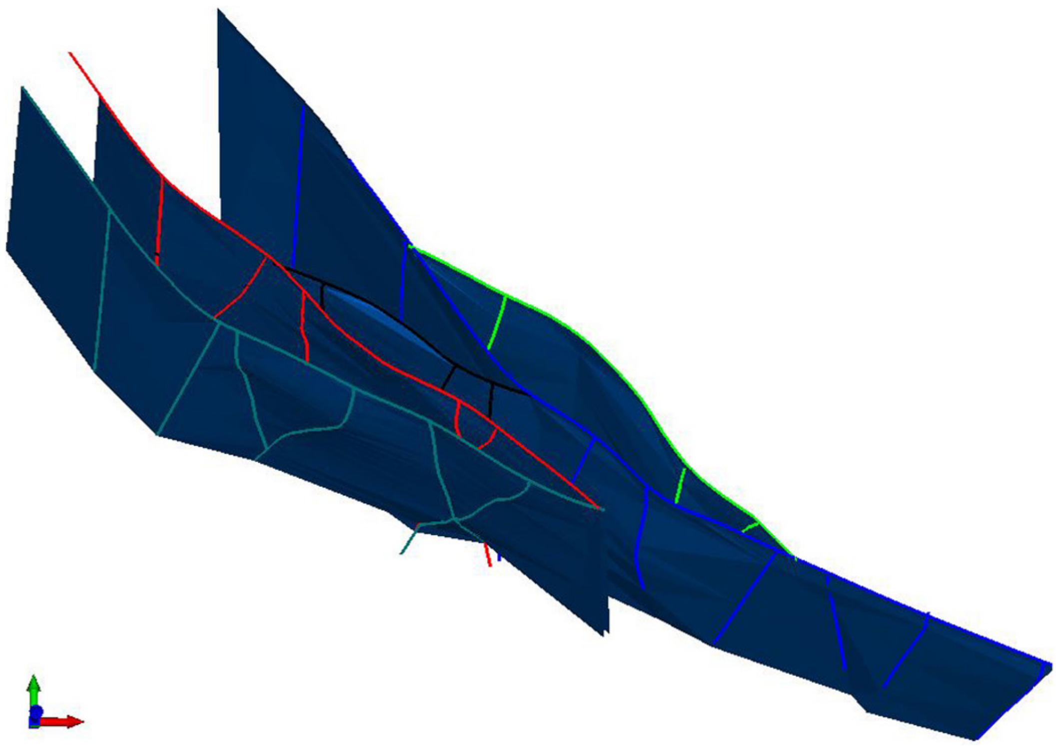
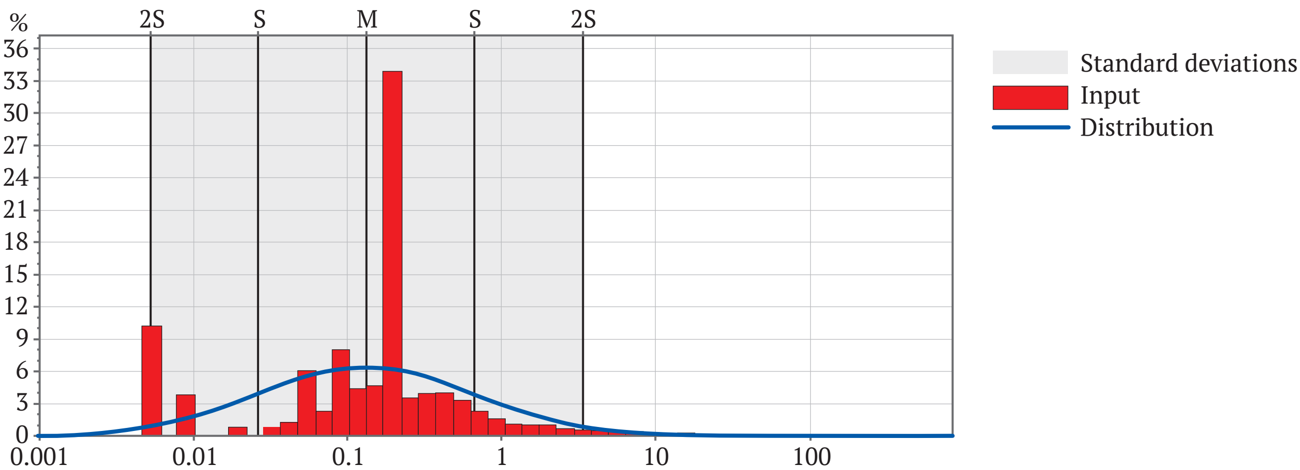


Fig. 8. Linked wireframe model of faults, Plan – Cross-Section, Berezkinsky area



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

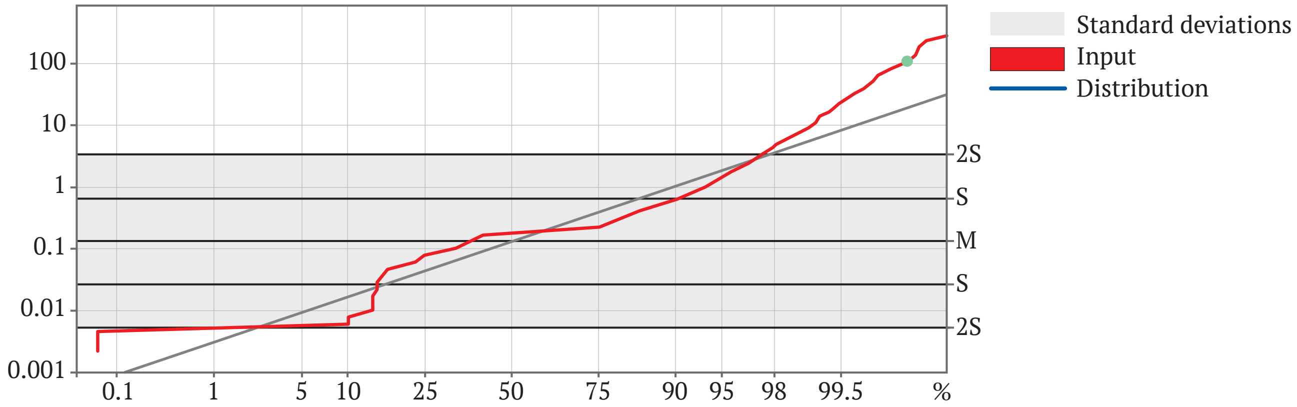


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Fig. 10. Graph of the cumulative probability of silver grades distribution in the fresh ores of the Berezkinsky area

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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