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Geostatistical analysis of the nickel source in Gllavica mine, Kosovo

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Abstract

Purpose. Geological research character and real quality assessment of Nickel source based on the geostatistical survey analysis and comparing the block quality grade results by assessing present mining condition of nickel mineral resources and its exploitation perspective.

Methods. New geological research has confirmed geological reserves, quality and extent of ore body and its position presented in geological transverse and longitudinal profiles. Herein we address the nickel ore exploitation stage by dividing the source in mini blocks and calculating the exploitable ore quality credibility interval.

Findings. Based on geological drills and ore quality at different depths, we have assessed the nickel ore quality at the source. This quality has been assessed by setting the nickel quality credibility interval according to terrain profiles and quota. Therefore, our findings provide complete assurance that during exploitation we will have ore homogenization and the quality will be reasonable.

Originality. The use of appropriate software, creation of databases according to the values acquired from field research provides us the best possible assessment that is argued in this paper.

Practical implications. Deep geological researches provide safety during exploitation, which should be continuous during the ore exploitation stage, therefore the geological research character is divided in two research stages, according to profiles and according to exploitation blocks.

Keywords: *nickel source, geological drilling, blocks, ore quality*

1. Introduction

The source of nickel silicate ore "Gllavica" is characterized by several favorable factors in relation to the ore exploitation; the most important being the drop and extent of ore bodies located in relatively shallow depths from the surface. On the other hand, the ore, the accompanying rock and the cover are characterized by the favorable geo-engineering conditions [1], [2].

Exploration of the Glavica mineral deposit is done in accordance with mine planning and exploitation needs of the mine. The goal of this research is intended to define exploitation limits of the deposit which is done based on deep drillings and optimized ore blocks having a reasonable grade for exploitation. From geological drillings in the field, the deposit data and interpolation of the mineral deposit zone will be processed. So, the stripping ratio will be determined based on the evaluated data of the deposit [2], [3]. It is suggested that drilling and blasting technique will not be applied. So, excavators which fulfill the mine needs and with high performance will be utilized to exploit nickel mineral deposit. Excavation and transportation of the overburden will be done using fully mechanized equipment [4].

The source was researched with the 25×25 m drilling grid, but seen from the practical sense, the ore body belongs entirely to the "crust of breaking", with a defined extent and drop. In the geological space of this stage, the research drills were initially conducted according to the 25×25 m grid density, in a research length of 125 m, the ore body contour and field geologic border was defined based on the results from the conducted drills (Fig. 1).

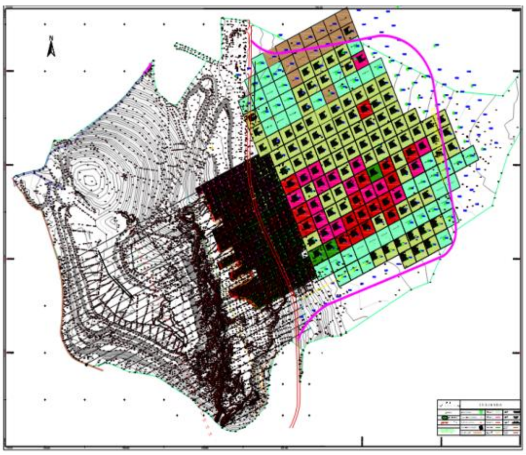

Figure 1. ***Map of Gllavica mine research and division of the source in blocks***

The exploration map clearly shows a large number of source segregation in blocks as the result of geological exploration by means of deep geological drilling. The different colored map section shows the new research area which is expected to move into the exploratory phase after scientific evaluations [5]. In comparison to the mine situation map the mine block model is presented in Figure 2.

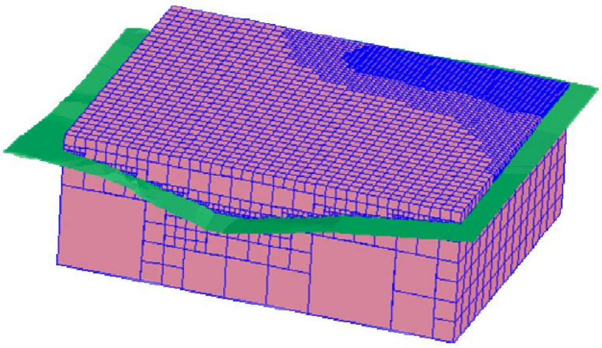

Figure 2. Source discretizetion in blocks

The creation of the discretized block model represents the surface and depth of the source field, precisely the green curved part shows the depth and extent of the nickel ore body defined after the completion of deep geological exploration. Below is the block model with all geological drills (Fig. 3).

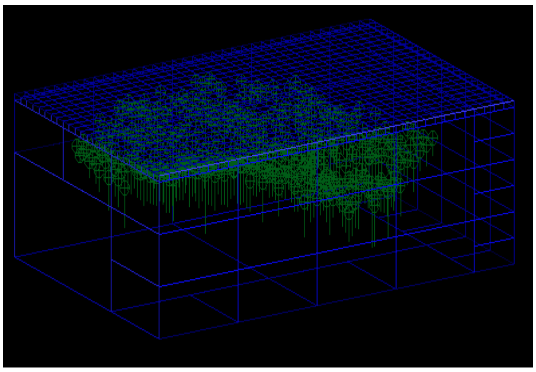

Figure 3. Presentation of geological drills according to depths

3D layout presentation of the deposit, especially in green color, shows all the geological exploratory drilling from the surface to the final depth. Below are presented all digital values of the nickel presence in the research zone (Fig. 4).

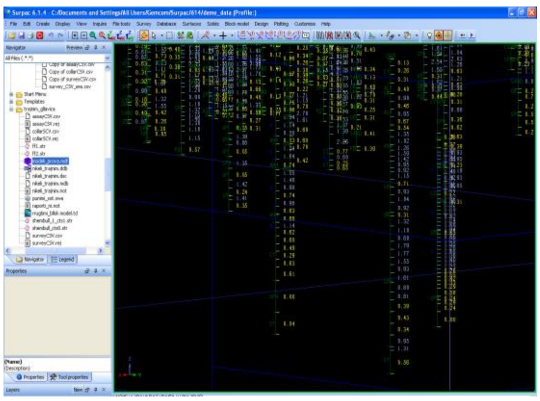

Figure 4. Presentation of Nickel quality in the segments of each geological drill

In all geological drilling, starting from the surface of the field to the final depth of each geological drilling, we have presented in 3D the quality of nickel metal in the depth intervals at every 1 m depth, so we evaluated the quality of nickel in the field after analyzing the samples in the laboratory and the values obtained in the laboratory have been attributed to the depths where the samples were extracted at each geological drill.

2. Methods

2.1. Nickel ore quality credibility interval at the 595 m level

Tracking the nickel ore quality during exploitation and setting the credibility interval provide us much deeper knowledge on the type of quality of the extracted ore while also considering the geological conditions of the source construction and the type of machinery as in the specific case it may often cause the increase of the ore impoverishment coefficient in the stage of its use.

In this specific case we are based on the amount of ore in all profile levels and the quality (presence in %) of nickel in ore. This study case provides accuracy in assessment; therefore, we must make sure that the accuracy of the volume and quality values is real-factual from the field research work [6].

2.2. Calculation of quality credibility interval

It is imperative that the nickel quality credibility interval is tracked and calculated in the ore exploitation stage while taking into consideration the chemical analyses (x_i) of the nickel composition and ore amount (p_i), in each profile where exploitable reserves have been calculated (Table 1) [7].

– average value of nickel content in the produced ore;
– average quadratic deviation or standard deviation;
– variation (dispersion);
– dominant;
– excess (pressure or flatness);
– nickel content credibility interval in the ore body with relevance level $\alpha = 0.05$.

Table 1. Presentation of exploitation profiles in the superficial nickel mine with the planned exploitation ore quality in the 595 m quota

Profiles	Ni, %	Ore, t
15	1.00	12.923
16	0.77	14.113
17	1.29	20.745
18	0.91	7.834
19	1.70	9.304
20	1.04	9.664

Average value of nickel percentage in the ore:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i p_i}{\sum_{i=1}^{n} p_i} = 1.12\% . \quad (1)$$

Average quadratic deviation:

$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x}) p_i}{\sum_{i=1}^{n} p_i} = 7.52 . \quad (2)$$

Assessment variation:

$$s = \sqrt{\sigma^2} = 2.74 . \quad (3)$$

Dominant:

$$M_o = \upsilon_3 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^3 \cdot p_i}{\sum_{i=1}^{n} p_i} = 20.95 . \quad (4)$$

Credibility interval with significance level (assurance) $\alpha = 0.05$, determined based on the relation:

$$\bar{x} - L \le \mu \le \bar{x} + L , \quad (5)$$

where:

$$L = Z_\alpha \frac{s}{\sqrt{N}} ; \quad (6)$$

Z_α – according to Laplace is: $\alpha = 0.05$, $Z_\alpha = Z_{0.05} = 2.21$, for:

$$L = 2.21 \frac{2.74}{\sqrt{6}} = 2.47 . \quad (7)$$

The credibility interval at the $\alpha = 0.05$ level is:

$$\begin{gathered} 2.47 - 1.12 \le \mu \le 1.12 + 2.47 \\ 1.35 \le \mu \le 3.59 \end{gathered} . \quad (8)$$

3. Results and discussion

Below are calculated the credibility intervals – statistical indicators through various profiles and presented in Tables 2-5. In the zone terrain where the nickel mine location is, a geodesic recording was conducted first and the factual terrain situation was established, the good geodesic outlining enabled the tracking of other researches by correctly assessing the location of the source and other geological circumstances (Fig. 5).

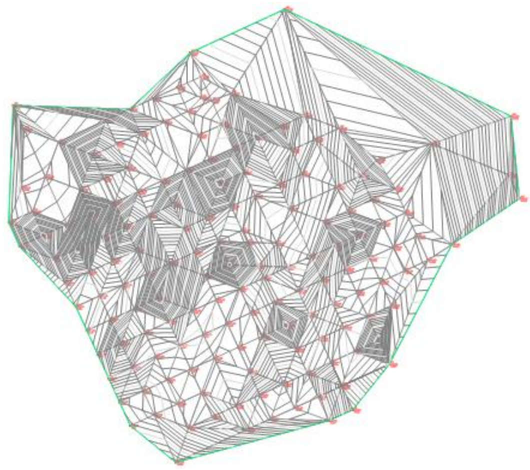

Figure 5. Terrain presentation with geodesic measures

From geological explorations conducted in the field of deposit have identified the upper contact of the ore body with the cover and this contact has been identified on the basis of geological structural changes thereby identifying the ore body and the upper structure contact.

In order to plan the nickel ore exploitation with advanced technologies deep studies were conducted be-forehand through geological transverse profiles that have enabled us to accurately assess the nickel ore quality, thickness of ore body, and floor and ceiling contact of the ore body.

Table 2. Credibility intervals in ore exploitation profiles P15 to P20, 595 m quota

Profiles	Ni, %	Ore, t	$\Sigma X_i \cdot p_i$	Average square displacement	Mode	Excess measure
15	1.00	12.923	12923.00	104819.80	298526.78	850204.27
16	0.77	14.113	10867.01	133707.75	411552.45	1266758.43
17	1.29	20.745	26761.05	135742.09	347228.26	888209.88
18	0.91	7834.460	7129.36	67625.84	198684.71	583735.67
19	1.70	9.304	15816.80	42927.76	92208.83	198064.58
20	1.04	9.664	10050.56	76199.33	213967.71	600821.32
Amount		74583.460	83547.78	561022.56	1562168.73	4387794.15

Table 3. Credibility intervals in ore exploitation profiles P16 to P28, 588 m quota

Profiles	Ni, %	Ore, t	$\Sigma X_i \cdot p_i$	Average square displacement	Mode	Excess measure
16	0.62	5204.06	3226.52	54226.22	175042.24	565036.36
17	1.60	17063.21	27301.14	86229.00	193842.79	435758.60
18	1.01	7321.33	7394.54	58967.78	167350.55	474940.87
19	1.02	15938.48	16257.25	127469.33	360483.27	1019446.70
20	1.11	35684.83	39610.16	267516.47	732460.09	2005475.72
21	0.99	34527.72	34182.44	282028.08	806036.25	2303651.61
22	0.91	27850.32	25343.79	240399.62	706294.08	2075092.00
23	1.24	12718.50	15770.94	86506.96	225610.16	588391.30
24	0.89	11837.82	10535.66	103578.13	306384.11	906284.20
25	0.77	19615.32	15103.80	185837.19	572006.87	1760637.14
26	0.77	14697.18	11316.83	139242.32	428587.85	1319193.42
27	1.23	10819.87	13308.44	74158.57	194147.13	508277.18
28	1.41	18631.68	26270.67	110743.80	269993.38	658243.87
Amount		231910.32	245622.18	1816903.46	5138238.78	14620428.96

Nickel quality credibility interval: $\begin{gathered} \bar{x} - L \le \mu \le \bar{x} + L \\ 0.656 \le \mu \le 2.774 \end{gathered} .$

Table 4. Credibility intervals in ore exploitation profiles P16 to P42, 581 m quota

Profiles	Ni, %	Ore, t	$\Sigma X_i \cdot p_i$	Average square displacement	Mode	Excess measure
16	0.84	8006.25	6725.25	72441.06	217902.72	655451.37
17	1.21	8006.25	9687.56	55715.85	146978.40	387729.02
19	1.16	4048.88	4696.70	29254.51	78636.14	211373.93
21	1.01	10980.00	11089.80	88435.60	250980.23	712281.89
22	0.83	6061.88	5031.36	55213.52	166634.41	502902.64
23	0.97	9721.88	9430.22	80525.16	231751.42	666980.58
24	1.38	47351.26	65344.74	288417.66	711814.79	1756758.90
25	1.12	51354.38	57516.91	382178.47	1042582.88	2844166.09
26	1.40	33626.25	47076.75	201512.16	493301.77	1207602.74
27	1.81	24476.25	44302.01	101660.73	207184.58	422242.16
28	1.30	34312.50	44606.25	222767.18	567610.78	1446272.26
29	1.33	36256.88	48221.65	229880.37	578838.76	1457516.00
30	1.62	38658.75	62627.18	191901.42	427556.36	952595.56
31	1.19	28021.88	33346.04	197973.57	526213.76	1398676.17
32	1.66	30423.75	50503.43	145648.96	318679.92	697271.66
33	1.23	25505.63	31371.92	174813.65	457662.13	1198159.47
34	1.22	32482.50	39628.65	224336.62	589556.63	1549354.83
35	1.53	17156.25	26249.06	92182.66	213679.40	495308.86
36	1.75	14525.63	25419.85	63936.07	134137.88	281421.27
37	1.78	10522.50	18730.05	45000.78	93061.60	192451.40
38	1.57	8578.13	13467.66	44514.35	101403.70	230997.62
39	1.53	14068.14	21524.25	75589.86	175217.30	406153.69
40	1.73	10011.88	17320.55	44912.53	95124.74	201474.21
41	1.01	5970.94	6030.65	48091.41	136483.41	387339.93
42	0.78	9046.88	7056.57	85154.88	261255.17	801530.87
Amount		519175.51	707005.05	3242059.04	8224248.87	21064013.14

$$\bar{x} - L \le \mu \le \bar{x} + L$$

Nickel quality credibility interval: $1.362 - 1.104 \le \mu \le 1.362 + 1.10$.

$$0.258 \le \mu \le 2.46$$

Table 5. Credibility intervals in ore exploitation profiles P15 according to 25×25 m geological drilling grid

Profiles	Ni, %	Ore, t	$\Sigma X_i \cdot p_i$	Average square displacement	Mode	Excess measure
23	0.92	9951.90	9155.75	85319.47	249815.41	731459.51
24	1.04	9198.00	9565.92	72524.98	203650.14	571849.60
25	1.46	31796.24	46422.51	181319.46	432990.86	1033982.19
26	1.42	41837.97	59409.92	246642.53	598848.07	1454003.10
27	1.62	29931.93	48489.73	148581.62	331039.85	737556.79
28	1.57	28525.12	44784.44	148024.95	337200.83	768143.50
29	1.20	43262.33	51914.80	303351.30	803274.26	2127070.23
30	1.20	33706.26	40447.51	236345.06	625841.72	1657228.87
31	1.60	25654.24	41046.78	129643.80	291439.27	655155.48
32	1.56	38258.42	59683.14	200280.69	458242.21	1048458.18
33	1.21	25803.00	31221.63	179564.21	473690.39	1249595.25
34	0.96	25817.84	24785.13	215334.83	621886.99	1796009.63
35	1.24	16927.48	20990.08	115135.03	300272.16	783109.80
36	1.75	18036.87	31564.52	79391.16	166562.65	349448.44
37	1.40	14057.75	19680.85	84243.93	206229.15	504848.96
38	0.99	22223.00	22000.77	181521.11	518787.33	1482694.18
39	1.23	29014.70	35688.08	198864.55	520627.39	1363002.50
40	1.51	23321.00	35214.71	127478.28	298044.21	696827.36
41	0.76	3659.90	2781.52	34899.87	107770.80	332796.22
42	0.92	10602.50	9754.30	90897.18	266146.95	779278.28
Amount		481586.45	644602.08	3059364.02	7812360.65	20122518.08

$$\bar{x} - L \le \mu \le \bar{x} + L$$

Nickel quality credibility interval: $1.338 - 1.245 \le \mu \le 1.338 + 1.245$.

$$0.093 \le \mu \le 2.58$$

Each transverse profile contains the topography, drilling number, ore body extent with the accompanying parameters defined by geological drills and other characteristics. (Fig. 6).

In the geological profile through exploration drillings we have presented irregularly formed nickel source with many fractures, as well as irregular source levels. So, red color represent nickel source where the bottom of each level of the body also shows the nickel content and trace elements that result from laboratory analysis by deep geological drillings [8], [9].

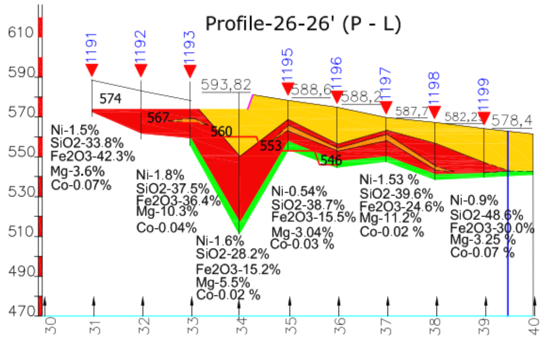

Figure 6. Geological profile of the source

Geological researches in mines have proven geological reserves, quality and extent of ore body and its position presented in contact with the floor and ceiling (Fig. 7).

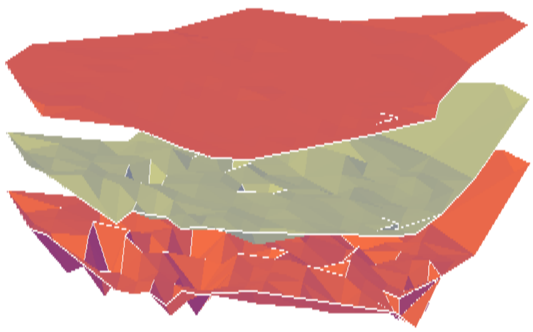

Figure 7. Ore body with geological contacts

Definition of layers or geological contacts on the floor and upper layer of the nickel source are presented in red while between these two layers is the nickel ore source which will be exploited by mining methods.

Finally, according to the calculations with advanced methods and the application of mining software we have concluded that the expected ore volume for exploitation is 1307256 (ton ore), with satisfactory ore quality credibility interval; the assessment results of quality credibility interval can be read under the foregoing tables.

During the ore exploitation it is recommended to pay attention to the ore digging and uploading by preserving the impoverishment limits, in addition under unknown circumstances attention should be paid to the selection of soils and clay in order to preserve the ore quality in the exploitation stage.

4. Conclusions

The source of nickel silicate ore "Gllavica" is characterized by several favorable factors in relation to the ore exploitation, the most important being the drop and extent of ore bodies located in relatively shallow depths from the surface. Gllavica source is under research with varying intensity, through the application of various methods of research-geological work, therefore the border of the source has been defined and the reserves have been calculated according to the 25×25 m research drilling grid.

The minerals thickness at the source ranges from 2-32 m, the average thickness is about 11 m. The source was formed in specific conditions during the formation process of the lateritic crust of the ultrabasic rocks' alienation. The most important part here is the calculation of nickel ore credibility intervals, meaning that before entering the exploitation stage we shall know this ore quality credibility interval.

After managing to divide the nickel source in mini blocks we can now mix the blocks and at the same time we have tracked their exploitation and data compliance with the situation in the field. From the practical sense of the presentation of reserves and resources of polymetallic ore, it is of interest to have a table presentation of the ore amount (tonnage) on one side, and the quality and credibility interval on the other side.

Acknowledgements

I had the honor and pleasure to contribute in this paper, which was completed thanks to the deep cooperation with the professional staff of the mine with whom we contributed jointly so that this paper would provide the best possible assessment for the managing and engineering staff that shall implement this study in the mine circumstances.

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Геостатистичний аналіз запасів нікелю на шахті "Главиця", Косово

Р. Зекірі

Мета. Дослідження геологічних особливостей, реалістична оцінка якості запасів нікелю за допомогою аналізу геостатистичних випробувань і порівняння результатів якості блоку на основі оцінки поточного стану видобутку мінеральних ресурсів нікелю та перспективи їх подальшої експлуатації.

Методика. Проведена серія геологічних досліджень з щільністю сітки 25×25 м, при довжині дослідження 125 м були визначені контур рудного тіла й геологічна межа родовища на основі результатів буріння. Починаючи з поверхні родовища до кінцевої глибини кожного геологічного буріння, в 3D представлено якість нікелевого металу в інтервалах глибини на кожен 1 м і оцінено граничну глибину експлуатації за економічним фактором.

Результати. Виявлено сприятливі умови залягання покладів нікелевої руди – падіння і протяжність рудних тіл та відносно невелика їх глибина. Встановлено із використанням сучасних методів і застосування програмного забезпечення для видобутку корисних копалин очікуваний обсяг руди для експлуатації, який становить 1.3 млн т із задовільним інтервалом достовірності її якості. Встановлено, що потужність покладів коливається в межах 2-32 м, з середнім значенням 11 м. Визначено достовірні межі якісних і бідних руд, що важливо для комерційних цілей.

Наукова новизна. В умовах шахти "Главиця" виявлено характер зміни геологічних особливостей залягання покладів нікелевої руди на основі програмного забезпечення та створеної бази даних польових досліджень, що дозволило провести ефективну оцінку запасів нікелю з комерційної точки зору.

Практична значимість. Глибокі геологічні дослідження, які необхідно проводити постійно, особливо під час періоду активної експлуатації рудника, забезпечують безпечну розробку родовищ і детально оцінюють якість руд. Результати представляють цінність з позиції визначення достовірних показників якості руд і межі експлуатації родовища.

Ключові слова: *запаси нікелю, геологічне буріння, блоки, якість руд*

Геостатистический анализ запасов никеля в шахте "Главица", Косово

Р. Зекири

Цель. Исследование геологических особенностей, реалистичная оценка качества запасов никеля при помощи анализа геостатистических испытаний и сравнения результатов качества блока на основе оценки текущего состояния добычи минеральных ресурсов никеля и перспективы их дальнейшей эксплуатации.

Методика. Проведена серия геологических исследований с плотностью сетки 25×25 м, при длине исследования 125 м были определены контур рудного тела и геологическая граница месторождения на основе результатов бурения. Начиная с поверхности месторождения до конечной глубины каждого геологического бурения, в 3D представлено качество никелевого металла в интервалах глубины на каждый 1 м и оценена предельная глубина эксплуатации по экономическому фактору.

Результаты. Выявлены благоприятные условия залегания залежей никелевый руды – падение и протяженность рудных тел и относительно небольшая их глубина. Установлено с использованием современных методов и применения программного обеспечения для добычи полезных ископаемых ожидаемый объем руды для эксплуатации, который составляет 1.3 млн т с удовлетворительным интервалом достоверности ее качества Установлено, что мощность залежей колеблется в пределах 2-32 м, со средним значением 11 м. Определены достоверные границы качественных и бедных руд, что важно для коммерческих целей.

Научная новизна. В условиях шахты "Главица" выявлен характер изменения геологических особенностей залегания залежей никелевой руды на основе программного обеспечения и созданной базы данных полевых исследований, что позволило провести эффективную оценку запасов никеля с коммерческой точки зрения.

Практическая значимость. Глубокие геологические исследования, которые необходимо производить постоянно, особенно во время периода активной эксплуатации рудника, обеспечивают безопасную разработку месторождений и детально оценивают качество руд. Результаты представляют ценность с позиции определения достоверных показателей качества руд и предела эксплуатации месторождения.

Ключевые слова: *запасы никеля, геологическое бурение, блоки, качество руд*

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