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IMPACT OF THE SHAPE OF GEOLOGICAL CONTACT ON MINING LOSSES IN THE PROCESS OF NEAR-CONTACT ZONE DEVELOPMENT

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In Russia development of mineral resources is carried out on a truly grand scale, and mining industry is in its essence a basic sector, supporting and facilitating the development of national economy. It predetermines the need of safe and responsible attitude towards riches of our subsoil – mineral resources. With this in mind, one of the key requirements to extraction technologies is minimization of mining losses and ore dilution.

The biggest ore losses in the mining block take place in the process of development of contact areas between the ore body and surrounding rocks, due to differences between development pattern and surface of geological contact. Complexity of the contact between ore and surrounding rocks is traditionally characterized by so called «stochastic contact zone». Technological difficulty of extracting ore from the ore – wallrock contact is determined by volatility of geometric parameters in «stochastic contact zone» in the plane of geological contact.

Current paper focuses on the issues of standard-setting for mining losses and ore dilution in the process of near-contact zone development. A method is suggested to estimate standard values of losses and ore dilution in stochastic zones. Authors have developed an algorithm of defining the shape of the contact. In the stochastic zone the contact can have a rectangular, sinusoidal, serrate and straight-line shapes. Research has established a relation between the contact shape and amounts of mining losses and ore dilution, formulas to calculate standard values are presented. Using suggested method, standard values for contact ore losses can be obtained in a quicker and more reliable way.

***Key words*:** estimation, near-contact zone, standards, losses, ore dilution, ore.

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Introduction. The problem of rational mineral resources development and search for technological solutions, allowing to attain economically acceptable rates of extraction, is one of the most relevant issues in the mining industry.

Depletability of mineral resources in the subsoil, significant losses in the course of extraction and processing, growing rates of resources consumption, caused by dramatic progress of science and technology and population growth, shortcomings of legislative and economic relations between subsoil owner (state) and subsoil users (commercial enterprises) are among the key premises of this problem.

For Russia solution to the problems of rational subsoil use has an exceptional importance, because development of mineral resources is carried out on a truly grand scale, and mining industry is in its essence a basic sector, supporting and facilitating the development of national economy [4, 9, 10].

With this in mind, one of the key requirements to extraction technologies is minimization of mining losses and ore dilution [16-19].

It has to be noted that questions of acceptability of losses and dilution in one case or another have to be resolved basing on scientifically justified economic assessment, as reliable estimation of standard values for mining losses and ore dilution holds great significance for the majority of important mining and economic problems [11-12].

Method of calculation standard values of mining losses and ore dilution. The biggest ore losses in the mining block take place in the process of development of contact areas between the ore body and surrounding rocks, due to differences between development pattern and surface of geological contact [13]. This differences are predetermined by volatility of spatial position of the ore – wallrock contact [15].

According to [14], complexity of the contact between ore and surrounding rocks is traditionally characterized by so called stochastic contact zone (SZ), within which fluctuations of spatial position of geological contact take place.

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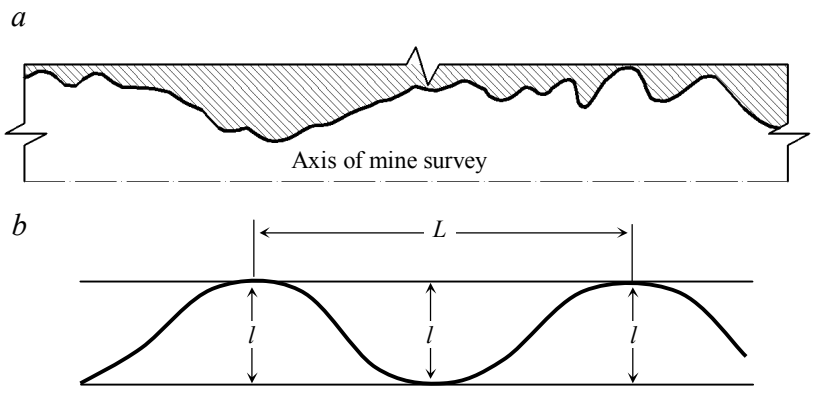


Fig.1. Diagram of contact coiling estimation: *a* – actual ore band outline for the mine «Komsomolskaya», JSC «MMC «Norilsk nickel»; *b* – diagram of parameter estimation

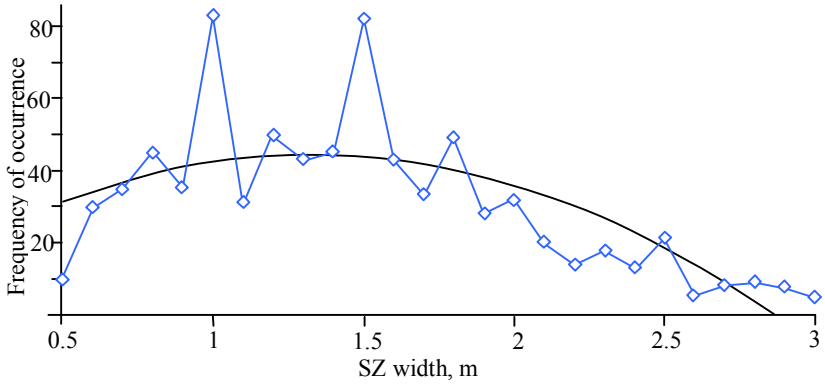


Fig.2. SZ distribution graph

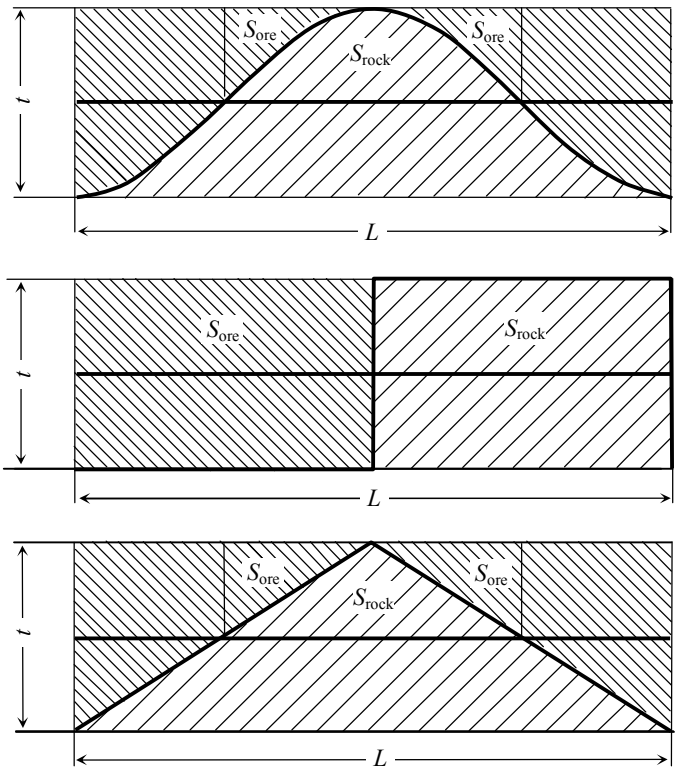


Fig.3. Diagrams of geologic contact shapes

Unlike zone of contact uncertainty, stochastic zone – zone of contact volatility (coiling) – can be identified directly, using geologic sketches, and reliability of its detections is very high.

Boundaries of this zone are limited by tangent lines to «humps» and «hollows» of ore band outline into the block of surrounding formation (Fig.1). Geometric parameters of the zone are width *t* and wave length *L*.

Technological difficulty of extracting ore from the ore – wallrock contact is determined by volatility of geometric parameters in stochastic zone in the plane of geological contact. To a great extent difficulty of ore extraction from the geological contact area is influenced by SZ width in the block under development. Fig.2 demonstrates results of SZ dimension measurements in one of mined-out blocks of the ore body in «Komsomolskaya» mine, JSC «MMC «Norilsk nickel». It is visible on the chart (Fig.2) that SZ width varies from 0.5 to 3.0 m and the most frequent values lie in the range of 1.0-2.0 m.

Precise detection of the geological contact spatial position and SZ geometric characteristics guarantee reliable estimations of standards on mining losses and ore dilution. A significant role in estimations of standard levels for losses and ore dilution belongs to establishing a relation between volatility of the contact within SZ – mathematical model of the contact.

Earlier research [5-7] has identified that ore – wallrock ratio within SZ can reliably be assessed under 50:50 condition. Such ratio is characteristic of contacts with rectangular, sinusoidal and serrate shapes (Fig. 3).

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Authors have developed a method of defining shape of the contact and established dependence of mining losses and ore dilution from the contact shape.

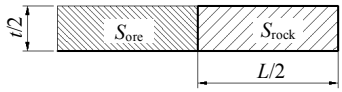
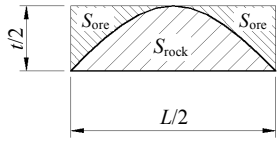
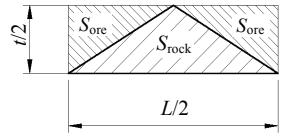
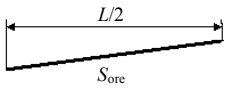
Contact shape index is calculated using the following expression and characterizes a certain contact shape:

$$i = \frac{S_{\text{ore}}}{0{,}25(tL)}, \quad (1)$$

where S_{ore} – area of ore block, penetrating the rock mass within stochastic zone, m^2 (Table 1).

Table 1

Characteristics of geological contact shapes within SZ

Shape of contact	Pattern of contact	Contact shape index *i*
Rectangular		1.0
Sinusoidal		0.63
Serrate		0.5
Straight line (linear)		0

Initial parameters for the calculation of contact shape index within SZ can be obtained from the geologic service of the enterprise.

Straight-line (linear) shape of geological contact is characteristic of sedimentary mineral deposits, e.g. deposits of construction raw materials.

Rectangular shape of geological contact (and its approximations) has not been detected on actual geological contacts.

As it was mentioned earlier, extraction of the ore body by the outer SZ boundary rules out ore losses, but increases tapping of surrounding rocks to the maximum. Development of ore body by the inner SZ boundary is characterized by maximum amount of mining losses and absence of surrounding rock extraction.

Thus, in the course of development operations on the geological contacts between the ore and the surrounding rocks, an economic dependence emerges between ore losses in the mining block and amount of wallrock tapping, when reduction of mining losses leads to rising ore dilution and vice versa – reduction of economic damage from wallrock tapping results in increasing damage from ore losses.

In this case the estimation amounts to definition of the development pattern within SZ, which can provide maximum economic efficiency of mining operations, and indicators of losses and dilution in this pattern are regarded as standards.

For ore deposits the criterion of economic efficiency of completeness and quality of extraction is maximum profit from 1 tonne of mined-out balance reserves of an extraction unit [14]:

$$\text{Pr} = V_b K_e E_e - (C_{\text{mer}} K_e)/K_q \rightarrow \max, \quad (2)$$

where Pr – average weighted profit from 1 t of mined-out reserves, rub; V_b – average weighted value of commercial components in 1 t of mined-out balance reserves, rub; K_e, K_q – coefficients of

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extraction and quality of mineral resources; E_e – end-to-end coefficient of commercial component extraction in the course of ore processing; C_{mer} – total costs of extraction, transport and processing of 1 t merchantable ore, rub.

Losses-dilution ratio in the optimal development pattern, expressed through areas of lost ore S_{los} and tapped wallrock S_{dil}, corresponds to coefficient μ_s, which defines relation between techno-economic and mining-geological parameters, having a significant influence on levels of losses and ore dilution [2, 3, 8]:

$$\sqrt{\frac{S_{los}}{S_{dil}}} = \mu_s, \tag{3}$$

$$\mu_s = \frac{C_{mer} - V_{gm}E_e}{V_b E_e - C_{mer}} \frac{\gamma_r}{\gamma_o}, \tag{4}$$

where μ_s – coefficient, defining relation between areas of lost ore and tapped wallrock in the optimal development pattern, provided that condition (1) is met; V_{gm} – gross value of 1 t of diluted γ_r – density of surrounding rocks in the block, t/m^3; γ_o – density of balance ore in the block, t/m^3; S_{los} – area of lost ore in the optimal development pattern, m^2; S_{dil} – area of tapped wallrock in the optimal development pattern, m^2.

Utilization of this coefficient simplifies calculations of standard values for mining losses and ore dilution, developed in the process of ore extraction on the geological contact.

Standards of losses and ore dilution for serrate shape of geological contact can be estimated using model in Fig.4, *a*.

Cross-section area of losses within SZ (in square meters) of serrate shape

$$S_{los} = \frac{2L\mu_s^2 t}{(2\mu_s + 2)^2}, \tag{5}$$

Cross-section area of tapped wallrock within SZ of serrate shape

$$S = \frac{2Lt}{(2\mu_s + 2)^2}. \tag{6}$$

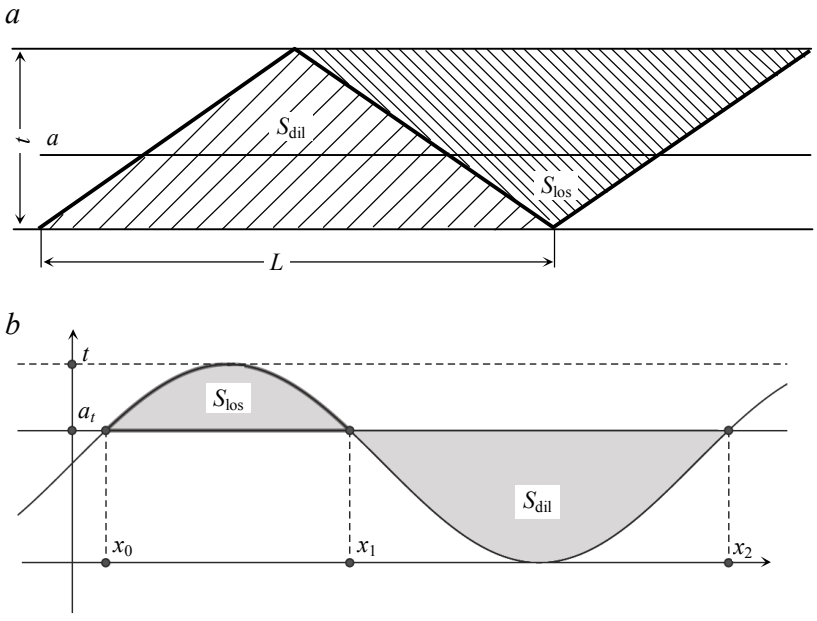


Fig. 4. Computational model for serrate shape of contact uncertainty zone (*a*) and sinusoidal (*b*) contact shape
t – SZ width; *a* – position of contact

In order to set standards of mining losses and ore dilution for sinusoidal shape of geological contact, areas of lost ore and tapped wallrock are calculated for the optimal development pattern, taking into account that the solution lies in finding an optimal position, defined by extraction boundary *a* under given value of μ_s Fig.4, *b*).

In this case

$$f(x) = \frac{t}{2} + \frac{t}{2}\sin\left(\frac{\pi x}{L}\right), \tag{7}$$

where $f(x)$ ranges from 0 to t, period equals $2L$.

Extraction boundary *a* is determined by the expression:

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$$f(x) = ax, 0 \le a \le 1. \quad (8)$$

Using equation

$$a_t = \frac{t}{2} + \frac{t}{2}\sin\left(\frac{\pi x}{L}\right) \quad (9)$$

we will find intersection points of the line $y = a_t$ and sinusoid $y = f(x)$ in the range [0; 3L]:

$$x_0 = \frac{L}{\pi}\arcsin(2a-1),\ x_1 = L - x,\ x_2 = 2L + x_0.$$

As

$$\cos\left(\frac{\pi x_0}{L}\right) = 2\sqrt{a(1-a)}, \quad (10)$$

Area of ore losses S_{los} and area of tapped wallrock S_{dil}

$$S_{los} = \int_{x_0}^{x_1}(f(x) - a_t)dx = \frac{tL}{2\pi}\left[(2a-1)(2\arcsin(2a-1) - \pi) + 4\sqrt{a(1-a)}\right], \quad (11)$$

$$S_{dil} = \int_{x_1}^{x_2}(a_t - f(x))dx = \frac{tL}{2\pi}\left[(2a-1)(2\arcsin(2a-1) - \pi) + 4\sqrt{a(1-a)}\right]. \quad (12)$$

Areas ratio S_{los}/S_{dil} is a square of the given value μ_s:

$$\mu_s^2 = \frac{(2a-1)(2\arcsin(2a-1) - \pi) + 4\sqrt{a(1-a)}}{(2a-1)(2\arcsin(2a-1) + \pi) + 4\sqrt{a(1-a)}}. \quad (13)$$

Unfortunately, equation (7) does not admit analytical solution in terms of elementary functions, nevertheless, it can be solved basing on a numerical method. An algorithm to calculate parameter a and areas S_{los} and S_{dil} has been implemented in the system of computer algebra Maple.

Results of numerical solution to equation (7) for different μ_s values are the following:

μ_s	1.0	0.5	0.33	0.25	0.2
a	0.5	0.6	0.67	0.71	0.74

Consider an illustrative example of defining an optimal development pattern for each option under the same conditions. Let us assume the following input data: V_b = 300 rub/t, E_e = 0.9, C_{mer} = 100 rub/t, V_{gm} = 0, $\gamma_o = \gamma_r$ = 1.0 t/m^3. Then μ_s = 0.588; B – ore reserves in the unit block with dimensions $t \times L$, L – ore losses on the contact, D – rock dilution on the contact.

Table 2

Selection of optimal development pattern in case of sinusoidal and serrate contact shapes

Pattern number	Pattern	B, t	D, t	L, t	K_e	K_q	*los*	*dil*	Pr, rub/t
				Sinusoidal					
1	0	6.28	6.28	0.00	1.00	0.50	0.00	0.50	70.00
2	0.2	6.28	5.19	0.16	0.97	0.54	0.03	0.46	82.97
3	0.4	6.28	4.25	0.47	0.92	0.58	0.08	0.42	89.63
4	**0.6**	6.28	**3.41**	**0.89**	**0.86**	**0.61**	0.14	0.39	**91.53**
5	0.8	6.28	2.66	1.40	0.78	0.65	0.22	0.35	89.93
6	1	6.28	1.99	1.99	0.68	0.68	0.32	0.32	84.58
7	1.2	6.28	1.40	2.65	0.58	0.72	0.42	0.28	76.09

Ending of Table 2

Pattern number	Pattern	B, t	D, t	L, t	K_e	K_q	*los*	*dil*	Pr, rub/t
8	1.4	6.28	0.89	3.41	0.46	0.76	0.54	0.24	63.51
9	1.6	6.28	0.45	4.25	0.32	0.82	0.68	0.18	47.80
10	1.8	6.28	0.16	5.20	0.17	0.87	0.83	0.13	26.64
11	2	6.28	0.00	6.28	0.00	1.00	1.00	0.00	0.00
Serrate									
1	0	6.28	6.28	0.00	1.00	0.50	0.00	0.50	70.00
2	0.2	6.28	5.09	0.06	0.99	0.55	0.01	0.45	87.30
3	0.4	6.28	4.02	0.25	0.96	0.60	0.04	0.40	99.20
4	0.6	6.28	3.08	0.57	0.91	0.65	0.09	0.35	105.70
5	**0.8**	**6.28**	**2.26**	**1.00**	**0.84**	**0.70**	**0.16**	**0.30**	**106.80**
6	1	6.28	1.57	1.57	0.75	0.75	0.25	0.25	102.50
7	1.2	6.28	1.00	2.26	0.64	0.80	0.36	0.20	92.80
8	1.4	6.28	0.57	3.08	0.51	0.85	0.49	0.15	77.70
9	1.6	6.28	0.25	4.02	0.36	0.90	0.64	0.10	57.20
10	1.8	6.28	0.06	5.09	0.19	0.95	0.81	0.05	31.30
11	2	6.28	0.00	6.28	0.00	1.00	1.00	0.00	0.00

Results show that under the same input conditions there are differences in the outcomes of various computational models (Tables 2, 3). It signifies that in order to set standards on mining losses it is important to make a correct choice of zone type and, subsequently, of the computational model. This will allow to make more precise estimations of standard losses value in the process of near-contact zone development.

Conclusions

1. In the process of estimating standard values of mining losses and ore dilution on the contact, the first step is to define geometric parameters of stochastic zone and the shape of geological contact.

2. Definition of geological contact shape can be done using contact shape index.

3. The shape of geological contact influences levels of standard losses and ore dilution in the process of ore extraction in the zone of stochastic contact.

4. Using suggested method, standard values of mining losses in the process of near-contact zone development can be estimated with greater simplicity and reliability.

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