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CALCULATION OF LOSS VOLUMES AND DILUTION OF MINERAL DEPOSITS IN NEAR-CONTACT ZONES

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ABSTRACT

In Russia, the mineral resource base is used on a particularly large scale, and the mining complex is essentially a basic industry for the maintenance and development of our country's economy. It determines the need for a careful and responsible attitude to our subsoil riches – mineral deposits. In this regard, minimizing the level of losses and dilution of ore becomes one of the key requirements for the stoping technology. The highest levels of ore losses in an array are formed in mining areas of ore bodies contact with the host rock mass as a result of a mismatch between the mining contour and the geological contact surface. The complexity of the contact of ore and host rocks is usually characterized by the so-called "stochastic contact area". The technological complexity of ore mining at the ore-rock contact is determined by variability of geometric parameters of the "stochasticity zone" on the geologic contact plane. In this article, the issues on setting of losses and dilution when mining the near-contact zones are discussed. The method of calculating the specified values of losses and dilution in the stochasticity zone is provided. The authors developed an algorithm for determining the profile of contact. In the stochasticity zone, a contact can take a rectangular, sinusoidal, sawtooth or straight profile. The research showed the influence of contact profile on the level of losses and dilution of ore; the formulas for calculating the ratios are provided. When using the proposed method, it is possible to most easily and reliably determine the specified values of ore losses on the contacts.

Keywords: losses, dilution, near-contact zone, mineral deposits, ore.

1. INTRODUCTION

1.1. The problem

When extracting minerals, minimizing the level of losses and dilution of ore becomes one of the key requirements for the stoping technology.

This is due to the fact that the high losses of minerals in mining entail more rapid depletion of deposits, as well as the need to increase the capacity of mining companies.

The reduction of quality losses (dilution of minerals) is of equal importance. Dilution causes significant economic losses in the process of production and processing. The associated with dilution excessive extraction of mining wastes that are then allocated to tailings in enrichment, in addition to the economic damage, also causes a significant damage to the environment, as the allocation of large areas for dumps and tailings storage facilities is required.

At the same time, reaching the level of deposits extraction approved by the technical project on the field development may not always be beneficial for an enterprise. In the process of deposit development, the mining and geological situation, the technical means of mining operations, as well as the design parameters of the technological units, may change. Usually, the mining and geological situation complicates, the technical means of mining with higher performance are accepted, and parameters of technological units vary in accordance with the geological situation and the applied technical means of mining.

Therefore, achieving a level of mineral deposit loss recorded in the original technical project often requires the significant time and material resources from an enterprise, which negatively affects the cost of production and competitiveness of products on the market. It is therefore necessary to achieve the parity of interests between the state and a mineral developing enterprise. It is achieved through the establishment of science-based standards for loss and dilution in mining [0-[3]].

Specified value of losses and dilution should combine elements of both the respect for the use of identified reserves of raw materials and the economical expenditure of forces and means on their mining and processing [[4]-[5]].

E.I. Panfilov defined the very process of normalization as a set of interrelated acts establishing the in-service field allowable amount (rate) of quantitative losses (extracted from the subsoil), the quality of extractable reserves, and other parameters [[6]].

In [0], the rationing of losses and dilution refers to the establishment of their level and ratio, which are technologically and economically feasible for specific geological and technical-economic conditions of the extraction and processing of minerals.

Consequently, standards should take into account the technical and technological possibilities of extracting minerals from the subsoil and the impact on the quality of the extracted mass indices of subsequent technological processes. The rationing should ensure the maximum economic benefit from the exploitation, the most complete and in-depth use of available resources, and strict limitation of losses and dilution.

Thus, the loss and dilution in the extraction of minerals are the key criteria for the rational use of mineral resources. Proper assessment of their values should be based on reliable indicators that can be prepared according to the existing mining enterprises accounting and reporting, as well as on the results of experimental work carried out at existing mines.

1.2. Overview of methods for assessing the losses and dilution

The aggregate of loss and dilution has a negative impact on the profitability of mining operations by reducing the amount of commercial component, which could be obtained from each ton of the processed ore [0, [8]]. Assessing the loss and dilution of ore necessitates considering the system of development. Empirical methods for determining these parameters [[9]-[11]] were recognized due to a simple and wide integration of the principles of stoping.

Currently, there are several methods for determining losses and dilution of minerals in mining. The use of a certain method for determining the rates of extraction from the subsoil has a great impact on their credibility; so, in order to avoid errors, the scope of each method should be defined.

The indirect method of mineral loss calculation is based on a comparison of the amount of principal commercial component in the depleted deposits, the mined minerals and the diluting rocks [[12]]. Dilution is set to reduce the content of commercial components in the produced mass of commodities in comparison with their content in the depleted balance deposits [[13]].

The indirect method is recommended to determine the loss and dilution during the field development with caving systems. At the same time, it should be possible to determine reliably the contour of depleted balance deposits at a relatively low variability in the distribution of content within the ore (with a coefficient of variation of 40-60%).

In general, the analysis of the indirect method accuracy is described in many works, in which its low reliability is emphasised, especially in the fields of non-ferrous metals with a complex configuration of the ore deposits and the uneven distribution of minerals. In addition, the indirect method does not reveal the sources of dilution and distribution of the diluting mass volume in the process of production, does not fix the places of losses and determines only their total value that is not conducive to the timely detection of the main causes of losses and dilution as well as the organization of measures for their management.

The graphical and analytical method for determining losses and dilution is proposed by M.I. Agoshkov and V.P. Ryzhov for the caving systems and the drawing of ore from beneath the caved debris. The essence of the method lies in the fact that losses and dilution according to the compared variants of block mining are determined using a characteristic curve constructed from the results of observations over the process of changes in the quality of minerals depending on the amount of the drawn rock output.

In determining losses and dilution according to the options for developing the block in question, only the nature of the ore drawing curve is taken into account, according to the mining data of which the curve is constructed, i.e. the ratio of ore and admixed rocks in drawing rates. The qualitative indicators of mining (the amount of extracted ore mass, the content of commercial component therein) are determined according to data of the block in question [[14]-[16]].

The direct method is the primary method of ensuring the efficiency and reliability of the results obtained. It is based on calculating the guideline values for each type of loss based on the passport execution of mining operations. To do this, the surveys and measurements of the volume of mineral loss and the volume of admixed rocks are carried out systematically, and the contours of ore bodies that are shown on the geological and surveying plans and sections are compared with the contours of the actual mining. The direct method for determining losses allows the differentiated determination of losses, and namely according to certain types, locations and sources of formation. This approach allows the identification of reasons for the formation of losses and dilution and, based thereon, the development of effective interventions to reduce quantitative and qualitative losses [[21]].

The petrographic method for determining the dilution of ore. The application of this method requires the visual difference between the ore and rock contained in the ore mass under study. Furthermore, the content of mineral components in the fine and coarse ore fractions should be equal to their contents in the initial ore [[17]].

In [[18]], it is noted that the overall errors of the petrographic method for determining clogging are comparable to the indirect method.

The gravimetric method for determining dilution is mainly used for operational control. Block dilution by gravimetric method is determined according to the results of the extracted ore weighing. This method is based on the difference in mass of the trolleys with pure and diluted ores, which is caused by the difference in average densities of ore and rock. The density difference must be at least 0.6-0.8 tons/m^3 [[17]].

The specific parametric method is used when the lengths (areas) of ore-rock contacts are established by the direct method, and the specific losses and clogging are assumed to be standard [[19]].

The analytical method [[20]-[21]] is based on the determination of losses and dilution of minerals on the basis of design parameters of the development systems (projected sizes of lost pillars provided by the project host rock slicing, etc.). The determination of losses and dilution of minerals by this method in caving development systems is based on the theory of drawing and laws of reduction in the content of commercial component in the extracted minerals as it is withdrawn from the block. The most reliable data on loss and dilution in the caving development systems are obtained using this method in combination with the data determined by the results of research concerning the nature of mineral drawing from the block and simulation.

The statistical method for rationing losses and dilution is established for each system based on the statistical data accumulated at each particular enterprise. Factual data for this method of rationing are obtained in the process of industrial application of the system. The main factors influencing the degree of rationing accuracy with this method are the mining and geological conditions of deposit and the applied technology. An indispensable condition for the application of the statistical method is a preliminary analysis of baseline information, as a result of which the sample is checked for homogeneity and the rejection of anomalous values, which are usually the result of violations in mining technology. Rejection of input data must not exceed 10% of the sample size.

Some scientists believe that the use of this method is the most convenient and justified [[5], [22]], because it uses a specific enterprise data actually obtained by using the development system within the given mining and geological conditions. At the same time, in the event when the enterprise has no experience in applying the development system, it is necessary to use the data of the enterprises' analogues, which naturally reduces the reliability of results.

The constructive method consists in defining the standards based on the adopted parameters of the development systems and the achieved thereby mineral recovery ratios [[5]]. This method of determining the specific losses contains some elements of the statistical method. However, as compared to the statistical method, it is more accurate. It allows planning the structure of losses and in conjunction with the method for determining actual losses by direct measurement.

The calculation method is used to determine the ratios of losses and dilution in development systems with sublevel and level caving. This method is based on the theory of drawing, according to which it is determined that with the withdrawal of particles of the caved mineral out of the boxholes, their efflux comes from the volumes having the profile of ellipsoid of rotation within the caved mass over the hole. This theory makes it possible to determine the optimum size of the structural elements of the development systems that provide the greatest drawing and minimal costs for mining and processing of commodity weight [[23]].

The computational and statistical method is a combination of the computational and the statistical methods [0]. Thus, the computational method determines the guideline value of the unavoidable dilution value inherent in the applied development technology. The statistical method takes into account the influence of some factors (e.g., folding of beds) on the value of specified parameters.

The technical and economic method. The essence of the method is to determine the optimal level of losses and dilution based on the inverse relationship between them through the economic assessment of possible options for their ratio [[14], [34], [37]].

The experimental method for rationing losses and dilution is based on determining a technically unavoidable level of losses and dilution through field observations over the work of each type of the applied equipment [[37]].

The rough set theory proposed by Pawlak [[24]-[25]] is often an excellent mathematical tool for the analysis of an uncertain object description [[26]].

The neuro fuzzy inference system is the integration of artificial neural networks and the fuzzy expert system (also called fuzzy logic inference system) [[3]].

In caving systems, there are many methods for determining the dilution, such as the principles of gravity flow [[27]-[28]], the theory of ellipsoid extraction [[29]], as well as the physical and numerical modeling [[30]-[32]].

2. RESEARCH METHODS

One of the most difficult areas when mining deposit resources are the near-contact zones subdivided into the geological (ore-rock contacts) as well as the man-made zones (ore-filling mass contacts).

When developing the reserves, the losses and dilution of mineral deposits are formed inevitably in the area of these contacts.

The features of the near-contact zone structure of ore bodies are reflected in a limited number of studies. Their serial analysis conducted in [[35]] shows that to date there is no generalized theoretical model describing the methodology and rational use of geological and geometrical relationships between the various parameters of the near-contact zones of the deposit.

According to the authors, the most appropriate for the performance of works on calculation of normative values of loss and dilution in the contact zone is to establish the parameters of the zone and the nature of the contact changes to it.

The contact zone is characterized by a "zone of contact uncertainty", which is a site of the rock mass in the contact zone limited by potential positions of technological surfaces formed in the array during mining operations, one of which corresponds to the maximum loss in the absence of dilution, and the other corresponds to the greatest dilution by the absence of losses [[36]]. The parameters of the zone of contact uncertainty are its width (t) and wavelength (L) (Figure-1).

A study of mine surveying [[37]] revealed that the ratio of ore and rock areas in the zone of contact uncertainty tends to the value of 1:1. Such a ratio corresponds to the sawtooth and sinusoidal profiles of contacts.

Each contact profile is characterized by the ratio of ore or rock area (S) on a site of ore wedging into the rock or vice versa (Figure-1) determined by the numerical value of the contact profile index - K_{cp}.

$$K_{cp} = 4 \cdot \frac{S}{L \cdot t}, \quad (1)$$

For the sawtooth contact profile, K_{cp} = 0.5 and K_{cp} = 0.75 for the sinusoidal contact profile.

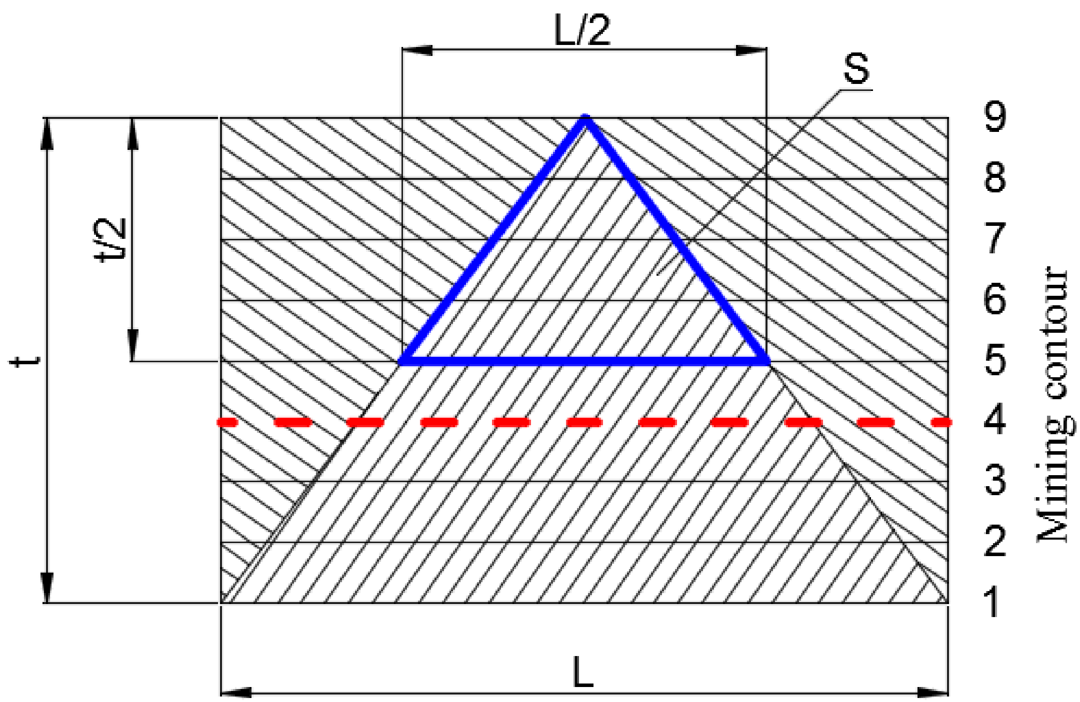

Figure-1. Scheme for determining the contact profile and the calculation of losses and dilution of minerals on geological contacts (Dashed line shows an optimal conditional position of the mining contour)

The related losses of minerals in the array and the dilution of mineral with rock on geological contacts are formed as a result of a mismatch of the breaking contour and the contact surface (Figure-1). Each mining contour (1, 2, 3, 4, 5, 6, 7, 8, 9) corresponds to the value of their mineral loss and undermining of diluting adjacent rocks (Figure-2).

The calculation reduces to determining the sound breaking contour that provides the greatest economic efficiency of stocks mining in the near-contact zone. The levels of losses and dilution corresponding to this contour are standard (Figure-2).

For comparison, the criterion of economic efficiency of mining is adopted as the maximum of profit from 1 ton of depleted balance deposits, which is recommended in [[21], [14], [37]] and defined by the following expression:

$$\Pr = V_b \cdot C_s \cdot E_t - \frac{C_{so} \cdot C_C}{C_q} \to \max\ , \quad (2)$$

where

V_b is the average weighted value of commercial components in 1 ton of depleted balance deposits, rouble/ton;

C_s is the coefficient of minerals extraction from the subsoil;

E_t is the through coefficient of commercial components extraction in the processing of ore;

C_{so} is the total cost of production, transportation and processing of 1 ton of saleable ore, rouble/ton;

C_q is the coefficient of changes in quality (recommended by typical methodological guidelines) [[38]].

The work [[37]] shows that the maximum profit is achieved on the contour, in which the ratio of losses and dilution is characterized by the coefficient:

$$\mu_s = \frac{C_{so} - V_{hr} \times E_t}{V_b \times E_t - C_{so}} \times \frac{\gamma_r}{\gamma_o}, \quad (3)$$

where

γ_r is the volumetric weight of the host rocks, t/m^3;

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γ_o is the volumetric weight of ore, t/m^3;
V_{hr} is the average weighted value of commercial components in 1 ton of host rocks (in the absence of commercial components in the host rocks, it is assumed to be 0), rouble/ton.

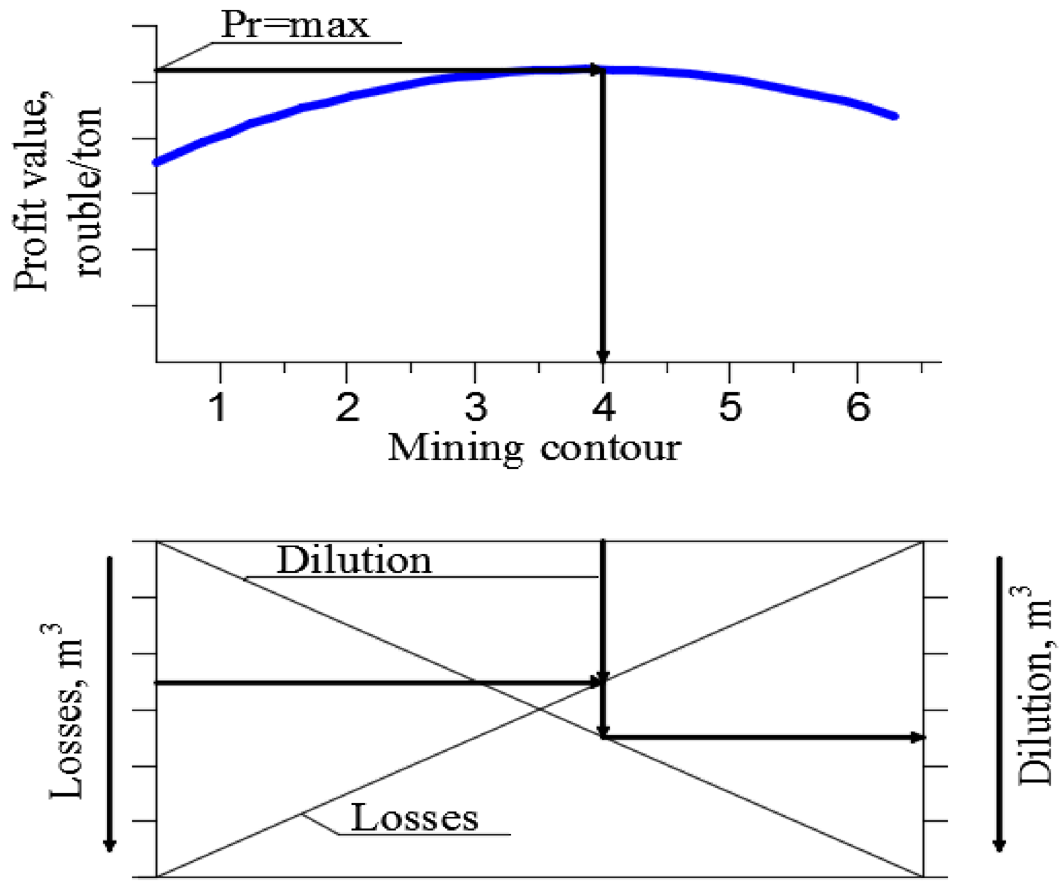

Figure-2. Scheme to the calculation of mineral loss and undermining of host rocks on geological contacts

The greatest difficulty in finding a sustainable breaking contour is the calculation of areas of ore losses and slicing of host rocks on the possible contours of stocks mining in the zone of contact uncertainty. It is especially characteristic of the sinusoidal contact profile. Therefore, it is desirable to make a final calculation of lost ore areas and undermining of host rocks on the rational mining contour without exhaustive search.

Let us consider each type of contact changing profile within the zone of contact uncertainty.

2.1. Sinusoidal zone of contact uncertainty

In mining the sinusoidal zone of contact uncertainty, the calculation is made for the conditions of Figure-3.

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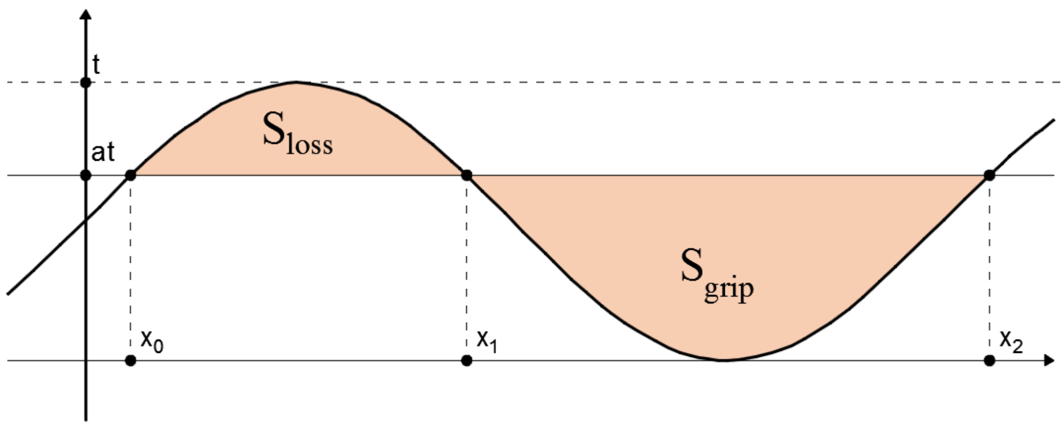

Figure-3. Estimated scheme for sinusoidal profile of the zone of contact uncertainty.

In this case,

$$f(x) = \frac{t}{2} + \frac{t}{2} \cdot sin\left(\frac{\pi \cdot x}{L}\right), \quad (4)$$

where $f(x)$ takes the values from 0 to t, and the period equals to $2L$.

Mining boundary (a) is set by the value (Figure-3)

$$f(x) = ax, 0 \le a \le 1. \quad (5)$$

Solving the equation

$$at = \frac{t}{2} + \frac{t}{2} \cdot sin\left(\frac{\pi \cdot x}{L}\right) \quad (6)$$

let us find the intersection points of the line $y = at$ and the sinusoid $y = f(x)$ on the interval [0; 3L]:

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

Further, given that

$$cos\left(\frac{\pi \cdot x_0}{L}\right) = 2\sqrt{a(1-a)}, \quad (7)$$

the area of mineral losses S_{loss} and the area of gripped rocks S_{grip} are obtained. They are equal to:

$$S_{loss} = \int_{x_0}^{x_1} (f(x) - at)dx = \frac{tL}{2\pi}\left[(2a-1)(2\arcsin(2a-1) - \pi) + 4\sqrt{a(1-a)}\right], \quad (8)$$

$$S_{grip} = \int_{x_1}^{x_2} (at - f(x))dx = \frac{tL}{2\pi}\left[(2a-1)(2\arcsin(2a+1) - \pi) + 4\sqrt{a(1-a)}\right], \quad (9)$$

The work [[37]] determines that the ratio of areas S_{loss}/S_{grip} is the square of a known size μ_S (Formula 3), then

$$\mu_s^2 = \frac{(2a-1)\cdot(2\arcsin(2a-1) - \pi) + 4\sqrt{a(1-a)}}{(2a-1)\cdot(2\arcsin(2a-1) + \pi) + 4\sqrt{a(1-a)}} \quad (10)$$

In this case, the solution is to determine the optimal position of mining set by the parameter a at the known value $(\mu_s)^2$, that is, in solving the equation (Formula 10) with respect to a. Unfortunately, this equation does not allow analytical solution in terms of elementary functions, but it can be solved numerically. The algorithm that calculates the parameter a and the areas S_{loss} and S_{grip} was implemented in the Maple computer algebra system.

Table-1 lists some of the obtained calculation values.

Table-1. The result of the numerical solution of the equation for different values of μ_s.

Parameter	Value				
μ_s	**1.0**	**0.5**	**0.33**	**0.25**	**0.2**
a	0.5	0.6	0.67	0.71	0.74
S_{loss}	0.16 tL	0.11 tL	0.09 tL	0.07 tL	0.06 tL

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S_{grip}	0.16 tL	0.22 tL	0.25 tL	0.28 tL	0.3 tL

The mathematical processing of the data in Table-1 made it possible to obtain a simplified formula for finding the parameter *a*:

$$a = 0.8e^{-0.5\mu_s} \qquad (11)$$

2.2. Sawtooth zone of contact uncertainty

In mining the sawtooth zone of contact uncertainty, the calculation is made for the conditions of Figure-4.

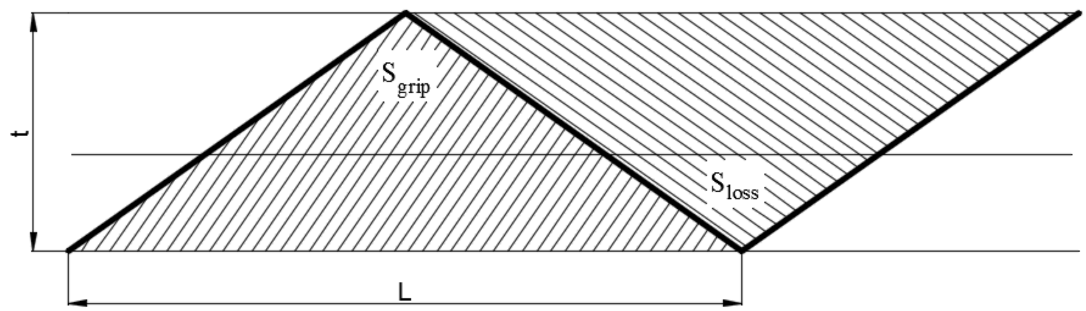

Figure-4. Estimated scheme for sawtooth profile of the zone of contact uncertainty.

The cross sectional area of losses in the sawtooth zone of contact uncertainty is equal to:

$$S_{loss} = \frac{2 \times L \times \mu_s^2 \times t}{(2 \times \mu_s + 2)^2}, \text{ m}^2 \qquad (12)$$

The cross sectional area of gripped rocks in the sawtooth zone of contact uncertainty is equal to:

$$S_{grip} = \frac{2 \times L \times t}{(2 \times \mu_s + 2)^2}, \text{ m}^2 \qquad (13)$$

The normative values of ore loss and dilution in an array at drawing of stocks in the near-contact zones in relation to sinusoidal and sawtooth contacts are calculated according to the following formulas:

$$P = S_{loss} \times l_m \times \gamma_o, \text{ t} \qquad (14)$$

where l_m is the length of mining area passing along the contour, m.

$$B = S_{grip} \times l_m \times \gamma_r, \text{ t} \qquad (15)$$

3. RESULTS

Assuming that the main goal in ore mining is to create the conditions for high performance of all production processes of ore extraction, it is necessary to be attentive not only to the issues concerning the expenditures for drilling blasting holes and wells, their breaking, transportation, etc., but also to seek to minimize losses and dilution of ore. This criterion of production efficiency in varying degrees affects the overall economic result of the entire technological chain of industrial processes: from stoped excavation to enrichment, since the increase in their share could lead to a general deterioration in the quality of the results of breaking.

In carrying out this work, the existing methods for assessing losses and dilution of ore, created for specific development systems and operating according to certain algorithm were analyzed [[3], [9]-[13], [18]-[22], [26]]. As a result of a literature review and analysis, the authors formulated the following interim conclusions:

a) When extracting minerals, one of the key requirements for the stoping technology is the minimization of the level of ore losses and dilution.
b) To date, no single theoretical and methodological principles for determining losses and dilution of ore are absent.
c) The near-contact zones are one of the most difficult parts of fields, in mining the stocks of which the losses and dilution of minerals are formed inevitably.
d) To establish the normative values of loss and dilution in a contact zone, the parameters of this zone and the contact change profile in this zone shall be defined.
e) Based on the studies, the dependencies for calculating areas for mineral losses S_{loss} and areas of gripped rocks S_{grip} are determined for each of the zones of contact uncertainty.

4. DISCUSSIONS

When considering the use of the mineral resource base, some natural tension appears in the interests of the state and subsoil using enterprises, which is reflected in the fact that the state, being the owner of the subsoil, is interested not only in obtaining economic benefits from the exploitation of oil fields, but also in lean spending of their reserves, while a subsoil using enterprise, without owning the subsoil, is mainly interested in getting the maximum economic benefit for itself. From the standpoint of public interest, the dominant purpose of the development of mineral resource base should be its rational use. Therefore, it is important to build economic relations between the owner and developer of mineral resources, bearing in mind that the achievement of this goal depends on the joint agreed efforts of both sides.

The proposed relationship allows for the balance of interests of the state and subsoil using enterprises, since at the establishment of the optimum mining contour, it becomes possible to meet the condition to achieve maximum profit from 1 ton of depleted balance deposits. Thus, on the one hand, the enterprise increases the efficiency of mining, and, on the other hand, the state improves the tax payments to budgets of different levels, all of which refers to the implementation of requirements to the rational subsoil use.

5. CONCLUSIONS

Thus, it is possible to state that when calculating the normative values of loss and dilution within the zone of contact uncertainty, first it is necessary to determine the contact profile, and then calculate according to one of the above presented formulas.

Significant establishment of evidence-based standards of extraction performance from the subsoils ensures the compliance with the balance of interests of the state and subsoil using enterprises, since this goal is not possible without ensuring the completeness and quality of extracting minerals from the subsoil.

This study is conducted by a team of authors from the Mine and Underground Construction Department in the Siberian Federal University.

REFERENCES

[1] Henning J.G. & Mitri H.S. 2007. Numerical Modeling of Ore Dilution in Blasthole Stoping. International Journal of Rock Mechanics & Mining Sciences. 44(5): 692-703.

[2] Najafi A., Farsangi M., & Saeedi G. 2015. A Fuzzy Logic Model to Predict the Out-Of-Seam Dilution in Longwall Mining. International Journal of Mining Science and Technology. 25(1): 91-98.

[3] Jang H., Topal E., Kawamura Y. 2015. Decision Support System of Unplanned Dilution and Ore-loss in Underground Stoping Operations Using a Neuro-Fuzzy System. Journal of Applied Soft Computing. 32, 1-12.

[4] Omelchenko A.N. & Glaser A.N. 1958. Ob ekonomicheskoi otsenke poter uglya [On the Economic Evaluation of Coal Losses]. Ugol, 1.

[5] Baikov B.N. & Luchko V.S. 1974. Tekhniko-ekonomicheskoe normirovanie poter i razubozhivaniya 0poleznykh iskopaemykh pri dobyche [Technical and Economic Rationing of Losses and Dilution of Minerals in Mining]. Moscow: Nedra. p. 216.

[6] Panfilov E.I. 2013. O proekte "Metodicheskogo rukovodstva po opredeleniyu, otsenke, normirovaniyu i uchetu pokazatelei polnoty i kachestva razrabotki mestorozhdenii tverdykh poleznykh iskopaemykh" [About the Project on "Methodological Guidelines for Identification, Assessment, Rationing and Accounting of Indicators of the Completeness and Quality of Development of the Solid Mineral Deposits"]. Marksheideriya i nedropolzovanie. 2, 30-36.

[7] Tikhonova T.S. 1984. Kombinirovannye metody kontrolya polnoty i kachestva izvlecheniya kaliinykh rud: Dis. ... kand. tekhnicheskikh nauk [Combined Methods of Monitoring the Completeness and Quality of Potash Ore Extraction (Ph.D. Thesis)]. Sverdlovsk. p. 195.

[8] Kalenchuk K.S., McKinnon S. & Diederichs M.S. 2008. Block Geometry and Rockmass Characterization for Prediction of Dilution Potential into Sub-Level Cave Mine Voids. International Journal of Rock Mechanics & Mining Sciences. 45, 929-940.

[9] Mathews K.E., Hoek E., Wyllie D.C. & Steward S.B.V. 1981. Prediction of Stable Excavations for Mining at Depths below 1,000 Metres in Hard Rock. CANMET report DSS Serial No. OSQ80-00081, DSS File No. 17SQ.23440-0-9020. Ottawa: Department of Energy, Mines and Resources.

[10] Potvin Y. 1988. Empirical Open Stope Design in Canada (Ph.D. Thesis). Vancouver: University of British Columbia.

[11] Pakalnis R. & Vongpaisal S. 1998. Empirical Design Methods - UBC Geomechanics. In Proceedings of the 100th CIM Annual General Meeting, Montreal. 3-7.

[12] Sergeev A.A. 1964. Ratsionalnoe ispolzovanie rudnykh mestorozhdenii [Rational Use of Ores Deposits]. Moscow: Metallurgiya. p. 248.

[13] Zaraiskiy V.N. & Streltsov V.I. 1987. Ratsionalnoe ispolzovanie i okhrana nedr na gornodobyvayushchikh predpriyatiyakh [Rational

Utilization and Conservation of Mineral Resources in Mining Enterprises]. Moscow: Nedra. (p. 293).

[14] Agoshkov M.I., Nikiforov V.I., Panfilov E.I. *et al.* 1974. Tekhniko-ekonomicheskaya otsenka izvlecheniya poleznykh iskopaemykh iz nedr [Technical and Economic Evaluation of the Extraction of Minerals from the Subsoil]. Moscow: Nedra. p. 312.

[15] Agoshkov M.I., Simakov V.A. *et al*. 1966. Sovershenstvovanie metodov ucheta i ekonomicheskoi otsenki poter i razubozhivaniya rudy pri razrabotke rudnykh mestorozhdenii [Improvement of Methods for Accounting and Economic Assessment of Losses and Dilution of Ore in the Development of Ore Deposits]. Moscow: Nedra. p. 44.

[16] Ryzhov V.P. 1975. Razvitie osnov tekhniko-ekonomicheskoi otsenki izvlecheniya poleznykh iskopaemykh iz nedr v rabotakh M.I. Agoshkova [The Development of Foundations of the Technical and Economic Assessment of Minerals Extraction from the Subsoil in the Works by M.I. Agoshkov]. In Povyshenie effektivnosti izvlecheniya rud iz nedr pri podzemnoi razrabotke mestorozhdenii [Improving the Efficiency of Ore Extraction from the Subsoil in Underground Mining] (pp. 3-15). Moscow: SFTGP AN SSSR.

[17] Bukrinsky V.A. 2002. Geometriya nedr. Uchebnik dlya vuzov [The Geometry of Subsoil. Textbook for High Schools]. (3rd ed., rev. and comp.). Moscow: Publishing House of the Moscow State Mining University. (p. 549).

[18] Mining S.S. 2008. Issledovanie vozmozhnostei primeneniya petrograficheskogo metoda pri opredelenii zasoreniya dobyvaemoi rudy v usloviyakh karera OAO "Mikhailovskii GOK" [Research of Possibilities of Applying Petrographic Method for Determining Blockage of Mined Ore within the Opencast JSC "Mikhailovsky GOK"]. Gornyi informatsionno-analiticheskii byulleten. 10, 255-259.

[19] Mining S.E. & Mining S.S. 2004. Ponyatie vyemochnoi edinitsy dlya krupnykh zhelezorudnykh karerov [The Term Selective Mining Units for Large Iron and Ore Opencasts]. Gornyi informatsionno-analiticheskii byulleten. 5, 192-196.

[20] Otraslevaya instruktsiya po ekonomicheskoi otsenke i normirovaniyu poter tverdykh poleznykh iskopaemykh pri dobyche na predpriyatiyakh ministerstva khimicheskoi promyshlennosti [Industry-Based Instruction for Economic Assessment and Rationing of Solid Minerals Losses in Mining at Enterprises of the Ministry of Chemical Industry]. Lubertsy. p. 25.

[21] Otraslevaya instruktsiya po opredeleniyu, normirovaniyu i uchetu poter i razubozhivaniya rudy i peskov na rudnikakh i priiskakh Ministerstva tsvetnoi metallurgii SSSR [Industry-Based Instruction for Determining, Rationing and Accounting of Losses and Dilution of Ore and Sands in Ore Mines and Gold Mines of the Ministry of Ferrous Metallurgy of the USSR]. Moscow, p. 127.

[22] Baikov B.N. 1977. Snizhenie poter i razubozhivaniya rud na karerakh tsvetnoi metallurgii [Reduction of Losses and Dilution of Ores in Opencast of the Nonferrous Metallurgy]. Moscow: Nedra. p. 296.

[23] Kulikov V.V. 1980. Vypusk rudy [Ore Drawing]. Moscow: Nedra. p. 303.

[24] Pawlak Z. 1982. Rough Sets. International Journal of Computer & Information Science. 11, 341-356.

[25] Pawlak Z. 1991. Rough Sets: Theoretical Aspects Reasoning about Data. Boston: Kluwer Academic.

[26] Owladeghaffari H., Shahriar K. & Saeedi G.R. 2008. Assessment of Effective Parameters on Dilution Using Approximate Reasoning Methods in Longwall Mining Method, Iran coal mines. In The 21st World Mining Congress & EXPO 2008, 7-11 September 2008, Krakow, Poland.

[27] Kvapil R. 1992. Sublevel Caving. In H.L. Hartman (Ed.), SME Mining Engineering Handbook (2nd ed., Vol. 2, pp. 1789-1814). Littleton, CO: Society for Mining Engineering.

[28] Castro R., Trueman R. & Halim A. 2007. A Study of Isolated Draw Zones in Block Caving Mines by Means of a Large 3D Physical Model. International Journal of Rock Mechanics and Mining Sciences. 44, 860-870.

[29] Janelid I. & Kvapil R. 1965. Sublevel Caving. International Journal of Rock Mechanics and Mining Sciences. 3, 129-153.

[30] Kvapil R. 1965. Gravity Flow of Granular Materials in Hoppers and Bins. International Journal of Rock Mechanics and Mining Sciences. 2, 35-41.

[31] Barker K.A. & McNearny R.L. 1999. Numerical Modeling of the Draw Behavior of Large-Scale Physical Models of the Block-Cave Mining Method. Soc Min Metall. 306, 79-85.

[32] DeGagne D. & McKinnon S.D. 2006. The Influence of Cave Mass Properties on Discrete Cave Mass Models. In Proceedings of the US Rock Mechanics Symposium, Golden, CO. pp. 1148-1155.

[33] Mechikov O.S. 2007. Metod upravleniya poteryami i razubozhivaniem rud pri otrabotke slozhnostrukturnykh prikontaktnykh zon [Loss Control Method and Dilution of Ore in Mining Structurally Complex Near-Contact Zones]. Gornyi informatsionno-analiticheskii byulleten. 4, 229-233.

[34] Vokhmin S.A., Zagirov N.H., Trebush Yu.P. & Kurchin G.S. 2010. Metodicheskie osnovy normirovaniya pokazatelei izvlecheniya iz nedr pri otrabotke rudnykh i nerudnykh mestorozhdenii podzemnym sposobom [Methodical Bases of Rationing Parameters of Extraction from the Subsoil in Mining of Ore and Non-Metallic Deposits by Underground Method]. Vestnik MGTU im. G.I. Nosova. 1, 10-15.

[35] Kurzhumin E. & Kurmankozhaev A. 2010. Sposoby otsenki geologo-geometricheskikh zavisimostei mezhdu parametrami vyemochnykh uchastkov po mestorozhdeniyu [Methods for Assessment of Geological and Geometrical Relationships between the Parameters of Excavation Sites on the Deposit]. Trudy universiteta. 1, 64-67.

[36] Holodnyakov D.G. 2000. Obosnovanie ratsionalnogo urovnya poter i zasoreniya poleznogo iskopaemogo pri otkrytoi razrabotke krutopadayushchikh mestorozhdenii. Diss. kand. tekhn. nauk [Justification of a Rational Level of Losses and Blockage of Minerals during an Open Excavation of Steep Formations (Ph.D. Thesis)]. Moscow: SPGGI named after G. V. Plekhanov. p. 135.

[37] Vokhmin S.A., Trebush Yu.P. & Yermolaev V.L. 2002. Planirovanie pokazatelei izvlecheniya pri podzemnoi razrabotke mestorozhdenii poleznykh iskopaemykh [Planning Parameters of Grawing in Underground Mining of Mineral Deposits]. Krasnoyarsk: GATsMiZ. p. 160.

[38] Tipovye metodicheskie ukazaniya po opredeleniyu i uchetu poter tverdykh poleznykh iskopaemykh pri dobyche. Sbornik rukovodyashchikh materialov po okhrane nedr [Typical Guidelines for Determination and Accounting of Solid Minerals Losses in Mining. Collection of Guiding Materials on Conservation of Resources]. Moscow: Nedra. pp. 65-86.