Identification and Planning of Mineral Losses and Dilution in Opencast Mine

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Abstract

The tendency of mining enterprises to mineral deposits rational development should be substantiated from two sides – technology and economy. Nowadays the rationality of mineral deposits development is evaluated based on quantitative and qualitative volumes of mineral losses, which are formed both in open pits and in concentration plants. Methodical rules of economic-technological standardization and counting of ore losses and dilution, according with the ratio of ore-waste in contact zones, allow conducting more strict control of the rational mineral resources extraction. Blasting block is recommended to take as a mining unit based on investigations of the open mining polymetallic ore-bearing deposits of complex structure and form. To accept such a mining unit it is required to develop in detail a separate project of blasting works for each block, which in turn requires conducting of deposit structure evaluation in blasting zone for making blasting with minimal changes of deposit structure. When conditions listed above are met, it is possible to make more authentic evaluation of contact zones development technology, especially, when ore and waste rocks are visually indistinguishable.

The equation to calculate economic damage from losses and dilution of minerals is given in dynamic type.

The optimum height of immixed rocks triangle on minimum economic damage from losses and dilution criterion is determined. The equation for determination of the optimum safety berm width when forming the final edge of an open pit based on minimum economic damage from losses and dilution criterion is presented.

Minimum damage from losses and dilution that provides minimum producing cost is accepted as a criterion of optimum technological standards of losses and ore dilution in ore-waste contact zones.

Keywords: mining unit, mineral deposit, losses and ore dilution, economic damage, technological schemes.

Introduction

The economically mineable part of a Measured and Indicated Mineral Resource includes diluting materials and allowances for losses, which may occur when the material is mined. Appropriate assessments and studies have been
carried out, and include consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction could reasonably be justified. Ore Reserves are sub-divided in order of increasing confidence into Probable Ore Reserves and Proved Ore Reserves.

The contamination of ore with barren wall rock in stoping. The assay of the ore after mining is frequently lower than when sampled in place. Dilution relates to the proportion of waste that is contained in the Run-of-Mine ore delivered to the metallurgical processing plant. Dilution relates to diluting tonnage expressed as a percentage of in-situ ore mined.

It is necessary to follow the defined criteria which allow to reach the required result in designing of mining project development and mining of mineral deposits. In this paper main partial criteria are shown which are used during open pit mining of mineral deposits. Based on presented partial criteria, mining enterprise increases likelihood of achievement of the main criterion – maximal economic profit from development of mineral deposit.

Aim of the work is description of aspects which allow to develop technique-technological ways to realize partial criterion – minimal economic damage from losses and dilution of minerals.

As it is known, losses and dilution of minerals occur mainly in contact zones of ore and waste rocks. This paper has main propositions which are necessary for development of contact zones on rational basis:

- geological exploration and designing of geological deposit model;
- substantiation of massif loosening technology;
- substantiation of minerals extraction technology.

Contact dilution is determined by resolution; specifically, the ability to accurately define and then mine along the limits of an ore zone, such that the mining equipment available can successfully extract the material within those limits. In some cases, contacts between ore and waste are clear, but geometrically difficult, such as contact dipping into a high-wall, or a particularly vicious curve in the boundaries of a stope. In these cases, the mining limit should be set based on the compromise between ore value and waste cost.

The internal dilution deals with waste material that is ingrained within the deposit. Contact definition assumes that you know the location of the contact between ore and waste. Internal dilution deals with the uncertainty of defining the contact. Contact dilution is primarily an operational and grade control issue for the mine engineers and geologists while internal dilution must be resolved by geologists and geostatisticians at the modeling stage.
The opposite side of dilution is ore loss. Ore loss is self-explanatory to miners, though there are subtleties here as well. Material that is expected from the model that does not appear in production is an ore loss. As with dilution, it is an old aspect of the mining business, and it assumes knowledge of the geology. To further complicate matters, there is a relationship between dilution and ore losses. We can recover more ore tonnage, but usually at the expense of higher dilution. Conversely, reducing dilution through more selective mining often results in higher ore losses. The remedies for ore losses are similar to those for dilution.

**Methods**

Proposed technological schemes to develop “Ore-waste rock” contact zones and conditions of its use. Significance of factor of visual distinguishability of ore and waste rocks in contact zones is shown.

Open pit mining is becoming a more widespread method of mining in the world. Modern mining enterprises must meet the highest requirements: maximal extraction of useful minerals from the bowels of the Earth, maximal extraction of useful components on the concentration plant and minimal ecological damage to the environment [1, 7, 14, 19].

Principled outline of work of mining enterprise should be based on the following criterion – maximal economic profit from development of deposit. At present, the sense of this criterion should be reviewed. It is necessary to understand that this criterion should be based on realization of specified conditions – of partial criteria, despite the fact that non-compliance of these partial criteria will bring extra profit for mining enterprise.

The partial criteria allow to provide most full extraction of valuable minerals from the bowels of the Earth and increase safety of production. For each of these partial criteria the requirements should be also established, for instance:

**Main requirements to mining equipment:**

- it must have productivity characteristics that allow to get constant volume of rock extraction;
- it must have high operational reliability that meets the requirements of operation conditions (climate conditions in the first place);
- it must not have downtimes during work time of open pit;

**Main requirements to concentration plant:**

- it must use up-to-date effective technologies for minerals processing;
- it must not have wastes of production.
Main requirements to stacking processes:

- a dump should occupy minimal required territory;
- a method of dump forming should take into account conditions of mine reclamation and further utilization of reclaimed territories.

In this paper some issues are stated which allow to ensure the realization of the criterion – minimal economic damage from losses and dilution of minerals.

Important issue is securing full-extraction of minerals if there is visual distinguishability or visual indistinguishability of ore and waste rocks in contact zone during open pit mining.

In this issue at least two aspects should be considered. First of all, presence of visual distinguishability or visual indistinguishability of ore and waste rocks. This requires careful studying of questions of geological exploration and technology of contact zones development. The second aspect is rock hardness of massif because almost always it has high values at polymetallic mineral deposits. These two aspects require the development of systems of technological solutions through loosening and extraction of rock mass into contact zones:

- Geological exploration and designing of geological deposit model;
- Technology of massif loosening;
- Technology of minerals extraction.

Results

Correctly and authentically designed geological model is one of the factors for successful realization of development project. Adherence to main requirements presented below allows to create reliable basis for development project.

Main requirements to designing of geological model:

- a geological model must be designed by using innovative achievements in sphere of geodesy, cartography and geology;
- the most accurate measurement devices which use modern navigation systems must be applied;
- during designing process one type of software should be used to avoid inaccuracy of model’s structure.

Different types of software can be used only for comparing and selection of the most suitable software for main processes of designing;

- a geological model must be updated by results of detailed geological exploration when there are any changes in basic data;
A software must have capacities to convert 3D geological model to another software for drawing up results of work (creation of data files with formats - .jpg, .doc, .dwg, etc.)

A geological model must contain information about all components of the mineral deposit.

The above list of requirements can be supplemented with additional requirements that depend on characteristics of minerals deposit. Carrying out these requirements will allow to decrease the likelihood of inaccuracy in development project. Choice of loosening way and minerals extraction way are following the conditions to secure the criterion – minimal economic damage from losses and dilution of minerals.

Cases of visual distinguishability of ore and waste rocks at contact zones of polymetallic deposits are very rare. Under the circumstances it is possible to as much as possible decreasing of geometrical dimensions of the contact zones.

If there is such condition the main factor is to decide how many waste rocks can be admixed to the ore. Because in the most cases it is impossible to mine the ore accurately. Because in the most cases it is impossible to mine the ore accurately according to the border of contact zone.

When there is visual indistinguishability of ore and waste rocks into contact zone then it is necessary to design special technological schemes. In this paper choice of loosening way is not considered, because this question requires existence of certain qualification. Based on investigations of questions of selective mining, technological schemes to develop “Ore-Waste rocks” contact zones were created. There are two principal differences in these schemes: depending on spatial disposition of contact zone, development can be carried out by transversal or by longitudinal pass [2, 9, 10, 16-17, 19-20]. Examples of these technological schemes are presented on figures 1 and 2. Presented schemes can be corrected depending on spatial disposition of contact zone and be shown for partial cases (for instance, when angle of contact zone slope – is 90 degrees).

When there are big geometrical dimensions of contact zone the quantity of cuts can be more than one at longitudinal development of mining [3-6, 8, 11-13, 15, 18]:

- the degree of curvilinearity of contact zone in the plan;
- the degree of curvilinearity of surface of contact zone in vertical section;
- presence of visual distinguishability of ore and waste rocks into contact zone;
- the parameters – course of ore body, width of ore body, angle of slope of ore body;
- value of rock hardness in contact zone.
Selective mining of contact zone is more reasonable when it has little curvilinearity in the plan and large extension. In this case pass of shovel has little changes in direction of development and productivity of shovel has constant value. Also, equal or similar rock hardness in contact zone has significant influence.

The examples of technological schemes give us an idea about possible directions of contact zones development.

**Discussion**

Mining never recovers all resources in an ore deposit. The amount of ore actually extracted from a deposit is referred to as the recovery factor and is expressed as a percentage. Certain amount of waste is usually mixed with the ore during mining. This waste mixed with ore is called dilution and is usually expressed as a dilution factor. Both recovery and dilution vary with in each ore body, but tend to be within a similar range for each mining method.

Blasting block is recommended to take as a mining unit based on investigations of the open pit mining of polymetallic ore bearing deposits having complex structure and form. To accept such a mining unit it is required to develop in detail separate project of works for each blasting block, which in turn requires conducting of deposit structure evaluation in blasting zone for making blasting with minimal changes of deposit structure. When conditions listed above are met, it is possible to make more authentic evaluation of contact zones development technology, especially, when ore and waste rocks are visually indistinguishable.
Minimum damage of an enterprise from losses and dilution of one ton of ore that provides minimum producing cost of ore mining is accepted as a criterion of optimum correlation of technological standards in ore-waste contact zones. It is necessary to count economic damage dynamically, i.e. it is necessary to include time factor into calculation of economic damage (equation 1). This suggestion is essential because the time of a deposit developing is 12 – 20 years on average. During this time there is a considerable increase in cost rates to carry out each technological process.

Equation (1) to calculate economic damage from losses and dilution in lead-zinc ore deposit mining is shown below

\[ U = \left( \left( \frac{1}{1 + E} \right) \cdot \left( \frac{1}{(1 + E)^t} \right) \right) \left[ \left( (C_{Zn\,ore} \cdot K_{Zn} \cdot D_{Zn}) + (C_{Pb\,ore} \cdot K_{Pb} \cdot D_{Pb}) \right) - N_{exc} + \sigma - \frac{N_{exc} + N_{proc} + a_w + d_w + r_o}{\Delta P \cdot y_{ore} + \Delta V \cdot y_w} \right] \]

where \( \Delta P \) – volume of lost ore at the contact, \( m^3 \); \( \Delta V \) – volume of immixed waste rocks at the contact, \( m^3 \); \( C_{Zn\,ore} \) and \( C_{Pb\,ore} \) – zinc and lead content at the contour of ore body, accordingly, conventional units; \( K_{Zn} \) and \( K_{Pb} \) – extraction of zinc and lead, accordingly, conventional units; \( D_{Zn} \) and \( D_{Pb} \) – price of zinc and lead, accordingly, rouble/ton; \( N_{exc} \) – ore mining producing costs, without counting overburden operations, rouble/ton; \( \sigma \) – costs for extraction and transportation lost ore from the open pit, rouble/ton; \( N_{proc} \) – producing cost of ore processing, rouble/ton; \( a_w \) and \( d_w \) – per unit capital charges of ore extraction and processing, accordingly, rouble/ton; \( r_o \) – per unit cost of ore prospecting, rouble/ton; \( y_{ore} \) and \( y_w \) – volume weight of ore and waste rocks, accordingly, ton/m\(^3\); \( E \) – discount rate, conventional units; \( t \) – discount period of economic damage rate under investigation, year. According to methodology of mineral losses calculation, standardization of losses magnitudes is carried out based on triangle areas determination which are formed due to the difference between the ore body dip angle and bench slope angle. These triangles are conventional because they are calculated without taking into account bucket movement trajectory. The schemes of triangle areas are shown on figure 3. Magnitudes of triangle areas are necessary to multiply by lengths of ore-waste contact lines in plan according to each mining unit. It is necessary to obtain of volume and weigh magnitudes of mineral losses.

Figure 3 – Scheme for calculation of mineral losses (\( \Delta P \)) and immixing (\( \Delta V \)) at ore body contacts:
a) mining of the bench from waste rocks to the ore body (from the hanging wall to the footwall);

b) mining of the bench from waste rocks to the ore body (from the footwall to the hanging wall);

c) mining of the bench from the ore body to waste rocks.

Equations to calculate triangle areas of mineral losses ($\Delta P$) and immixing ($\Delta V$) for figure 3:

- scheme (a):

$$\Delta P = \frac{(h-a)^2}{2} (\text{ctg } g - \text{ctg } j),$$

$$\Delta V = \frac{a^2}{2} (\text{ctg } g - \text{ctg } j)$$

- scheme (b):

$$\Delta P = \frac{(h-a)^2}{2} (\text{ctg } g + \text{ctg } j),$$

$$\Delta V = \frac{a^2}{2} (\text{ctg } g + \text{ctg } j)$$

- scheme (c):

$$\Delta P' = \frac{(h-a)^2}{2} (\text{ctg } g + \text{ctg } j),$$

$$\Delta V' = \frac{a^2}{2} (\text{ctg } g + \text{ctg } j),$$

$$\Delta P'' = \frac{(h-a)^2}{2} (\text{ctg } g - \text{ctg } j),$$

$$\Delta V'' = \frac{a^2}{2} (\text{ctg } g - \text{ctg } j),$$

where $h$ – bench height, m; $a$ – height of immixing rocks triangle, m; $j$ – angle of bench slope, degree; $g$ - dip angle of the ore body, degree.

It is necessary to determine the optimum height of the triangle of immixing rocks for identifying the rational balance between mineral losses and immixing rocks triangle areas. It is possible to obtain the required parameter from transforming equations (equations 1, 2, 3). The optimum triangle height of immixing rocks is shown on figure 4. The equation to calculate this parameter is given below ($a_{opt}$)

$$a_{opt} = \left[ h \cdot y_{w0}((Zn) + (Pb)) - N_{exc} + a - N_{proc} - a_M - d_M - t_0) \right] \left[ y_{w0}(((Zn) + (Pb)) - - N_{exc} + a - N_{proc} - a_M - d_M - t_0) + (N_{exc} + N_{proc} + a_M + d_M + t_0 - a - ((Zn) + (Pb)))y_{w0} \right]$$

Based on obtaining the parameter $a_{opt}$ it is possible to consider a particular case of determining safety berm width. The given optimum height of immixing rocks triangle based on minimum economic damage from losses and dilution.
The criterion of minimum economic damage from losses and dilution of minerals gives an opportunity to identify safety berm width and to compare it with the normative prescribed for opencast developing of the final edge contact zone.

The scheme to find the optimum safety berm width based on the criterion suggested is shown on figure 4.

Figure 4 - Scheme for optimum safety berm width determination.

There are the following designations on figure 4: $h$ – bench height, m; $a_{\text{opt}}$ – optimum immixing rocks triangle height, m; $b_{\text{opt}}$ - optimum safety berm width based on the criterion of minimum economic damage from losses and dilution, m; $p$ - triangle height of losing minerals, m; $j$ – bench slope angle, degree; $g$ - ore body dip angle, degree; $\theta$ (m), $k$ (m) и $\zeta$ (degree) – auxiliary magnitudes for calculation.

Using the results of geometrical calculation the equation of the optimum safety berm width based on the minimum economic damage from losses and dilution of minerals criterion is defined – $b_{\text{opt}}$

$$b_{\text{opt}} = (h - a_{\text{opt}}) \cdot (\tan g - \tan \zeta),$$

(11)

Magnitude $b_{\text{opt}}$ is characterized by the following condition

$$b_{\text{opt}} \geq B_S,$$

where $B_S$ – safety berm width according to the requirements of technological standards projecting.

When the parameter $b_{\text{opt}}$ less than $B_S$ it is necessary to take the value of the parameter $B_S$ because magnitude $b_{\text{opt}}$ calculation does not take safety requirements into account.
Based on magnitudes obtained according to the equation (11) it is necessary to carry out an analysis and consideration of the probable magnitude change of the open pit final edge.

**Conclusions**

The schemes should be chosen depending on following conditions:

Technological scheme with longitudinal pass should be chosen when contact zone has large extension and almost has not changes in direction. Technological scheme with transversal pass should be chosen when contact zone is very curvilinear and has very changeable directions in the plan.

It is reasonable to carry out longitudinal pass in contact zone during development of steeply-dipping ore body with visual distinguishability of ore and waste rocks. Then a face can be divided into two parts – with ore and with waste rocks.

It is reasonable to carry out transversal pass in contact zone during development of gently-inclined ore body, because contact zone has large magnitude within one mining level.

The basic requirements for extraction of rock mass from contact zones should be marked as follows:

1) operative geological exploration within “Ore-Waste rock” contact zone;

2) consideration of changes in geological data upon the results of geological exploration and application of these changes for contour of contact zone in the working plan of mining development;

3) obligatory transportation of rock mass from contact zone to buffer store or to homogenization stockpile.

This step is not necessary when the mining equipment is supplied with a device which allows to do quick analysis of ore grade in mining face.

Thereby, this paper covers on meeting the criterion – minimal economic damage from losses and dilution of minerals.

The aspects shown are especially important in design of project development and development of valuable mineral deposits.

**References**


