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OPTIMIZATION OF ORE DEPOSIT MINING SYSTEMS WHILE CHANGING CUT-OFF PARAMETERS FOR RESERVES ESTIMATION

Stanislav LYTVYNIUK
PhD in Geology, Deputy head of SCMR,
State Commission of Ukraine on Mineral Resources (SCMR), Ukraine

Summary
The paper defines the basic cut-off parameters for the reserves calculation of ore deposits, which affect the ore body morphometry. The optimal choose of the cut-off parameters ensures the substantiation of effective opening and extraction systems. For deposits that have been exploited for a long period, the use of irrelevant cut-off parameters may lead to the need to partially change mining systems and reduce the efficiency of economic indicators. The study determined typical cut-off parameters for iron ore deposits. The example of an underground iron ore mining deposit was analyzed, where it was necessary to partially change the mining system due to the presence of small isolated ore deposits. As an alternative option, the cut-off parameters were reevaluated, additional parameters were implemented - minimum ore reserves in isolated ore bodies and economical cut-off grade. The implementation of these parameters made it possible not to change the mining system and to improve the ore grade. The use of parameters of minimal isolated ore deposits also reduces loss and clogging of mineral compared to design solutions. According to forecast calculations, this option of mining development will provide greater indicators of economic efficiency.

Introduction

Mining technical and technological solutions for the opening and extraction of ore minerals are based on the results of the balance reserves calculation within the deposit. Contouring of ore bodies and reserves calculation of ore deposits is implemented on the basis of cut-off-parameters. The list of parameters is individual for each deposit and their selection should be justified by optional calculations.

Cut-off parameters for mineral are the main tool of geological and economical modeling of mineral deposits, which contain the necessary list of limit indicators for effective development of the deposit. According to the regulatory documents cut-off parametres - a set of limit requirements for the quality and quantity of mineral raw materials in the subsoil, mining and geological, mining technical and other conditions for the deposits development, compliance with which during the calculation ensures the most complete and cost-effective extraction and use of available reserves and mineral resources (*Classification, 1997; Regulation, 2004; Regulation, 2006*).

Cut-off parameters are limit values of indicators, which are set for a sample, interval, exploratory cross section, mining ledge or calculation block on the basis of technical and economic calculations, current standards and technical conditions, technical tasks of subsoil users, experience of geological exploration work and mining operation. The cut-off parameters contain a list of limit indicators, with the use of which the most comprehensive, rational and safe use of ore deposit reserves is achieved. As a rule, not 1-2, but 4-10 limit parameters are set, which together give such an effect.

For individual cases, the same cut-off grade in deposits cause a change in the volumes of reserves in different ways, since the cut-off parametres of the mining and technical direction cause a change in the morphometry of ore deposits and act on these volumes in a complex manner.

The list of parameters of conditions for calculating reserves of an individual deposit requires geological, mining and economic justification. Geological justification includes the analysis and determination of the following characteristics: conditions of occurrence, features of the internal structure, variability of ore deposits, engineering-geological and hydrogeological conditions of development, spatial position of ore bodies, patterns of distribution of ore quality, their technological types and grades.

The mining and technical justification involves the assessment and determination of the following components:

• the choice of the method and system of deposit`s opening, development, and mining system for individual ore bodies, the choice of the technological scheme of processing, the maximum level of extraction of the main and added useful components.

• determination of the production capacity and life of mine, selection of mining equipment types, means of mechanization, other design solutions,

• justification of the amount of losses and the degree of minerals impurity.

In this study, the relationship between cut-off parameters and changes in the mining system is determined for one of the domestic iron ore deposits of the Kryvyi Rih Basin, therefore, the following section provides information on the basic and additional cut-off parameters for iron ore deposits.

Basic cut-off parameters for reserves calculating of ore deposits.

Cut-off parameters for iron ore deposits are used at all stages of geological study and development: preliminary and temporary parametres - at the stage of exploration, constant parametres - at the stage of detailed exploration and mining operation, operational conditions - in case of significant unforeseen changes in mining and geological or economic conditions of operation.

In order to justify individual set of cut-off parametres, variable technical and economic calculations are carried out, which fix the maximum economic effect for a separate set of indicators. Indicators and cut-off parameters are characterized by significant dependencies (direct and inverse) among themselves. Thus, when the cut-off grade and the minimum capacity of ore bodies change, other geological, mining and technical-economic parameters change significantly (the reserves tonnage, their grade, the amount of capital investments, possible fluctuations in production capacity for ore extraction, etc.). Most of the cut-off parameters are determined by numerical multivariate calculations, which are aimed at identifying regular corelation between geological, technical, and economic indicators *(Instruction, 2003; Regulation, 2004)*.

The object of this study is the minable and extractable reserves of iron ore deposits that are exploited. So the main attention in this section is focused on the constant parametres that are defined for the explored reserves for a long period of time. For iron ore deposits, the following cut-off parameters are most often used, which are grouped here according to the main direction of their impact:

Quality parameters of iron ores, which are adopted in domestic practice (*Instruction, 2003; Regulation, 2004; Kurylo, 2021*):

1. Economic cut-off grade for magnetic iron (for magnetite quartzite reserves), and general iron – for rich ores. The parameter is applied to counting blocks and devides balance and off-balance reserves.

2. Natural cut-off grade of magnetic iron (for reserves of magnetite quartzite), and general iron - for rich ores. The parameter for contouring ore deposits, as a rule, is applied to edge sections, edge samples, to determine the outer contours of ore bodies. The parametre is used in the absence of clear geological boundaries of the ore body.

3. Cut-off grade in the marginal cross-section - the minimum grade of the useful component in the marginal cross-section, which is included in the reserves calculation during the contouring of the deposit along the dip and extension beyond the boundaries of the mine.

4. In case of presence of multicomponents iron ores, coefficients of transition from the main metals to added components are defined.

5. Limit content of harmful impurities.

6. Conditions for selection of types and grades of iron ores for selective mining, if they have different technological properties.

7. For rich iron ores and deposits with very complex geological structure with complex patterns of useful component distribution, a minimum ore bearing coefficient can be set in the counting block.

8. Minimum thickness of ore bodies or the corresponding minimum metro-percentage.

9. The maximum permissible thickness of layers of empty rocks or substandard ores, which are included in the reserves calculation.

10. Minimum reserves of isolated ore bodies.

11. Maximum depth of reserves calculation.

12. Limit stripping ratio.

Current cut-off grade of iron associated with magnetite for domestic ferruginous quartzite deposits vary significantly from 10 to 20%. The lowest values are for Novokryvorizke, Artemivske, Petrivske, Velika Gleyuvatka deposits, average values of 14-16% are for Horyshne-Plavnynske, Lavrykivske, Yeristivske, Valyavkinske, Inguletske, Gannivske deposits. The Skelevatske Magnetitove deposit has high values of 18%. Larger values are set for objects of underground mining of ferruginous quartzites. For BIF deposits, where oxidized varieties are present in the structure of the reserves, increased values of the cut-off grade are also used precisely for them, due to the difficult processing. Thus, for the oxidized quartzites of the Valyavky deposit, the cut-off grade is 28%, for the oxidized quartzites of the Velika Gleyuvatka deposit, it is 32%.

For rich iron ores, which are mined underground, the cut-off grade is usually within 46-48%, which provide sufficiently effective mining operation (*Kurylo, 2021*).

Case study

As an example of determining additional cut-off grade parametres for reserves calculating, one of the iron ore deposits of the Kryvyi Rih Basin is described below. Production is localized in the central part of the Kryvorizke deposit. In the geological structure of the deposit, the mine field includes metamorphic rocks of novokryvorizkaya, skelevatskaya, saksaganskaya, gdantsivskaya and gleyuvatska, and cenozoic deposits sediments.

The main ore-bearing stratum of the deposit is the saksagan serie, which consists of seven iron and seven shale horizons. It has the total thickness 1860 m where the most productive are the fifth and sixth iron horizons. The fifth iron horizon lies directly on the third and fourth shale horizons. The maximum depth of the horizon is 2400 m.

The majority of ore deposits belong to the fifth horizon. The content of total iron in the ores is from 45% to 70%. The thickness of the horizon is 30-90 m. In the southern part of the deposit, the horizon is cut by a diagonal fault and is observed only in the form of small remnants with a thickness of 6 to 25 m. The horizon is mainly composed of martitic quartzites with jespilites.

The sixth iron horizon is also the main ore-bearing layer. The horizon is composed of red-striped martite quartzites. The iron content in martite quartzites is from 20 to 45%. Rich martite ores are characterized by high iron content (47-70%), goethite-hematite-martite and goethite-hematite ores contain 47-60% iron. The total horizontal thickness of the horizon is 250-300 m, the dip is northwest at an angle of 50-60°.

The rich iron ores of the deposit are represented by two types according to their material composition: saksagan and ingulets. Oxidized ores of the saksagan type, confined to the fifth and sixth iron horizons, predominate. The mineral composition of saksagan type ores corresponds to the mineral composition of the host rocks and differs only in the quantitative ratio of the ore minerals that make up the framework and the wider development of the processes of superimposed epigenetic mineralization. Ores of the ingulets type have a magnetite composition.

The deposit is dominated by martite ores, which make up 38% of rich iron ores. The second place is iron-sludge-martite ores - 31%. Quartz-martite and quartz-iron-lime-martite ores make up 12%, dispersed hematite-martite - 8%, dispersed hematite ores of shale horizons - 5%. Unoxidized ores of the ingulets type - 6%.

The distribution of mineralization within iron horizons is extremely uneven and discontinuous. Ore bodies have an extremely complex morphology - they are interrupted, sometimes merge with each other, form numerous apophyses.

Taking into account theore bodies morphology, the variability of qualitative indicators, the area of the rich iron deposit is classified as a deposit of a very complex geological structure (group 3), in accordance with the Classification of Mineral Reserves and Resources of the State Mineral Resources Fund.

The mine is developing separated sheet-like, pillar-like and nest-like ore bodies, the length of which varies from 110 to 600 m, the thickness from 8 to 25 m, and the angle of incidence is 55-72 °. Approximately 65% of ore deposits have a strength of 100-120 MPa, and 35% - 30-60 MPa. The hanging side is composed of martite quartzites with a strength of 90-130 MPa, and the lying side is composed of hematite quartzites with a strength of 70-90 MPa.

The deposit is opened by two ore-lifting shafts and two ventilation shafts. Development systems: floor-chamber, sub-floor-chamber and sub-floor collapse with ore removal by deep bore-holes.

The main system of reserve development is underground rockfall with ore hammering by deep holes into the compensation space with ore release through ducts. For this system, the project adopted the following indicators: losses - 15%; impurityt - 15%, loss of quality (iron content) 3.23%. The adopted annual design capacity is 1.3 million tons.

In order to outline the ore bodies and calculate the rich iron ore reserves of the mine field, the typical cut-off parameters for rich iron ore deposits developed underground are applied:

1. The cut-off grade of total iron in the marginal sample, which is included in the reserves calculation for contouring the ore bodies by thickness, is 46%.

2. The minimum thickness of the ore body included in the reserves calculation is 4 m.

3. The maximum thickness of intra-ore layers of empty rocks and substandard ores included in the reserves calculation is 6 m.

4. The economical cut-off grade of total iron in the calculation block of balance reserves is 50%

5. The maximum depth of calculation to the horizon is 1500 m.

Use of additional condition parameters. The minimum reserves of isolated ore bodies.

Separated ore bodies are present within the defined deposit, the development of which is considered difficult. Mining and technical conditions are fixed here, which complicate or make their effective development impossible:

• self-rockfall of unstable quartz-carbonate rocks into the cleaning space. The chamber contains more mobile and less dense quartz-carbonate rocks with an Fe content of 5-10%. Mined ore with a content of 20-35%, even after processing on a magnetic separator, does not allow obtaining commodity products of the required quality.

• high risk of destruction of auxiliary ventilation objects. Refortification of wich is not possible due to the lack of safe approaches and delivery of materials for fixing.

• areas of destruction and splits of production holes that occurred after the explosion, mechanical destruction of metal fasteners by mining pressure. In order to extract the lost stockpiles, it is necessary to go through a complex of mining works.

Determination of minimum reserves in isolated ore bodies. Determination of minimum reserves in isolated ore bodies was carried out in order to determine the industrial value of reserves in blocks that have particularly difficult mining and technical development conditions. The feasibility of industrial development (loss-free mining) of isolated ore bodies (sites) carried out with the formula

$$Q_{мін}=Ex_1 \times \mathrm{I}/(Pi\text{-}Ex_2) \times L,$$

where Q_{min} is the minimum reserves in isolated ore body with a given content of useful components in the ore;

Ex_1 - additional costs associated with the opening and working of the ore body

I - ore impurity, %;

P - the value of all useful components per 1 ton of mined ore;

Ex_2 - operating costs for extraction and processing to final commodity products of 1 ton of ore of the estimated (isolated) ore bodies;

L - operational losses during mining, %.

The following values of technical and economic indicators were used to determine this condition parameter for reserves calculation.

$Q_{мін} = Ex_1\ I / (P_i - Ex_2)\ L$	Q_{min}	9 тис т
additional costs associated with the opening and extracting of the ore body	Ex_1	4 000
impurity	*I*	16%
value of all ore components per 1 ton of mined ore	P_i	1600
operating costs for production and processing to final commercial products 1 ton of ore, evaluated (isolated) ore bodies	Ex_2	1150
експлуатаційні втрати operational losses	*L*	16%

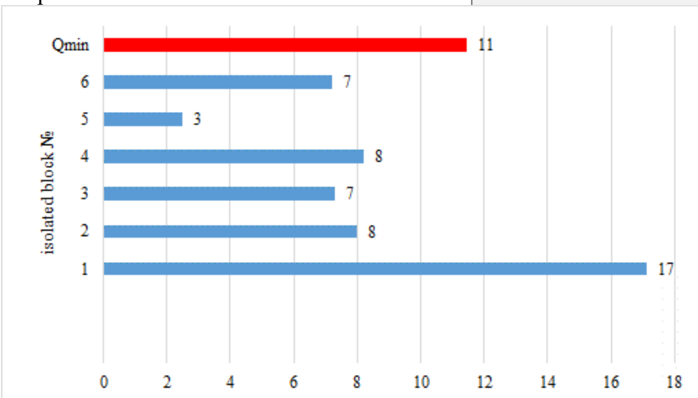

Fig. 1. Distribution of tonnage in isolated ore bodies and comparison with cut-off parameter

Additional costs associated with the opening and working of the ore body are determined by the average value of the specific costs of 40m3/1000t of ore for preparatory cuttings and 3 p.m. drilling wells.

Based on the results of calculations of minimum reserves in isolated ore bodies, the blocks listed in the following table do not meet the specified parameter and are not of industrial importance.

Determination of the economical cut-off grade for blocks with complex mining and technical development conditions

The economical cut-off grade is the content of a useful component that ensures the equality of the costs of extraction and processing of a useful mineral and the processing of commodity products and the value of the useful component that is extracted at the same time. This indicator determines the level of break-even mining and processing and at the same time ensures the closest connection of mining and geological, technical, technological and economic characteristics of the deposit. The economical cut-off grade is recommended to be determined based on the following ratio:

$$C_{min} = Ex / P \cdot K_e \cdot I,$$

where C_{min} is economical cut-off grade;

Ex - full operating costs for extraction and processing of a unit mass or volume of a mineral;

P - the price of a unit of mass or volume of commodity products of a mining enterprise;

K_e - extraction of a useful component into commodity products from a useful mineral, part of a unit;

I - mineral impurity during extraction and transportation, fraction of a unit.

The following data were used to determine the economical cut-off grade in blocks that are defined as having difficult mining and technical conditions:

Ex - UAH 1200/t;

P - determined individually by blocks, taking into account the Fe % content and the weighted average cost of 1% Fe - UAH 28.67;

P - 16%.

K_e - 0.867.

According to the results of the calculations of the minimum industrial content of the useful component, selected blocks with an iron content in the mined ore mass in the range of 20-45% are outside the limit values of C min - 62% and have no industrial value.

Conclusions

Reserves of rich ores in blocks of “bottoms” and isolated ore bodies characterized by complexity of mining condition and reduced indicators of the ore’s pittance, which is accumulated instead of the bark component in species. girnichy mass. The average value of the vegetable oil in individual blocks is 18.9-54.7%, the average value is 24.52%. Such values, instead of the increase in the type of footwear stocks, are responsible for the extremely high increases in the indicators of ore detected, which are found in the range of 11.9-69.4%.

Based on the results of the breakdown of minimal reserves in isolated ore bodies, the blocks listed in the following table do not correspond to the specified parameter.

As a result, the reserves are classified as off-balance and may be excluded from the distribution circuit. This makes it possible to further adopt a mining system - subsurface deboning with ore knocking with deep drills into a compensation area with the release of ore through the chutes. The effectiveness of the change in additional conditioning parameters is also due to changes in the indicators of consumption and ore volume, and the river design volume of 1.3 million tons was adopted until then.

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