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Improvement of extracted iron ore grade in underground mining

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Improvement of extracted iron ore grade in underground mining

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Abstract. Decrease in grade and high losses of broken ore are stated to be important problems that accompany the process of marketable production in mining of iron ore deposits by underground methods. The article analyzes and generalizes causes of high losses and dilution of broken ore during its drawing underground. It is found that dilution of ore with waste rocks results in the decreased iron content in the extracted ore mass as compared to that in the ore massif. The research performed enables development and scientific substantiation of a rational technology of ore drawing and transportation that improves the mined ore grade by more complete extraction of broken reserves of clean iron ore from the ore body footwall.

1. Introduction

Resulted from increased mining depths and a decreased ore body dip, deterioration of mining and geological conditions is one of the main problems of underground iron ore mining in Kryvyi Rih basin. These conditions reduce the possibility of using highly efficient level mining systems.

In this regard, underground mining of rich iron ores in Kryvyi Rih basin is performed mainly by sublevel mining systems with caving ore and country rocks. Such systems account for over 54% of total production [1, 2, 7, 23].

Application of different options of sublevel caving makes it necessary to find ways to increase mined ore extraction indicators while maintaining their natural grade [12, 24-27]. However, difficult mining and geological conditions and lack of efficient technologies for mining ore bodies with insufficiently steep dip reduce the extracted ore mass grade [5, 28-30]. Losses and dilution of iron ores remain high and their reduction prospects require new technological solutions [2, 7, 31-35].

As a rule, losses of broken ore are due to its location in the slow moving zone on the footwall of ore bodies [2, 36-40]. If dips of ore bodies are smaller than angles of the broken ore lumps movement to a drawpoint, a so-called "dead area" is formed on the footwall, figure 1. For instance, V.R. Chernokur notes in [7] that when drawing broken ore under caved rocks in ore bodies of low thickness with a 50-65° dip, a significant part of ore remains in the footwall, provided that

$$\frac{h_1}{m} > \operatorname{tg}\alpha ,$$

where h_1 is the broken ore layer height, m; m is ore body thickness, m; α is the ore body dip, degrees.

To determine absolute losses of ore in the "dead" area of the footwall, the authors suggest using the expression

$$Q_{\text{n}} = 0.5h^2\left(\text{ctg}\,\alpha_{\text{b}} - \text{ctg}\,\alpha_{\text{d}}\right)l\gamma,$$

where h is the drawn ore layer height, m; α_b is the ore body dip, degrees; α_d is the angle of ore drawing under caved rocks, degrees; l is the block length, m; γ is caved ore density, t/m^3.

With further drawing, this part of ore remains almost stable and is referred to losses of broken ore on the footwall if no special measures for its extraction are undertaken. [2, 7, 40]. If drawing is continued, some minimum part of the ore can be extracted, during the process waste rocks are mixed into it thus diluting clean ore of the natural grade [2, 40-42]. Further drawing results in further dilution and steady decrease of the natural ore grade. Finally, waste rocks completely replace the broken ore [40, 43-46].

To determine the volume of ore that remains on the footwall of the ore body before dilution, figure 1, the formula proposed by academician H.M. Malakhov is used [2]

$$\rho_0 = \left(\frac{H}{\tan\lambda} + d\right)\frac{H}{2}S - Q_{\text{ell}},$$

where H is the broken ore layer height, m; λ is the ore body dip, degrees; d is the drawpoint diameter, m; S is the distance between the axes of drawpoints, m; Q_{ell} is the volume of the draw ellipsoid truncated additionally by two planes that are located across the strike in the middle between drawpoints, m^3.

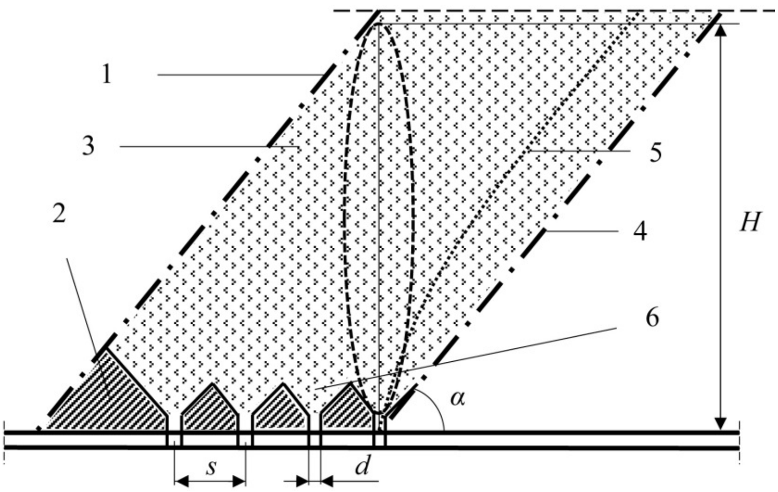

Figure 1. Scheme for calculation of the volume of broken ore remaining on the ore body footwall before dilution: 1 – the contour of the ore body; 2 – the undisturbed ore massif; 3 – broken ore; 4 – the footwall of the ore body; 5 – the contour of the volume of broken ore remaining on the ore body footwall before dilution; 6 – draw cones [2].

Since the broken ore that remains on the footwall of the ore body while drawing can theoretically be extracted, it is reasonable to refer it to "conditional losses" [40].

Based on the practice of mining rich iron ores underground, we can distinguish main factors influencing indicators of broken ore extraction from the ore body footwall [47-51].

First, "conditional losses" of ore on the ore body footwall depend on mining and geological conditions and the ore body dip and can reach 30-50% of the total reserves of a block (e.g. at Kryvbas underground mines). Under these conditions, the most efficient measures to reduce the volume of ore remaining within the "dead area" of the ore body footwall involve creating additional draw cones in the footwall rocks [2, 40]. Since workings are driven in waste rocks, the amount of driving should be minimized [40, 52-56]. However, on the other hand, workings should be located as close to each other as possible to extract the maximum amount of ore remaining on the footwall [57-61]. In this regard, the technologies should be optimized to provide the best extraction indicators with the lowest material costs [40, 61, 62].

Thus, the work is aimed at development and scientific substantiation of a rational technology of ore drawing and transportation which improves the mined ore grade by means of more complete extraction of broken reserves of clean iron ore from the ore body footwall.

2. Methods

To achieve this goal, the following methods are used in the work:

- analysis and study of the process of drawing broken ore from the footwall of ore bodies with insufficiently steep dips [4, 10, 11, 16-18,22];
- study of the extracted ore grade depending on the amount of ore losses and dilution [9, 12, 13, 15];
- consistent analysis of options and enhancement of stoping technologies that allow improvement of the mined ore grade due to more complete extraction from the footwall of ore bodies [8, 14, 19-21, 24].

3. Results and discussions

Analysis and study of the process of broken ore drawing from the footwall of ore bodies with insufficiently steep dips allow establishing the following. The amount of "conditional losses" of ore on the footwall of ore bodies depends on the ore body dip and thickness.

To draw broken ore that remains within the "dead area" of the ore body footwall, the following basic technologies are used.

1. Blasting rocks of the footwall, drawing blasted waste rocks of the footwall first followed by drawing the broken ore from the "dead area" of the ore body footwall [2, 7, 40].

The advantage of this technology is simplicity of the technological process.

The main disadvantage of this technology is significant costs of blasting, drawing and transporting waste rocks. Such costs significantly increase costs of stoping and, as a result, increase the total cost of ore production. In addition, the cost of hoisting and disposal of waste rocks on the daylight surface rises as well. Such costs are useless and do not conform with the concept of rational use of natural resources.

2. The second and perhaps the main option of broken ore extraction from the "dead area" of the footwall of ore bodies involves driving an additional collecting level (sublevel) in footwall rocks. The number of such sublevels depends on the height of the block (panel) being mined and the ore body dip. As a rule, underground mines create one or two such additional collecting levels.

The design of such a level involves driving a scraper drift in the footwall rocks, creating additional draw cones in the footwall rocks and additional discharge, ventilation-service and manway raises [2, 40].

The advantages of this technology include simplicity of design and considerable practical experience of using it in underground mines.

The major disadvantage of the considered technology is a significant amount of work on driving additional collecting levels resulting in increased mining costs and time. This slows down and reduces concentration of operations due to introduction of additional sublevel stope faces at different levels.

Since workings are driven in waste rocks, it is desirable to mininize the amount of driving. A significant number of additional workings on collecting sublevels, sometimes created for drawing an insignificant amount of broken ore of the "dead area", increase greatly the cost of production under the mining system in general.

In addition, residual ore losses after application of additional collecting levels are quite significant. To determine the level of residual ore losses, laboratory tests for average conditions of underground mines of Kryvyi Rih iron ore basin for ore bodies with small dips are performed. Thus, the simulated dip angle is 40 °, the ore body thickness is 25 m, the sublevel height is 40 m, the number of additional levels is two, figure 2.

Additional collecting levels are located 15 m and 25 m above the main draw level. Figure 2 presents main stages of ore drawing from the "dead area" of the ore body footwall:

Stage I – the model of the block with broken ore before drawing through drawpoints.

Stage II – ore drawing from draw workings of the main draw level with formation of a "dead area" of broken ore on the ore body footwall.

Stage III – ore drawing from draw workings of the additional collecting level +15 m for extracting the broken ore from the "dead area" on the ore body footwall.

Stage IV – ore drawing from draw workings of the additional collecting level +25 m for additional extraction of the broken ore from the "dead area" on the ore body footwall.

Table 1 presents the results of modeling ore drawing under the standard technology of broken ore extraction from the "dead area" on the ore body footwall according to the above stages.

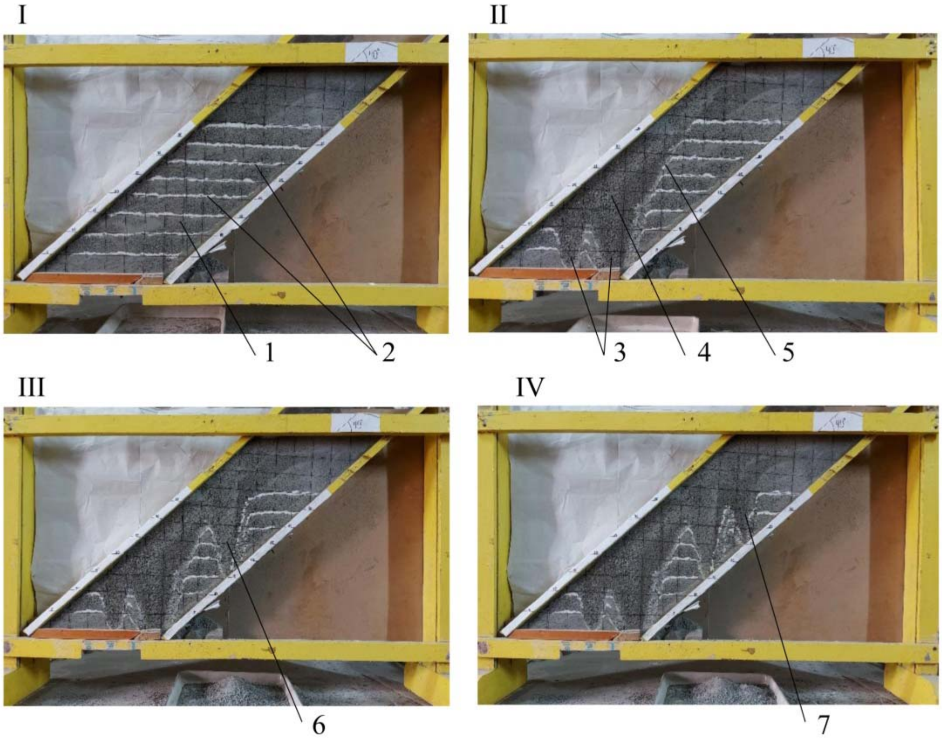

Figure 2. Stages of broken ore drawing from the "dead area" of the ore body footwall: I-IV – stages of broken ore drawing; 1 – broken ore, 2 – chalk, 3 – draw cones of the main level, 4 – waste rock, 5 – the contour of the "dead area", 6 – draw cones of the additional collecting level +15 m, 7 – draw cones of the additional collecting level +25 m.

Table 1. Results of modeling ore drawing under the standard technology of broken ore extraction from the "dead area" on the ore body footwall.

No.	Conditional losses of ore in the "dead area" after drawing from workings of the main level, %	Ore losses after drawing from level +15 m, %	Ore losses after drawing from level +25 m, %
1	56	32	22
2	59	34	20
3	55	28	18
4	54	31	24
5	56	30	21
Average	56	31	21

To obtain the correct results, 5 experiments with the same drawing conditions are performed. Losses and total reserves of ore are calculated in grams, and then switched to percentage to simplify perception of the overall picture of broken ore drawing.

To visualize the ore drawing process, a chalk layer is added every 5 m between the broken ore layers.

The results of the laboratory tests enable stating that broken ore losses on the ore body footwall make over 50% for the considered rather complex conditions of ore body occurrence. Additional collecting levels reduce these losses to 18- 22% on average which is acceptable for such dips and insufficiently thick ore bodies as compared to underground mine extraction indicators.

In addition, according to the underground mine data, two additional collecting levels increase the cost of ore mining by 25- 30% on average.

To eliminate the mentioned disadvantages, we propose the technology (named *drawing through "block collecting cones"*) of ore extraction from the "dead area" of the ore body footwall, figure 3.

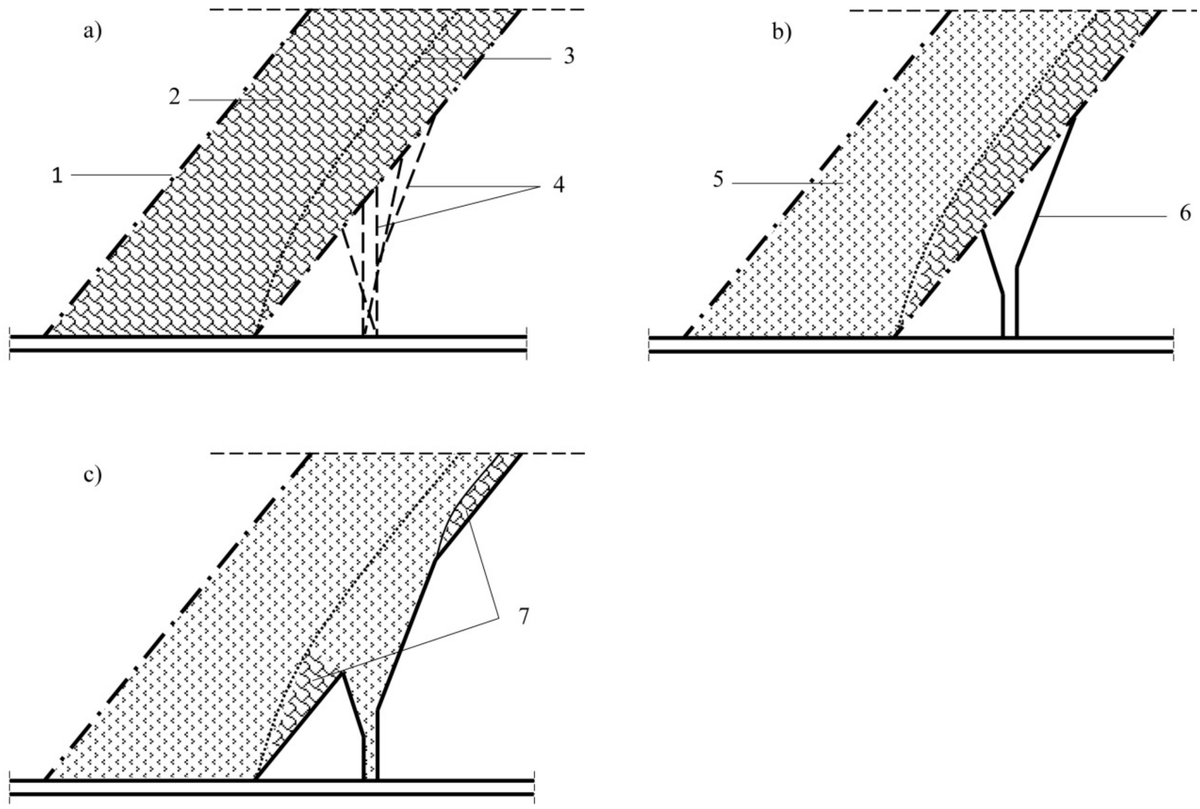

Figure 3. The recommended technology for ore extraction from the "dead area" of the ore body footwall through "block collecting cones": a, b, c – stages of forming a "block collecting cone"; 1 – the ore body contour within a block; 2 – broken ore in the block; 3 – the contour of the "dead area" of broken ore on the ore body footwall; 4 – longholes for creating "block collecing cones"; 5 – waste rocks after drawing broken ore from the block; 6 – the "block collecting cone" created in the ore body footwall; 7 – residual ore losses on the ore body footwall after drawing the broken ore from the "dead area" of the ore body footwall through the "block collecting cone".

The proposed technology consists in the following. Longholes 4, figure 3*a*, are drilled from workings of the main draw level in the footwall rocks to form "block collecting cones" 6, figure 3 *b, c.*

The proposed technology has the following advantages:

- as compared to the existing technology (that implies blasting the footwall rocks, immediate drawing of the blasted waste rocks of the footwall and subsequent broken ore drawing from the "dead area" of the ore body footwall), the proposed technology involves reducing the volume of blasted waste rocks by 65- 80%. This reduces the cost of broken ore drawing by about 30%, without considering reduction of costs for waste rock hoisting and disposal on the daylight surface.

- as compared to the technology of driving additional collecting levels in the footwall rocks, the proposed technology allows reducing costs for additional collecting levels by 25- 30% on average.

To determine the level of residual losses on the ore body footwall under the proposed technology, laboratory tests are performed for similar conditions of Kryvyi Rih iron ore basin.

Table 2 presents the results of modeling ore drawing under the proposed technology of broken ore extraction from the "dead area" on the ore body footwall through "block collecting cones".

Table 2. Results of modeling broken ore drawing from the "dead area" on the ore body footwall through "block collecting cones".

Ore losses in the "dead area" after drawing through "block collecting cones", %					
Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5	Average
14	15	14	17	18	15.6

The results of the laboratory tests enable stating that broken ore losses on the ore body footwall make 14-16% on average for the recommended technology of ore extraction from the "dead area" on the ore body footwall through "block collecting cones". These indicators are significantly lower (by 5-6%) as compared to the results of applying additional collecting levels; they are a satisfactoty indicator for the considered complex conditions of ore body occurence.

4. Conclusions

The results of the laboratory tests enable stating that broken ore losses on the ore body footwall make over 50% for the considered conditions of ore body occurrence. Additional collecting levels reduce these losses to 18- 22% on average which is acceptable for such dips and insufficiently thick ore bodies as compared to underground mine extraction indicators.

In addition, according to the underground mine data, two additional collecting levels increase the cost of ore mining by 25- 30% on average.

To eliminate the mentioned disadvantages, the authors propose the technology (named drawing through "block collecting cones") of ore extraction from the "dead area" of the ore body footwall.

As compared to the technology of driving additional collecting levels in the footwall rocks, the proposed technology allows reducing costs for additional collecting levels by 25- 30% on average.

The research allows determining the fact that broken ore losses on the ore body footwall make 14-16% on average under the technology of ore extraction from the "dead area" of the footwall through "block collecting cones". These indicators are significantly lower (by 5- 6%) as compared to the results of applying additional collecting levels; they are a satisfactoty indicator for the considered complex conditions of ore body occurence.

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