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INCREASING THE EFFICIENCY OF DEVELOPMENT OF SLOPING THIN ORE DEPOSITS IN ENERGY-DISTRUCTED MASSIFS

Lyashenko V.
candidate technical Sciences, *State enterprise "Ukrainian Research and Design and Intelligence Institute of Industrial Technology",*
ORCID: https://orcid.org/0000-0001-8361-4179
Andreev B.
Dr. Eng. Sc, Senior Researcher, Professor, Head of the Department State Construction geotechnology Kryvyi Rih National University,
ORCID: https://orcid.org/ h-index (Scopus or Google Scholar) https://www.scopus.
Stus V.
doctor of medical sciences, professor, Professor of the Department of Surgery No. 1 and Urology of the Dnipro State Medical University,
ORCID: https://orcid.org/0000-0002-4539-8126
Oliinyk T.
Senior Professor, Head of the Department of Mineral Processing, Kryvyi Rih National University,
ORCID: https://orcid.org/0000-0002-0315-7308 h-index 5 Scopus Author ID: 36173274800, h-index 7 Google Scholar http://surl.li/snyll
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Abstract

Topicality. It is caused by the growing needs of industrial society for metal supply. To achieve this, it is necessary to increase the efficiency of subsoil use and use the reserves of the existing mining technology. The greatest problems are associated with the development of gently dipping thin ore deposits in energy-disturbed massifs, where it is difficult to use high-performance mining machines and mechanisms with large overall dimensions.

Research object. Technologies and technical means for the development of gently dipping thin ore deposits with separate extraction of ore and host rock in energy-disturbed rock massifs.

Objective. Justification of the possibility of increasing the efficiency of developing gently dipping thin ore deposits with separate extraction of ore and rock in energy-disturbed massifs by implementing the reserves of the organization of work during the separation of ores from the rock massif, as well as improving the quality of ore raw materials, mining and environmental safety. This will improve the rational use and protection of the subsoil, reduce the volume of waste rock and off-balance ores in terms of useful component content on the surface and reduce the negative impact of the mining region on the livelihoods of the population and the environment.

Methods. The methods of complex generalization, analysis and assessment of practical experience and scientific achievements in the field of underground geotechnology, theory and practice of explosive destruction of solid media, methods of continuum mechanics, mathematical statistics, as well as methods for studying wave processes according to standard and new methods of leading specialists from developed mining countries of the world with the participation of the authors were used.

Results. Based on experimental studies of the indicators of a continuous development system with gross ore extraction, the results of dilution calculations for the compared variants of development systems are substantiated. The indicators of ore sorting and graphs of ore distribution by metal content in balance reserves and mined ore are given. The variants of development systems with selective ore extraction, tested experimentally, are proposed. The technical and economic indicators of the development of deposit reserves by a continuous development system along the rise with selective extraction of the ore body, as well as gross extraction of ore and rock are presented. The recommended technology can be in demand at enterprises of the mining industry, in particular, ferrous, non-ferrous, radioactive and other metal ores.

Keywords: ore deposits, main stresses, low power, gentle dip, ore quality, mining and environmental safety.

1.Introduction

The growing needs of industrial society require metals. The trend in the development of mining production is the intensification of deposit development processes with an increase in the size of ore fields due to geometrization and the use of mobile high-performance equipment [1, 2]. Increasing the efficiency of subsoil use is increasingly ensured by using the reserves of the existing mining technology. The greatest problems are associated with the underground development of gently dipping, thin ore deposits, where it is impossible to use high-performance mining machines and mechanisms with large dimensions [3, 4]. This work is a continuation of research, the main scientific and practical results of which are most fully presented in works with the participation of the authors [5, 6].

Research object. Technologies and technical means for the development of gently dipping thin ore deposits with separate extraction of ore and host rock in energy-disturbed massifs.

Objective. Substantiation of the possibility of increasing the efficiency of development of gently dipping thin ore deposits with separate extraction of ore and rock in energy-disturbed massifs by implementing reserves in the organization of work during separation of ores from the rock massif, as well as improving the quality of ore raw materials, mining and environmental safety. This will improve the rational use and protection of the subsoil, reduce the volume of waste rock and off-balance, in terms of useful component content, ores to the daylight surface and reduce the negative impact of the mining region on the life of the population and the environment.

To achieve this goal, the following tasks were solved:

1. To establish the deformation in the support, which is activated after the first 3 months, steadily maintaining the trend of increase over time.

2. To develop a technology and technical means for the development of gently dipping thin ore deposits with separate extraction of ore and host rock in energy-disturbed rock massifs.

3..Recommend further research aimed at establishing the patterns of development of the massif's stress-strain state in the zone of its weakening (geomechanical monitoring).

2. Materials and research methods

The dependence of the quality indicators of ores mined using different variants of a continuous development system is studied within the framework of an industrial experiment, during which the general quality indicator, ore dilution, is assessed using direct and indirect methods [7, 8]. The curves of ore distribution by metal content make it possible to clarify the mechanism of interaction of different grades of process products. The quality of ores during their extraction is assessed during the development of experimental blocks using a generally accepted method based on block development maps with geological and mine survey data. The metal content in the ore was calculated based on the results of ore testing in blocks at all stages of work. The data on the technology indicators were interpreted using graphs. Recommendations for the selection of development system options are substantiated by the results of experimental development of ore bodies. Based on the results of the experiment using the engineering forecasting method, development system options optimized by the dilution criterion were proposed [9, 10].

2.1. Discussion of research results. The main direction of solving these problems remains the improvement of the indicators of completeness and quality of extraction of minerals from the subsoil due to the still hidden resources of known technologies and technical means [11, 12]. From thin ore bodies with a dip angle from 0 to 30° and a thickness of 0.7 to 2.0 m, up to 50% of non-ferrous and rare metal ores are mined by the underground method. Gently dipping thin deposits exceed 20% of vein deposits [13, 14]. Low thickness and difficult bedding conditions of ore bodies are accompanied by high dilution of the mined ore, the damage (economic consequences) of which reaches 40% of the cost of metals and is the reason for the low efficiency of extraction and processing of ores from such deposits. The direction of improving the quality and environmental safety of mining such ores is to improve the technology of breaking, taking into account the location of the useful component in the ore-bearing massif [15, 16].

The ore bodies of the type under consideration are characterized by variable angles of incidence, uneven thickness, faults and constrictions. The host rocks are generally stable and allow significant outcrops of roof rocks, which makes it possible to use development systems with an open stope. For their development, options for a continuous development system are used. The main disadvantage of a continuous development system is the high dilution of the ore, reaching 60% and reducing the content in the commercial ore compared to the metal content in the subsoil by up to 40%. The reason for the high dilution is the seizure of 0.3 to 1.0 m of rocks during breaking, due to the need to work in a stope and the lack of small-sized mining equipment [17, 18].

There are two prevailing trends in improving the technology of intersecting ore body extraction: continuous mining with ore breaking from boreholes and mining with separate ore and rock extraction. In the first trend, it was found that under comparable conditions, breaking from boreholes compared to bench breaking from the working space allows increasing the productivity of a miner in cleaning operations by an average of 10...12%, increasing the productivity of the production block by 15...18% and reducing dilution by 10...12%. With a decrease in the depth of mining operations, the conditions for ore extraction become more complicated. A decrease in capacity, variability in the angle of incidence, dumps and constrictions necessitate a decrease in the width of the extraction panel and, consequently, an increase in the volume of cutting operations by up to 50%, which reduces the efficiency of the system [19, 20].

3. Research results

The Ishim deposit (Republic of Kazakhstan) is composed of gently dipping ore bodies with an average thickness of 2 m, located in large geological faults. The strength coefficient according to M.M. Protodyakonov of ores is 8...14 and of host rocks 8...10. To assess the quality indicators of the continuous development system with bulk ore extraction, experimental blocks were developed, the development conditions of which are typical for most ore bodies of the deposit (Table 1).

Table 1.

Conditions for testing experimental blocks

Parameters of ore bodies	Block 1	Block 2
Interval of change of the angle of incidence, degree	33-41	20-31
Width along the stretch, m	116	136
Area, m^2	4030	6170

Preparation and cutting of blocks consisted of making inclined raise, ventilation and boring drifts, ore passes, ore breaking was carried out by blasthole charges, ore delivery was carried out by scrapers. Characteristics of block 2: dip angle 250, ore thickness 0.78 m, ore body area 5167 m, metal content 75 conventional units. Dilution (***R***) was calculated by the direct method and indirect method based on the metal content in balance and commercial ore, as well as in the diluting ore mass: $R = \frac{c-a}{c-b} \times 100,\ \%$ (1)

Where *c*, a, b – respectively, the metal content in balance and commercial ore and diluting rock mass, %.

Under generally identical conditions of development of the experimental blocks, the dilution of the mined ore was 41...43%, and after sorting 3...38%. The quality indicators of block 1 development: dilution of ore issued for sorting 46%, sorting tailings yield 7.1%, marketable ore dilution 42.0%, metal content in marketable ore 55 conventional units, decrease in metal content in marketable ore 36 conventional units. The quality indicators of block 2 development: dilution of ore issued for sorting 50%, sorting tailings yield 13.2%, marketable ore dilution 42.5%, metal content in marketable ore 47 conventional units, decrease in metal content in marketable ore 38 conventional units [21, 22]. In Fig. 1 shows the curves of ore distribution by metal content in reserves and ore received for sorting determined for experimental blocks 1 and 2.

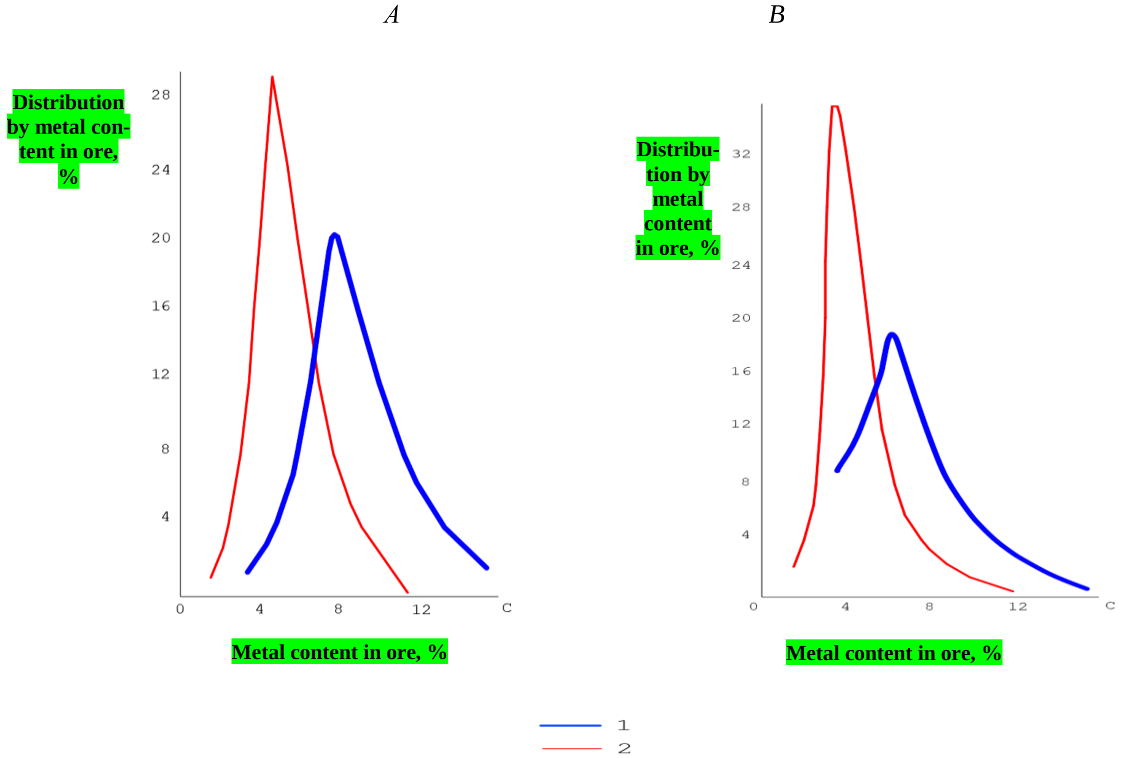


Fig.1. Ore distribution by metal content in blocks: A -block 1, B - block 2; 1:1 - metal content in the subsoil; %; 2- metal content in the issued ore

The graphs show a shift in the curve of commercial ore distribution with its maximum towards lower contents, characterizing a decrease in the metal content in commercial ore compared to the metal content in balance reserves. This occurs when off-balance ore and waste rock are mixed with balance ore during bulk ore breaking and its movement along the block. In blocks 1 and 2, the metal content in commercial ore turned out to be 37% lower than in balance ore. The output of sorting tailings fluctuates by blocks from 3 to 14%, averaging 8...10%. However, it should be noted that with metal content in balance ore, When due to dilution the metal content in balance ore decreases in broken ore to the level of off-balance ore, the output of tailings at the ore control station (RCS) rises to 40%, and metal losses in tailings increase to 40% or more. [23, 24]. The main task of increasing the efficiency of development of thin and gently dipping intersecting ore bodies is to reduce the level of ore dilution, while ensuring the mining and environmental safety of their development in energy-disturbed rock massifs.

3.1.*Geomechanical audit of the dynamics of the stress-strain state (SSS) of a rock massif (theory of the issue*). One of the methods for studying the dynamics of the load on rigid metal arch support of mining development workings was measurements using strain gauges. In addition, the change in the dimensions of the support section was determined by measuring the distances between the benchmarks embedded in the support by mine surveying surveys.

Strain gauges and survey benchmarks were placed on the supports installed in the workings. In working No. 1, metal frames were installed on the rigid metal supports of a 13 m long section at intervals of 0.5 m from each other. In working No. 2, 9 metal frames were installed at intervals of 1 m. The measuring strain gauge station was placed on 5 metal frames in working No. 1. Each frame was equipped with 9 measuring points, each of which contained three sensors glued to three planes of a special profile. Rock deformations were recorded using strain gauge equipment. Based on the measured principal stresses, their diagrams were constructed around the working, which served as the basis for assessing the weakening of the massif under the influence of mining operations (Fig. 2).

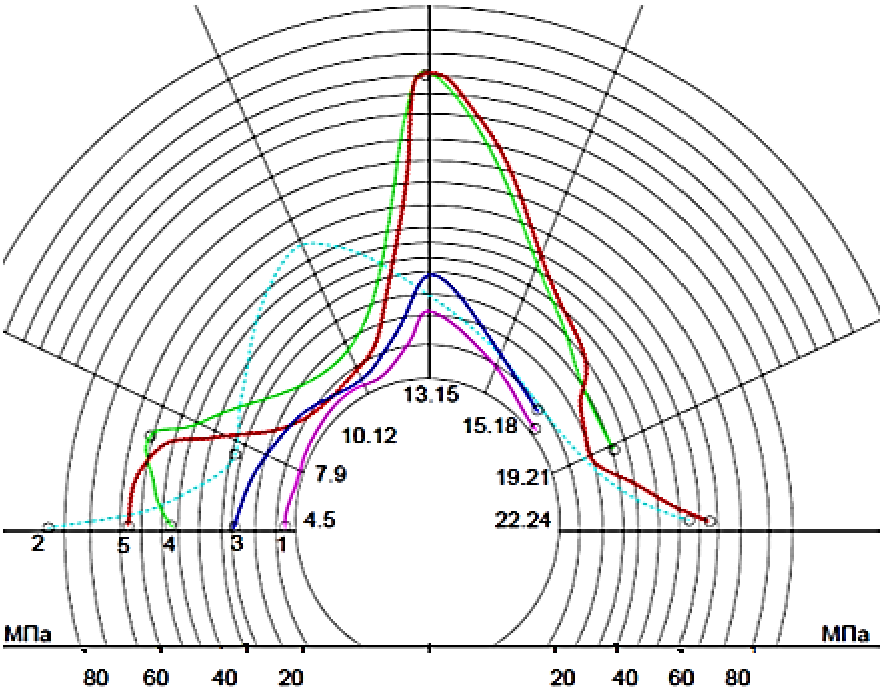


Fig. 2. Stress diagrams σ z: 4-24-strain gauges; 1-5 – measurements

Based on measured deformations $\xi_{,0}$, $\xi_{,f1}$, $\xi_{,f2}$ The main deformations were determined:

$$\xi_{1,2} = \frac{\xi_{f_2} + \xi_{f_1}}{2} \pm \frac{\sqrt{2}}{2}\sqrt{(\xi_{f_2} - \xi_{f_1})^2 + (\xi_0 - \xi_{f_1})}, \quad (2)$$

and the angle φ between the directions $\xi_{,0}$ and $\xi_{,1\,1}$:

$$\mathrm{tg}\varphi_0 = \frac{\xi_{f_1} - \xi_{f_2}}{2\xi_0 - \xi_{f_1} - \xi_{f_2}} \cdot \mathrm{tg}\varphi_1, \quad (3)$$

Principal stresses at the point under study based on Hooke's law:

$$\sigma_1 = \frac{E}{1-\mu^2}(\xi_1 + \mu\xi_2), \qquad \sigma_2 = \frac{E}{1-\mu^2}(\xi_2 + \mu\xi_1), \quad (4)$$

Where ***E*** - modulus of elasticity; μ - Poisson's ratio.

Principal normal stresses: σ_z and σ_x – respectively, vertical and horizontal: $\sigma_z = \sigma_1 \sin\alpha - \sigma_2 \sin\alpha$ and and

$$\sigma_x = \sigma_1 \sin\alpha - \sigma_2 \sin\alpha. \quad (5)$$

It was found that the deformations in the lining are activated after 3 months, steadily maintaining the trend of increase with time. This can be explained by relaxation phenomena when pressure is perceived on the lining. The deformations increase starting from the 4th to 6th month and reach a maximum after 11th to 12th months. The first phase is the beginning of the development of the operational block. The deformations of the lining increased from 2 to 16 mm (Fig. 3).

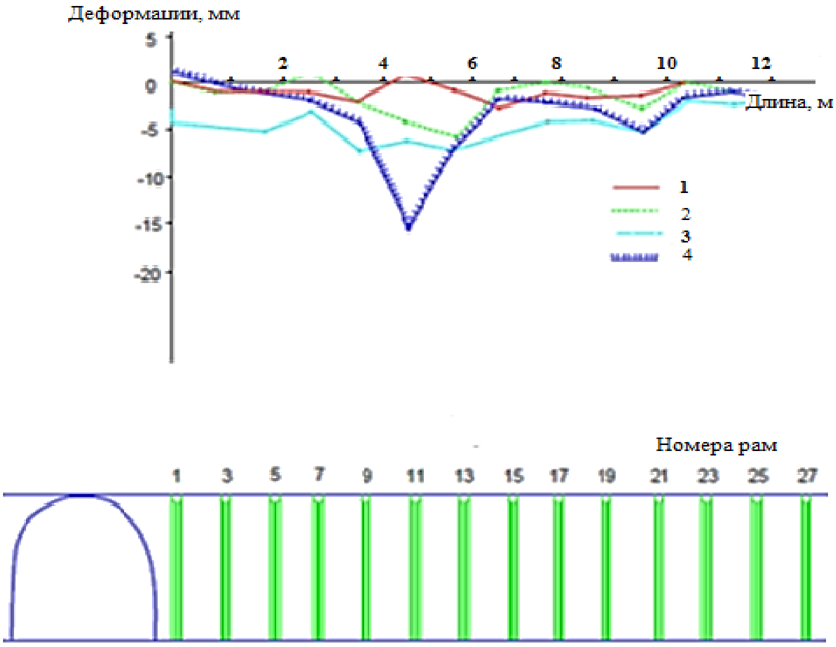


Fig. 3. Dependence of the deformation of the support lining on its length in the first phase: 1,2,3,4 - measurements, 1-27 – frames

It follows from Fig. 3 that the development of deformations is not monotonous. Thus, the greatest deformation of frame No. 11 was 19 mm, reflecting the influence of the fault. The second phase is the section of the ore body from the side of the hanging wall. The third phase is the development of deformations of the support during ore extraction, which is characterized by intensive deformation of the support. If outside the cleaning zone the deformations were insignificant, then during ore extraction the average deformations of 27 arches over 1, 2 and 3 months, according to sensor data, increased to 43, 119, 128 mm, respectively. The width of the workings at a height of 0.5 m from the ground decreased by 85 mm in the first month and by 175 mm in the second month. The maximum deformations of the metal arch support were noted at the frames located close to the working face, and at frame No. 4 in the fault area. After 6 months, the deformations in the upper arch of frame No. 4 were 233 mm, and the width of the support at a distance of 0.5 m from the soil increased by 55 mm. At this time, frame No. I 9 came apart at the locks and failed. The center of the upper arch of the frame dropped by 432 mm, the width at the locks increased by 312 mm. In the upper arch of frame No. 8, the deformations were 340 mm. The maximum deformations of the support in working No. 2 were observed at the frames close to the working face and at frame No. 4 in the fault area (see Fig. 3). Based on the results of the analysis of the practice of mining low-power flat and inclined intersecting ore bodies, variants of mining systems with selective ore extraction were developed (Fig. 4).

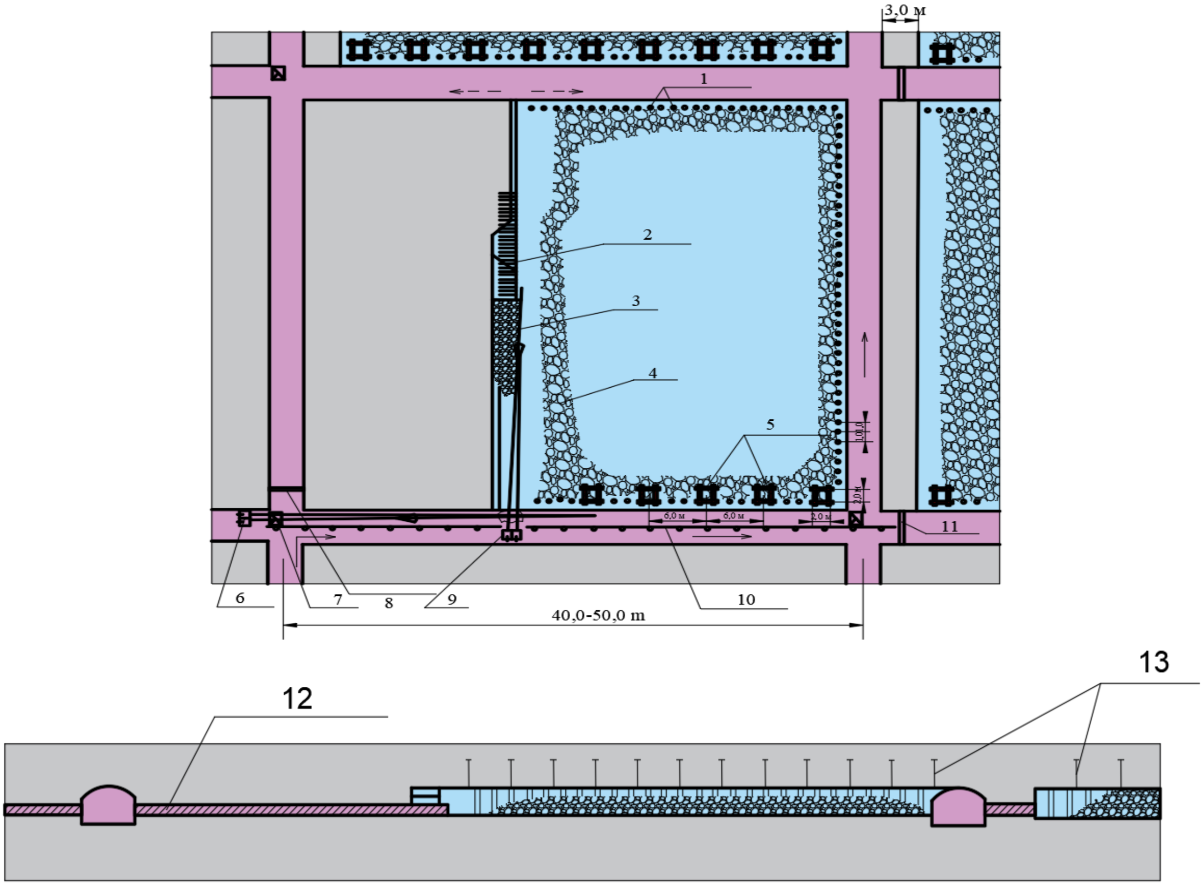
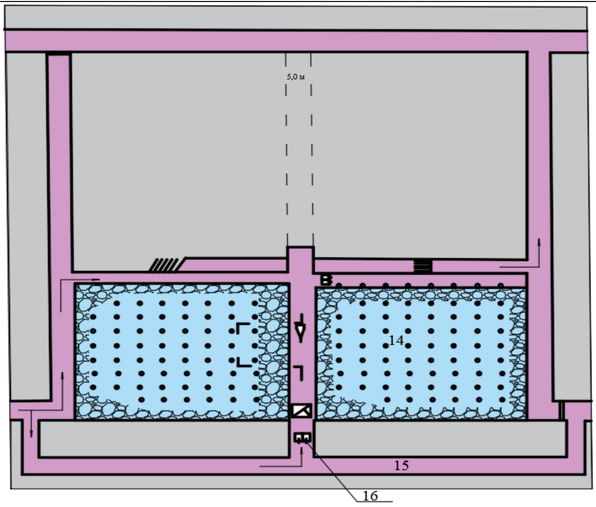


Fig. 4. Solid mining system with separate extraction of ore and rock: 1 - wooden racks; 2 - face; 3 - beaten ore; 4 _ rock; 5 - fire support; 6 -scraper winch; 7 - ore intake; 8 - ventilation door; 9 - scraper winch; 10 - stitching of the running compartment; 11 - jumper; 12 - ore body; 13 - anchor support

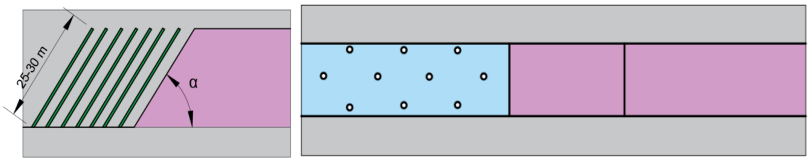
The variant with selective extraction of ore bodies was tested on the section with the thickness from 0,3 to 1,3 m. The strike of the ore body from north to south, the dip is to the west at the angle of 23…43°. The ore is dense, finely fractured. The variant is applied for development of ore bodies with the thickness of 0,2…1,0 m with the dip angle from 0 to 40°. It provides separate breaking of host rocks and ore by hiding; when the compensation gap is formed, the rock is thrown by blast into the worked-out space, where it is left as a backfill, and the ore with minimal rock sticking is broken off on the compensation gap, delivered by scraper to the undercutting drift and along it to the ore pass. When choosing the height of the working space, the necessity of providing normal working conditions for the worker in the face and high technical and economic indicators of block development is taken into account [25, 26].

When extracting ore bodies with a thickness of 0.2...0.3 m, the height of the working space is taken to be 1.2...1.4 in, and for extracting ore bodies with a thickness of 0.4...1.0 m, 1.8...2.0 m. To improve the quality indicators of mining, the face is given a stepped shape, which is maintained both at the stage of forming the compensation gap and at the stage of breaking the ore body, when the width of the step is minimal, but not less than the thickness of the ore body. To prevent the scattering of rock along the compensation gap when it is formed, a rock breaker is installed at a distance of up to 5-6 m from the face. The roof of the stope is supported by wooden spacers with a diameter of 0.2...0.3 m every 2.5...3.0 m or by metal rods 2.0 m long on a grid of 2.5 × 2.6 m. At the boundary of the stope and the undercut adit, as the stope works progress, fires measuring 2.0 × 2.0 m are laid out every 6.0 m. At the contact with the stope, the mine workings are supported by additional supports. In the variant of the continuous face development system, ore was extracted along the rise with subsequent expansion of the worked-out space by undermining the soil (Fig. 5).

a



b



c

Fig. 5. Layered mining system with selective ore extraction: a - block projection on a vertical plane; b - ore stripping; c - rock blasting in the soil

To prevent ore from scattering into the mined-out space, spacer posts were installed along the cleaning belt and boards were used to line it. After breaking and removing two ore belts to a depth of 2.7 m with an extraction capacity determined by the ore body capacity, boreholes were drilled through the rock in the soil to expand the mined-out space. The broken rock, most of it, was moved into the mined-out space by the force of the blast and a scraper winch. This development system variant is used for mining ore bodies up to 1.2 m thick with a dip angle of 30…600. Ore is mined in ascending layers with selective breaking of the ore and the host rocks of the footwall. The block is prepared by driving the upper and lower horizon drifts, inclined raisers and a collector. A raiser for lifting loads is installed in the center of the block as the cleaning work progresses. An ore pass is made at the intersection of the load raiser and the ventilation drift of the lower horizon. The cleaning excavation begins with drilling the ore of the first layer above the ventilation drift.

The ore of the first layer is broken onto the ventilation drift and transferred to the ore pass. After the first layer ore is released, the rock bench of the first layer is formed. The mined-out space is fenced with wooden shields.

The ore of the second layer is broken onto the rock bench of the first layer and delivered by a scraper to the cargo raise. After the ore is released, the fence of the mined-out space is removed and the first bench of the second layer is formed. The rock is broken onto the mined-out space and used to fill technological voids. The ore is broken into boreholes 2.5…3.0 m long with an inclination towards the cleaning space of 55…60°. The rock bench is formed by blasting explosives in boreholes 1.8…2.5 m long drilled by telescopic perforators, located parallel to the cleaning space.

The bench width is selected equal to 1.5...2.5 m, the distance from the bench soil to the roof of the working space does not exceed 3 m. After the bench is formed, support posts with a diameter of 16...18 m are installed along the boundary of the bench with the mined-out space every 1.5...3.0 m, on which shields are attached, preventing the broken ore of the next layer from getting into the mined-out space. After unloading the broken ore in the layer, the shields are removed for use in the next layer, and the posts remain as a safety support.

To reduce ore losses on the bench soil, it is cleaned. As the block is mined, the sides of the ventilation and cargo risers are secured and lined with wood from the side of the working space. To improve the ventilation parameters, the lining is compacted with film or fabric. Ore is mined in ascending layers with selective breaking of the ore and host rocks of the footwall [27, 28].

3.2. Economic efficiency. Economic comparison of development technologies is carried out on the basis of an economic and mathematical model by comparing the values of the optimum points for the target functions and selecting the values of the parameters corresponding to the optimum point for the final product, taking into account the metal extraction according to the Golik-Lyashenko model [21]. The main indicators for cleaning extraction are adopted according to the data of reports and projects for deposit development:

$$\text{П}_{\text{УТТ}}=\left[\text{З}_{\text{То}}\left(1-\frac{Q'_{\text{н}}+Q'_{g}}{Q_{\text{б}}}\right)+\frac{\text{З}_{\text{ЗК}}}{\rho}\left(1+\frac{Q''_{\text{н}}+Q'_{\text{п}}}{Q_{\text{б}}}\right)+\text{З}_{\text{Тн}}\frac{Q'_{\text{н}}+Q''_{\text{н}}}{Q_{\text{б}}}+\text{З}_{\text{Тп}}\frac{Q'_{\text{п}}+Q''_{\text{п}}}{Q_{\text{б}}}\right]-$$
$$-\Delta\gamma_{\text{Т}}\text{Ц}_{\text{Тбαт}}-\frac{R_S}{(1-R_S)P}\left[\left(\text{З}_{\text{То}}+\frac{\text{З}_{\text{ЗК}}}{\rho}\right)+(1-\Delta\gamma_{\text{Т}})\text{У}_{\text{Т}RS}\right]-\frac{1-P}{P}\times \qquad (6)$$
$$\times\left[\text{З}_{\text{Тбд}}-B\left(\text{З}_{\text{То}}+\frac{\text{З}_{\text{ЗК}}}{S}\right)\right]+\frac{(1-P)(1-B)(1-в)}{P}(1-\Delta\gamma_{\text{Т}})\text{У}_{\text{Т}RP},$$

Where $Ц_{Тбал}$ – value of extracted balance ore, rub.; $Ц_{Тбат}$ – value of lost ore with metal content αT, rub.; $З_{То}$, $З_{Тн}$, $З_{Тп}$, $З_{ЗК}$ – costs for breaking, releasing and transporting ore, for cutting, mining preparation and stowage work, respectively, rub.; $Q_{б}$, $Q_{н}$, $Q'_{п}$, $Q''_{п}$ – volumes of ore, rock and off-balance ore within the boundaries of the ore body, as well as cutting and mining preparatory work on ore and rock, respectively, m^3; ρ – ore density, t/m^3; $З_{Тбал}$ – costs of extraction of balance ore, rub.; R_S – ore dilution, i.e.; P – ore losses, etc.; B – amount of diluting rocks, t; $в$ – metal content in diluting rocks, fractions of units.

The technical and economic indicators of mining with selective extraction of the ore body and the expected indicators of block mining with gross extraction of ore and rock at an extraction thickness of I.2...1.3 m are presented in Table 2.

The efficiency of mining production can be determined by comparing the options for developing deposits (including man-made ones) taking into account the costs at all stages. In this case, it is necessary to take into account the costs of protecting the population (including the costs of environmental protection, rehabilitation of contaminated and disturbed areas, human health, etc.) living in the zone of influence of mining facilities according to the proposed analytical model:

$$П=\sum_{i=1}^{n}\left[\left(Ц_{Ар}-C_{Ар}\pm\left(У+З_{и}\right)\right]\frac{1}{1+E^{t-1}}\cong \max, \qquad (7)$$

Where $П$ – profit from obtaining final products from metal-containing ores, monetary units;

$Ц_{др}$ – total extractable value of the final product from metal-containing ores, monetary units;

$C_{др}$ – total costs of extraction and obtaining final products, monetary units;

$У$ – total damage (economic consequences) caused (-) to the environment or prevented (+) taking into account the costs of protecting the population living in the zone of influence of mining enterprises (Зн), monetary units;

E – cost and profit discount factor over time t of application of the technology being evaluated, units.

Table 2.

Indicators of solid system development

Indicators	**Recess option**	
	Selective	**Gross**
Angle of incidence, degree	31	31
Ore Square, м^2	1024	1024
Ore body capacity, m	0,04	0,64
Balance sheet stocks, m^3	650	650
Area of recaptured ores, m^2	1024	1024
Dredging ore capacity, m	0,86	1,20
Height of the cleaning space, m	2,0	1,25
Recaptured ore mass, m^3	081	1280
Repulsed rocks for expansion, m^3	1167	-
Ore content before sorting,%	60	51
Commercial ore after sorting, m^3	677	740
Output of off-balance sheet ore, m^3	198	490
Metal content in commercial ore, %	66	55
Dilution in commercial ore, %	40	45
Dilution of the breed from the outside, %	25,6	40,0
Dilution by the breed in the block, %	3,3	45,0
Total metal losses, %	13,2	37,0
Metal losses in off-balance sheet ore, %	9,8	34,0
Metal loss in voids, %	3,4	3,0
Productivity of the downhole worker, m^3/person cm	3,2	4,0

The obtained results correspond with the conclusions of specialists in this area of mining in Ukraine, the Republic of Kazakhstan, Canada and other developed mining countries of the world [29, 30]. The research results are of interest to related industries of the mining industry, in particular, ferrous metallurgy [31, 32].

Further research. As an alternative to the trend of developing mining production by intensifying underground mining of deposits with an increase in the size of ore fields and the use of high-performance equipment, there remains the direction of increasing the efficiency of mining by reducing the amount of ore dilution by implementing reserves in the organization of work during the extraction and processing of ores.

In our opinion, the following new scientific and methodological provisions:

Since the middle of the last century, the practice of mining ores with backfilling of mined-out spaces with hardening mixtures of various compositions and strengths has been improved. The correlation of ore dilution by backfilling on the parameters of breaking has been determined, the direction of reducing dilution by activating and coarsening the components of the mixture has been substantiated, methods for optimizing the compositions of hardening mixtures in activators have been developed, increasing the indicators of the completeness of subsoil use and the quality of the mined ore [33].

Observations of the state of the rock mass indicate an insignificant increase in deformations and stresses during the first three months of mining operations. Stresses in the rock mass increase more slowly than in the ore. Upon completion of mining operations, stresses and deformations in the massif stabilize. The area where the preparatory and production works junction occurs is characterized by the formation of a weakened rock zone with the following dimensions:

- length, depending on the angle of inclination of the thick ore body and the location of tectonic structures, approximately 30 m or more in the footwall and about 10 m in the hanging wall;
- width: when mining across the strike of the ore body - the width of the stope section, when mining along the strike - the extracted thickness of the ore body;
- height: the vertical distance to the boundaries of the forming arch of natural rock equilibrium.

Rock collapse within the junction zone can be prevented by supporting the workings, the parameters of which are determined by the interaction of the rocks within the arch:

- if the thrust force of the jammed rocks in the roof of the working is sufficient, lightweight support can be used;
- if the thrust force is insufficient, the support of the workings must be calculated based on the condition of maintaining a column of rocks up to the daylight surface or the formation of a new arch of natural equilibrium.The possibility of increasing the quality of mineral resources, mining and environmental safety of the development of gently dipping thin ore deposits by reducing the amount of ore dilution is confirmed by an industrial experiment using reliable geological and mine surveying control. Of interest is also the introduction of engineering forecasting using special programs such as Edu Net (Phoenix Contact), Power Chute Network Shutdown (PCNS) and Network Management Card (NMC) (Schneider Electric), SITRAIN (Siemens), GIS K-MINE® ("KAI Scientific and Industrial Enterprise" LLC, Ukraine), VENTSIM and others for the training of mining engineers [34].

The prospects for the use of continuous development with gross ore extraction are confirmed by the results of dilution in the variants of continuous development by rise with selective and gross extraction of ore and rock. Variants of two-stage selective development with breaking from boreholes can be an alternative to gross extraction and can be in demand at enterprises in various industries, including mining and metallurgy [35].

4.Conclusions.

It was found that deformations in the lining are activated after 3 months, steadily maintaining the trend of increase with time. Deformations increase starting from the 4th - 6th month and reach a maximum after 11 - 12 months. The distribution of the main stresses with all the spread of values obeys the general pattern and the curves of the graph are close in shape. It was determined that the development of deformations is not monotonous. The greatest deformation of frame No. 11 was 19 mm, reflecting the influence of the fault. It is shown that the increase in load in the stress concentration zone is 15-20% of the gravitational component, or 39 MPa, which is less than the compressive strength of rocks - 54-75 MPa.

4.1.Prospective studies. Further studies aimed at establishing the patterns of development of the massif's SSS in the zone of its weakening (geomechanical monitoring) are recommended. This will allow adjusting the development parameters with the receipt of an economic effect due to the reduction of ore dilution, while ensuring the improvement of mining and environmental safety, as well as the labor of underground workers.

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