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Research Article

METHODOLOGY FOR DETERMINING THE BOUNDARIES OF A QUARRY DURING THE TRANSITION TO UNDERGROUND MINING OF UPLAND DEPOSITS

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ABSTRACT

The article presents a method for determining rational boundaries during the transition to underground mining of upland deposits, by performing calculations, comparing overburden coefficients and rock mass.

This method is the simplest for determining $V_{гм}$ – volume of rock mass, m^3, $Д_{р.м}$ - volume of mined ore mass in the pit contour, t, $M_э$ - operational metals in the pit contour, kg, $V_{вск}$ – volume of overburden rocks, m^3, $K_{вск}$ - coefficient of overburden rocks, $K_{г.м}$ - coefficient of rock mass at different depths of the open pit with the use of graphoanalytic method by using the AutoCAD computer program.

KEYWORDS

Upland deposit, rock mass, ore, quarry, operational metal, overburden rocks, overburden rocks coefficient, rock mass coefficient, graphoanalytic method, balance reserves, side angle.

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INTRODUCTION

Currently, there is no unified methodology in mining science and practice for determining rational boundaries when switching to underground mining of upland deposits. There are several well-known principal approaches to the feasibility study of the depth of open works based on the use of various economic criteria, discussed in detail in technical literature. [1,2,3]

Currently, there are various works, theories, practical developments, etc. to determine the boundaries of a quarry during the transition to underground mining of upland deposits, which each of them justifies determining a separate mining point, which in turn makes it possible to technically and economically determine the boundaries of a quarry at the stage of transition to underground mining.

The data determined by known methods are labor-intensive, which take a lot of time. Nevertheless, by this time there is no methodology for establishing the boundary of the transition from open to underground mining during the development of deposits, which takes into account complex indicators that affect from a technological and economic point of view when developing reserves of upland deposits. [4,5,6]

MATERIALS AND METHODS

This method is the simplest for determining the rational boundaries of a quarry when switching to underground mining of upland deposits. At the same time, the developed technique makes it possible to reduce the time and labor costs, as well as to promptly perform technical calculations for determining the rational boundaries of a quarry when switching to an underground method of mining a deposit using a graphoanalytic method using the AutoCAD computer program of the quarry in question at various depths.

THE MAIN PART

The methodology substantiates the depth of open-pit mining operations during the transition to underground mining of upland deposits.

Deposits with known geological, topographic, as well as known data on ore and metal reserves are considered as the object of research.

With the available data on reserves, the location of ore bodies and other mining and geological conditions of the deposit, the preliminary final contours of the quarry in various depths H of its development are determined by the graphoanalytic method, using the AutoCAD computer program.

The calculated indicators obtained using the AutoCAD computer program for mining of the reserves of the deposit are entered in the following table No. 1.

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Table No. 1.
Calculated indicators of quarry mining to a depth of *H*, m.

Parameters	Designation	Units of measurement	Quarry depth, m
			H
Volume of rock mass	$V_{гм}$	thsd m3	
Reserved rock mass	P	thsd. t	
Reserved metall	$M_б$	kg	
Content	C	gr/t	
Loss ratio	$К_п$	%	
Dilution ratio	$К_р$	%	
Volume of mined ore mass	$Д_{рм}$	thsd. t	
Operational metal	$M_э$	kg	
Maintenance operational	$C_э$	g/t	
Overburden volume	$V_{вск}$	thsd. m^3	
Overburden ratio	$К_{вск}$	m^3/t	
The coefficient of rock mass	$К_{гм}$	t/gr	

To perform the enlarged calculation, the volumes of ore, rock mass, overburden, the amount of metal, the average metal content are also taken into account by creating a longitudinal section of the deposit being worked.

At the same time, depending on the sections of the areas, as well as the angle of the stable side of the quarry in question, the volume of rock mass is determined in the Microsoft Excel software for each considered depth of the quarry.

The angle of inclination of the side of the quarry α is taken according to previously designed conditions and conditions of spent quarries of various depths *H*. Depending on the angle of inclination of the side of the quarry, α is determined by the volume of rock mass $V_{г.м}$ for different sections of the quarry, the depths of mining *H* are considered graphically, the data obtained are used to compare the parameters of the quarries.

To determine the volume of the rock mass $V_{г.м}$, the method of horizontal parallel sections is used at specified intervals of the depth of the quarry, with the horizontal application of the $B_{г.п.}$ stable angle of slope of the side of the quarry.

The determination of the horizontal position of the side of the quarry $V_{г.м}$ based on the angle of inclination of the side α for different depths *H* of the quarry is determined by the following formula:

$$B_{г.п.} = \frac{H}{tg\alpha}, \text{ м.}$$

where, *H* is the depth of the quarry, m

α is the angle of inclination of the side of the quarry, deg.

Further preserving the lower area of $S_{н.п}$ quarry it is possible to find the upper area of the quarry $S_{в.п}$ using the obtained result of horizontal applications of the side of the quarry $B_{г.п.}$.

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The volume of rock mass $V_{г.м}$ of the quarries under consideration for different H depths is also determined graphically.

Analytically, the volume of rock mass $V_{г.м}$ in the considered sections of the quarry for different depths H is determined by the following formula.

$$V_{г.м.} = \frac{(S_{н.п.}+S_{в.п.})}{2} \cdot \frac{H}{1000}, \text{ m}^3.$$

where, $S_{н.п}$ – the lower area of the quarry, m².

$S_{в.п}$ – the upper area of the quarry, m².

H – the depth of the quarry, m.

The amount of ore (balance reserves P, volume of mined ore mass $Д_{р.м}$, operational metals $M_э$) at different depths H of the quarry is also determined analytically and graphically.

Graphically, according to the vertical projection of the ore body, in accordance with geological materials, the area of ore $S_р$ in the contours of the quarry is determined at specified depth intervals using the AutoCAD software (Fig.1).

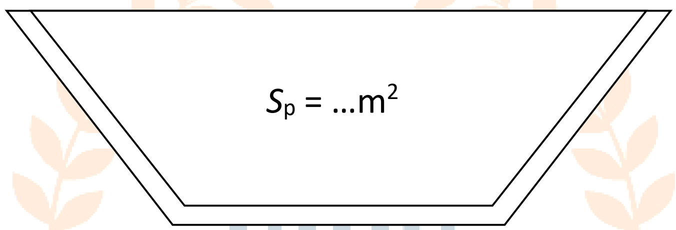

Figure 1. Diagram of the graphical definition of $S_р$ in the section of a quarry at different depths H, m.

Having information about the capacity of $m_р$ ore from geological reports, it is possible to determine the volumes of $V_р$ ore.

The volumes of ore $V_р$ are analytically determined by the following formula:

$$V_р = S_р \cdot m_р, \text{ m}^3.$$

where, $m_р$ – ore thickness, m³.

$S_р$ – the area of the ore projection, m².

The amount of balance reserves P in the pit contour is determined by the following formula:

$$P = V_р \cdot \gamma, \text{ т}.$$

where, Vp – ore volumes, m³.

γ is the volume of ore, t/m³.

Further, the volume of extracted ore mass of $Д_{р.м}$ and the amount of operational metal $M_э$ are determined by the following formulas:

$$Д_{р.м} = P \cdot \frac{(1-К_п)}{(1-К_р)}, \text{ t}.$$

$$М_э = М_б \cdot (1 - k_п), \text{ kg}.$$

where, P is the balance reserves of ore in the contour of the quarry, t.

$К_п$ – is the loss coefficient %.

$К_р$ – is the dilution coefficient %.

$М_б$ – metal in the balance ore in the contours of the quarry, kg.

The volume of overburden rocks is determined by the formula:

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$$V_{вск} = V_{г.м} - \frac{Д_{р.м}}{\gamma}, \text{ m}^3.$$

where, $Д_{р.м}$ is the volume of extracted ore mass in the contour of the quarry, t;

$V_{г.м}$ – volume of rock mass, m³;

γ is the volume of ore, t/ m³.

The overburden coefficient of $V_{вск}$ is determined by the following formula:

$$K_{вск} = \frac{V_{вск}}{Д_{р.м}}.$$

where, $V_{вск}$ is the volume of overburden, m³.

The coefficient of rock mass $K_{г.м}$ is determined by the following formula:

$$K_{г.м} = \frac{V_{г.м}}{М_э}.$$

where, $M_э$ – operational metals in the contour of the quarry, kg;

$V_{г.м}$ – volume of rock mass, m³.

When applying the developed methodology for determining the rational boundaries of the quarry when switching to the underground mining method of upland deposits using the graphoanalytic method by using the AutoCAD computer program, the indicators $V_{г.м}$ – volume of rock mass, m³, $Д_{р.м}$ - volume of mined ore mass in the contour of the quarry, t, $M_э$ - operational metals in the contour of the quarry, kg are determined, $V_{вск}$ – overburden volume, m³, $K_{вск}$ - overburden coefficient, $K_{г.м}$ - rock mass coefficient at different depths *H* of the quarry.

The results obtained make it possible to determine the boundaries of the quarry during the transition to underground mining of upland deposits.

The criterion for the boundary of the transition from an open-pit mining method to an underground one is the technical and economic indicators of the mining of upland deposits, depending on the world price of minerals.

For a visual representation, all the calculated data obtained in the Microsoft Excel software are reflected in the table and graphical dependencies.

Approbation of this technique was carried out for the conditions of the gold deposit of the Ziaetdinsky ore field of the upland type – ore bodies No. 51 and No. 7. Let's consider several options for working out with the following depths:

- 50 m; - 100 m; - 150 m - 200 m; - 250 m.

Using the available data on reserves, the location of ore bodies and other mining and geological data, we formulate the contour of the quarry to a depth of *H* – from 50 to 250 m. [7,8,9]

The calculated indicators obtained according to the developed method of mining ore bodies No. 51 and No. 7 of the Karakutan quarry of the Ziaetdinsky ore field are shown in Table No. 2.

For a quick assessment of the situation and finding the transition point to the underground mining method, we formulate a schematic mathematical model for quarries with a depth of 50 m, 100 m, 150 m, 200 m and 250 m.

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Table No. 2.
Calculated indicators of mining of ore bodies No. 51 and No. 7 of the Karakutan quarry of the Ziaetdinsky ore field at a depth of the quarry from 50 to 250 m.

Parameters	Designation	Units	Quarry depth, m				
			50	100	150	200	250
Volume of rock mass	$V_{гм}$	thsd. m³	617	5 796	10 018	22 056	41 431
Reserved rock	P	thsd. t	105	595	699	1 154	1 749
Reserved metall	$M_б$	kg	610	3 458	4 061	6 710	10 165
Content	C	gr/t	5.81	5.81	5.81	5.81	5.81
Loss ratio	$K_п$	%	6	6	6	6	6
Dilution ratio	$K_р$	%	30	30	30	30	30
The volume of the extracted ore mass in the contour of the quarry	$Д_{рм}$	thsd. t	141	799	938	1 550	2 348
Operational metal	$M_э$	kg	575	3 257	3 825	6 320	9 574
Metal content of operational ore	$C_э$	gr/t	4.08	4.08	4.08	4.08	4.08
Overburden volume	$V_{вск}$	thsd. m³	564	5 495	9 664	21 471	40 544
Overburden coefficient	$K_{вск}$	m³/t	4.0	6.9	10.3	13.9	17.3
The coefficient of rock mass	$K_{гм}$	t/gr	1.1	1.8	2.6	3.5	4.3

Thus, using the AutoCAD software, we compare the parameters of quarries on five vertical sections for different *H* depths of the quarry Fig. 2.

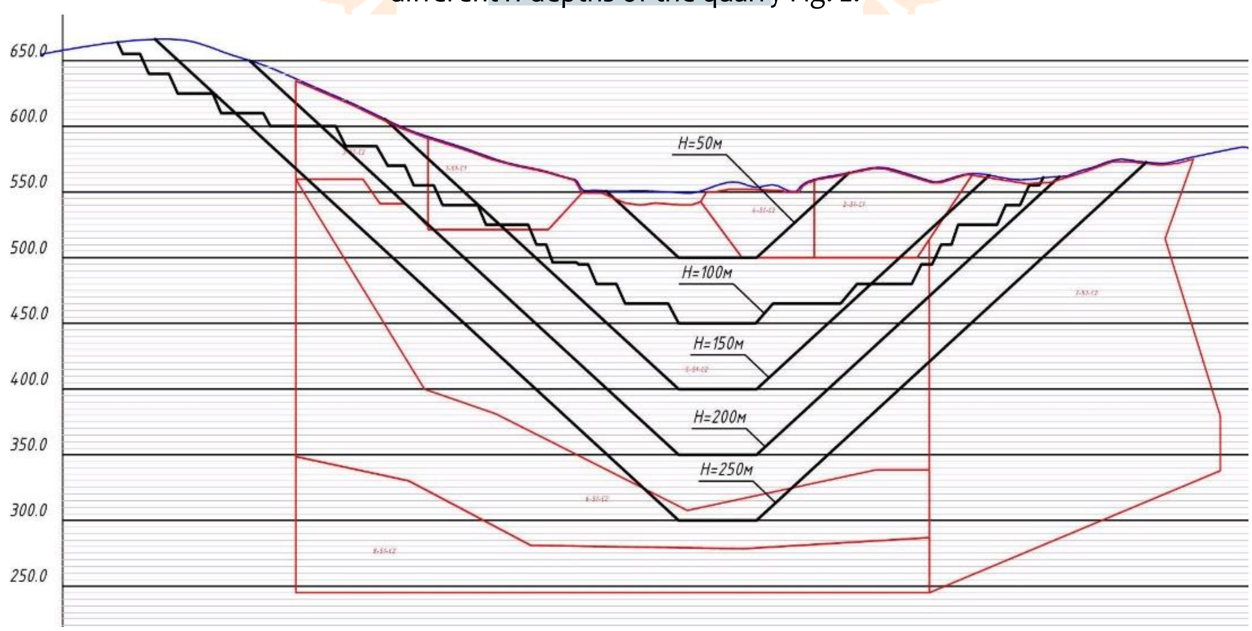

Figure 2. Quarry section at different working depths of 50-250 m

For a visual representation, all the calculated data obtained in the Microsoft Excel software are reflected in graphical dependencies.

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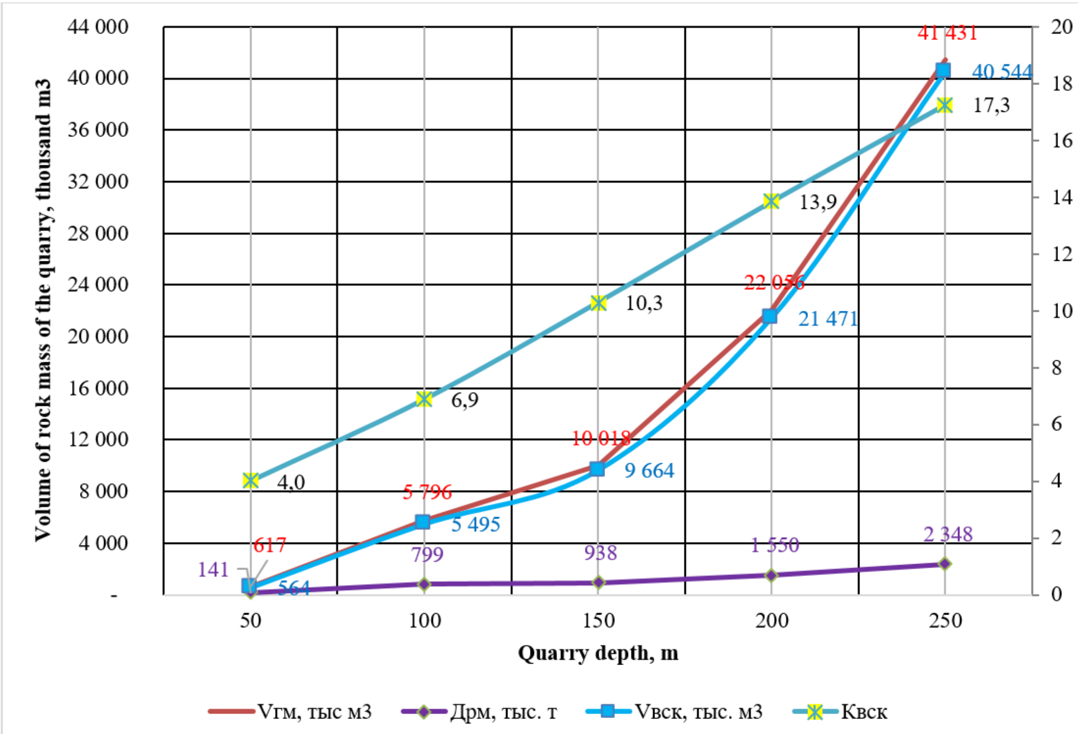

Figure 3. Graph of the dependence of the volume of rock mass, ore, overburden and overburden coefficient at different depths of the quarry

The analysis of the dependence graph shows that with an increase in the depth of the quarry:

- The volume of rock mass increases several tens of times (from 617 thsd m^3 to 41,431 thsd m^3) compared to the volume of ore;
- The overburden ratio increases from 4 to 17.3;
- The volume of overburden increases from 564 thsd m^3 to 40,544 thsd m^3;
- The volume of extracted ore increases from 141 thsd tons to 2,348 thsd tons.

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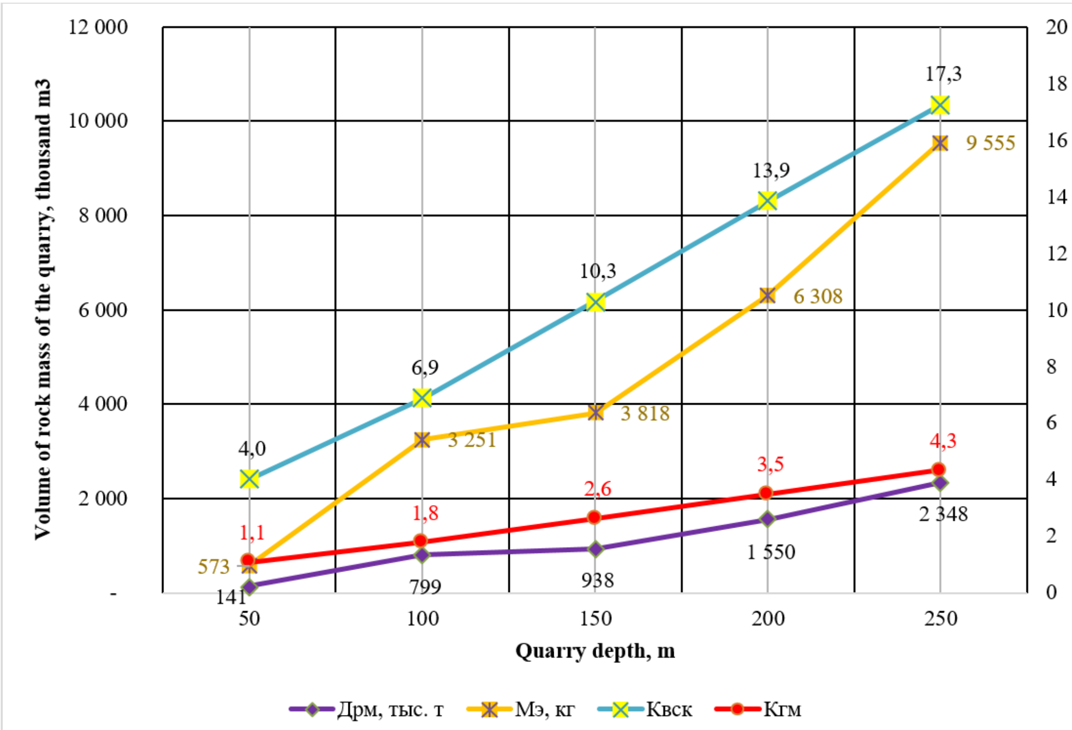

Figure 4. Graph of the dependence of the change in the stripping coefficient, the operational amount of metal, the coefficient of rock mass and the volume of ore extracted depending on the depth of the quarry

The analysis of the dependence graph shows that with an increase in the depth of the quarry:

- increases the operational metal from 573 to 9 555 kg.;
- increases the coefficient of rock mass from 1.1 to 4.3;

Figure 5 shows a generalized graph of the dependence of the change in the volume of rock mass, the volume of mined ore in the pit contour, the production metal in the pit contour, the volume of overburden rock, the overburden coefficient and the rock mass coefficient at different depths *H* of the quarry.

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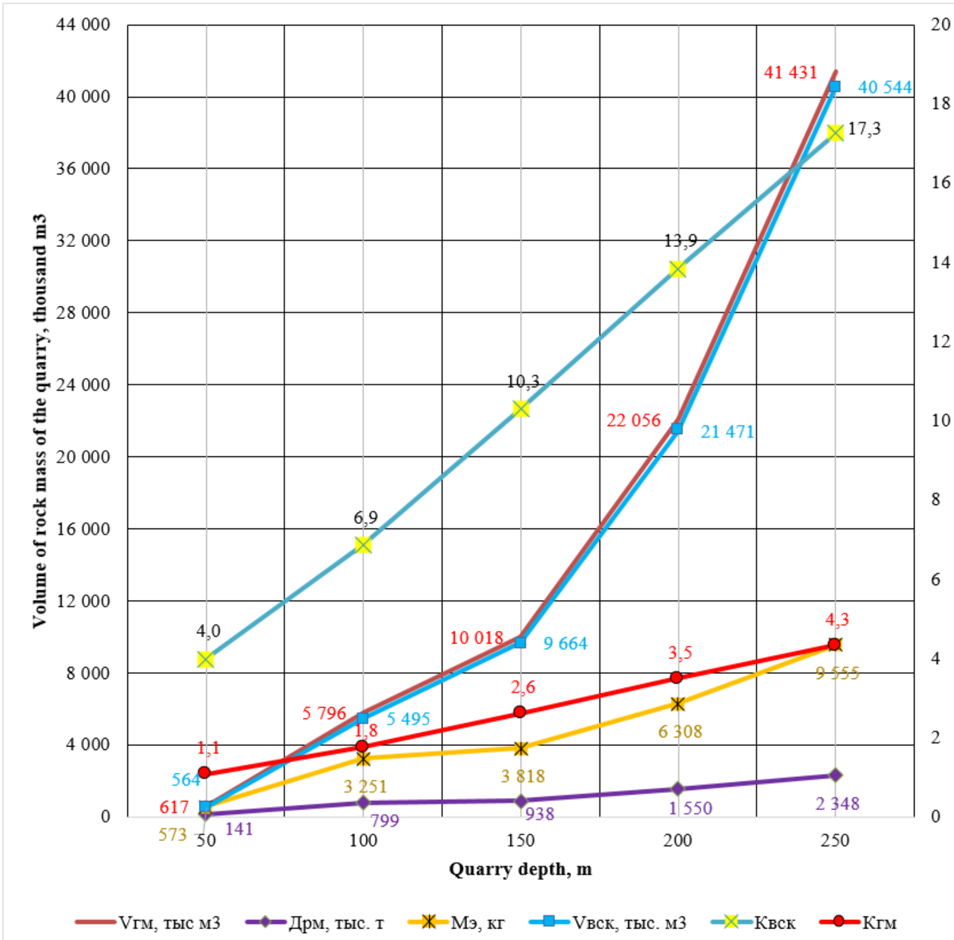

Figure 5. Generalized graph of the dependence of the change in the volume of rock mass, the volume of mined ore in the pit contour, the operational metal in the pit contour, the volume of stripping, the stripping coefficient and the rock mass coefficient at different depths *H* of the quarry.

The analysis of the generalized dependence graph shows that with an increase in the depth of the quarry, the volume of rock mass increases several tens of times compared to the volume of ore, the volume of stripping, the stripping coefficient, the operational metal, the volume of ore mined and the rock mass coefficient.

CONCLUSION

This technique is the simplest and the only one of its kind for determining the rational boundaries of a quarry when switching to underground mining of upland deposits.

In this methodology, the depth of open-pit mining is justified, taking into account the following indicators $V_{г.м}$ – volume of rock mass, m^3; $Д_{р.м}$ - volume of extracted ore mass in the contour of the quarry, t; $M_э$ - operational metal in the contour of the quarry, kg; $V_{вск}$ – overburden volume, m^3; $K_{вск}$ - overburden ratio; $K_{г.м}$ -

the coefficient of rock mass at different depths *H* of the quarry.

Having determined the optimal depth of mining of upland deposits by the open method, the lagging part of the reserves of the deposit is considered as reserves for underground mining. The boundaries of the transition from an open-pit mining method to an underground one are determined taking into account the technical and economic indicators of the development of the deposit, depending on the world price of the mineral.

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