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Substantiation of resource-saving technology when mining the deposits for the production of crushed-stone products

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Abstract

Purpose. Scientific substantiation of the expedient depth of mining the non-metallic deposits of rocky minerals on the basis of mathematical and statistical methods, which will ensure resource-saving and rational use of natural resources.

Methods. To solve the purpose set, the following methods are used: graphical-analytical – when optimizing the maximum depth of mining the deposits of building materials, and the method of mathematical modeling – for determining the maximum depth of mining the non-metallic deposits with internal dumping. By means of statistical processing according to systematized types of deposits, the patterns of a change in the maximum depth of mining the basic deposits, depending on the main parameters of the quarry field, have been studied.

Findings. A new methodology, which is distinguished by taking into account in-pit dumping, has been developed for calculating the maximum depth of granite quarries, which most of all influences the efficiency of mining operations and the value of economic indicators while ensuring the maximum economic effect with the achievement of a rational maximum depth of mining the deposit. A new, theoretically substantiated methodology has been created for determining the maximum depth of mining the mineral deposits for the production of crushed-stone products while providing the resource- and land-saving during the quarry operation.

Originality. For the first time for these deposits, the dependence of their maximum mining depth on the main parameters of the quarry field and the place of internal dumping of overburden rocks has been determined. This has become a determining factor in the appropriate mining of deep non-metallic deposits of building materials with internal dumping, which provides a minimal land disturbance.

Practical implications. The research results have been tested and implemented in working projects for mining the Liubymivske, Chaplynske, Pervomaiske, Mykytivske, Trykratske and Novoukrainske granite deposits; as a result of additional mining of mineral reserves, their additional increment in the volume from 1 to 48 million m^3 is possible, which will ensure 5-40 years of sustainable operation of the mining enterprise.

Keywords: *non-metallic quarries, quarry mining plan, depth of dumping, in-pit dumping, maximum mining depth*

1. Introduction

Ukraine is one of the leading places in the world in terms of reserves of rocky non-metallic raw materials suitable for the production of building materials. Deposits of rocky building materials in Ukraine belong to the deposits of igneous rocks of the Ukrainian Crystalline Massif and are widespread deep into the earth's crust, forming laccoliths, batholiths, bunches and other deposits [1]-[2]. Most fields of sedimentary building materials are mined to a depth of 80-120 m to the deposit bottom using the technology with internal dumping. Deposits of pyrogenetic rocks are mined to a depth of 70-100 m, sometimes 140-150 m with external dumping [3].

In the practice of designing the indicated deposits of pyrogenetic and metamorphic rocks, their maximum mining depth is limited by many parameters: the depth of the explored mineral reserves; increased groundwater inflow at a great depth, which leads to a sharp increase in the cost of water-removing and drainage; built-up area adjacent to the quarry fields, which limits their spatial dimensions; possible increase in radioactivity of minerals with depth; small transverse dimensions of igneous rock deposits [4]-[6].

A significant number of more than 300 quarries of igneous rocks in Ukraine have now reached their design depth. There is no possibility to expand the quarry field boundaries

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by increasing the reserves in the flanks. This is conditioned by the necessity of relocating the roads, buildings, structures, pipelines, power lines, as well as the allocation of new areas of privatized land. It remains to implement another way – to develop mining operations in depth, increasing the reserves located below. At the same time, the scientific substantiation of the rational maximum depth of mining such deposits, especially during their mining with internal dumping of overburden rocks, has not been performed. In this regard, an important task arises to determine the maximum depth of mining the deposits of non-metallic building materials.

The first printed works on the determination of the quarry boundaries date back to 1924. Since 1927, the problems of determining the depth of quarries have been intensively studied. In those years, such studies were based on the quarries of Kryvyi Rih, which already had a depth of 80-100 m. At this stage, when conducting mining operations in a surface way, a method based on the comparison of the contour and the average expedient stripping ratio was used to determine the final depth of the quarry.

Problems of the theory development of surface mining the mineral deposits are presented in the works of Ukrainian [7]-[12] and foreign scientists [13]-[15]. Analysis of these works, design solutions and research, carried out at mining enterprises extracting minerals, has shown that the efficiency of mining operations is primarily determined by the issues of resource-based [16], [17] ecological expediency [18], [19], as well as developed transport achievements [20]-[22].

In general, the analysis of the technology of dump operations indicates that about 85% of all quarries for the extraction of sedimentary rocks and 100% of pyrogenetic rocks are mined using the technology with the overburden rocks transfer to external dumps [23], [24]. This is characterized by the use of traditional technology of the fields development in the process of their design. To a greater extent, the research results are devoted to the problems of improving the technology of surface mining of the deposits for the extraction of rocky non-metallic minerals [25]-[27]. However, the task of scientific substantiation of the maximum depth of mining the above-mentioned mineral deposits for the production of crushed-stone products remains unsolved.

Mineral raw materials should be extracted with account of the technologies that meet the following requirements [28]-[31]:

– minimal disturbance of the structure and fertility of lands;

– use of the most environmentally friendly equipment during surface mining;

– the use of modern environmentally friendly methods of dust prevention and dust suppression during production processes;

– the use of special methods and techniques for performing blasting operations that will minimize the emission of dust/gas substances (or completely exclude them), seismic impact on the adjacent objects from a charge unit, shock wave and scattering of rock pieces in different directions;

– the most complete use of the created mined-out areas of the quarries;

– completeness of minerals extraction;

– ensure dewatering of fields and drainage works during the extraction of raw materials in such ways that best provide the natural or close to it hydrological regime of the region without significant changes in the direction of supplying the enterprises and the population with volumes of drinking and industrial water;

– reclamation and revitalization of lands disturbed by mining operations to the most ecologically acceptable landscapes of territories and their recreation.

At the same time, mineral deposits should be mined taking into account the development of Clean High Technologies during mining the deposits of different types of origin, as well as the technology of their mining [32]-[36].

Quarries for the extraction of rocky non-metallic minerals for the production of crushed-stone products operate in many regions of the country. Most of these fields are mined to a depth of 40-130 m and, in rare cases, 150 m. Quarries of a small area (up to 20 ha) are mined to a depth of 43-93 m (on average 60 m), a medium area (20-60 ha) – to a depth of 50-100 m (on average 77 m), a large area (more than 60 ha) – to a depth of 58-130 m (on average 87 m) [1], [37], [38].

Deposits of igneous and metamorphic rocks are distinguished by significant diversity in composition, thickness, structure of deposits, location relative to the levels of predominant surface, shape and sizes, approved reserves, water cut and water content, thickness and nature of overburden rocks [39], [40].

The depth of mining the mineral deposits has a great influence on the quality and physical-and-mechanical properties of mineral resources [41]. With increasing the depth, the rocks are less exposed to weathering, as a result of which the strength of minerals increases [42]. There is also a decrease in fracturing, which can influence on a change in the system or scheme of the field development, but it can still occur due to natural factors [43], [44].

The depth of mining such deposits is influenced by many factors that constraint the depth of mining the quarries of building materials [29], [30], [38]:

– spatial dimensions of deposits (length, width);

– depth of explored mineral reserves;

– increased inflow of groundwater (with increasing depth) and surface water (with increasing spatial dimensions of the quarry field);

– change in indicators of radioactivity and other harmful radiation of minerals with increase in mining depth;

– built-up area adjacent to the quarry fields, which limits their spatial dimensions;

– change in the hydrogeological regime in adjacent settlements and on agricultural lands located near the fields;

– volumes of overburden rocks that are stockpiled in the mined-out space;

– economic indicators of rational extraction of raw materials (mining cost of 1 m^3 and the level of profitability).

Based on the analysis of the current state and the existing practice of mining enterprises operation, scientific-technical literature and scientific research on determining the maximum rational depth of mining the granite and stone quarries, it can be concluded that the further design of granite quarries to their rational maximum depth is relevant, primarily without expanding of their flanks. The above provisions determine the relevance of the research on substantiation of the maximum depth of mining the non-metallic deposits with internal dumping, without additional expanding of their flanks beyond the boundaries of the existing mining allotment, which leads to a decrease in the area of additional land for mining operations.

The purpose of the research is to substantiate the expedient depth of mining the non-metallic deposits of rocky minerals, which will ensure the rational use of natural resources. To achieve this purpose, it is necessary to solve the following tasks:

– to set the optimal depth of internal dumping, which ensures the maximum depth of mining the deposit;

– determine the growth of the total cost of finished products with the depth of mining operations;

– substantiate the economically expedient depth of mining the typical deposits;

– substantiate the depth of mining the non-metallic deposits of rocky minerals with stockpiling the overburden rocks in the mined-out space.

2. Research methods

When optimizing the depth of mining the non-metallic deposits with in-pit stockpiling of overburden rocks, the determining parameters are the length and width of the deposit. These parameters are taken into account for determining the final depth of the quarry field [45], [46]. One of the most important factors influencing the implementation of the resource-saving technology for mining the above-mentioned deposits during in-pit stockpiling of overburden rocks is their thickness. Analyzing the above, a general systematization of non-metallic deposits of rocky minerals for the production of crushed-stone products has been developed, where the allocation of basic deposits, as objects of further research, is performed according to the spatial dimensions and thickness of overburden rocks.

Given the accepted classification criteria, 9 basic (typical) deposits are identified, the averaged parameters of which are presented in the work [30]. These types of deposits are proposed as the main objects for further research on resource-saving technologies and the development of a methodology for determining the maximum economically expedient depth of their mining with in-pit stockpiling of overburden rocks. The use of the proposed basic deposits of granite and stone raw materials will provide the research with a high convergence of the theoretical and practical results, which is important when implementing the ecological, land- and resource-saving technologies for mining the deposits of igneous rocks for the production of crushed-stone products and building materials.

Based on the tasks set for the research on rational schemes for mining the non-metallic quarries of building materials, possible schemes will be considered and the most rational one for conducting mining operations will be selected, ensuring the feasibility and efficiency of the field development. Let us study the following technological schemes for mining the deposits [29], [47], [48] (Fig. 1).

Scheme A – with this scheme, the deposit is mined to a depth of the design level, until all the explored commercial reserves of the field are extracted. At the same time, at the moment of reaching the design level of one of the quarry ends (stage I), the formation of an internal dump begins, which is located at the bottom of the quarry. This scheme can be used in quarries with a depth of estimated reserves up to 70 m, for the quarries with a large area up to 100-120 m.

Scheme B – this scheme is similar to scheme A. The difference is that the internal dump is located at the level above the design level. This scheme is used when it is impossible to form a dump at the design level of the bottom due to any factors. It can be used in quarries with a depth of estimated reserves of 100-120 m. In this case, internal dumping occurs at a depth of 60-70 m (stage I) with its subsequent transfer to the design depth after the stage II development.

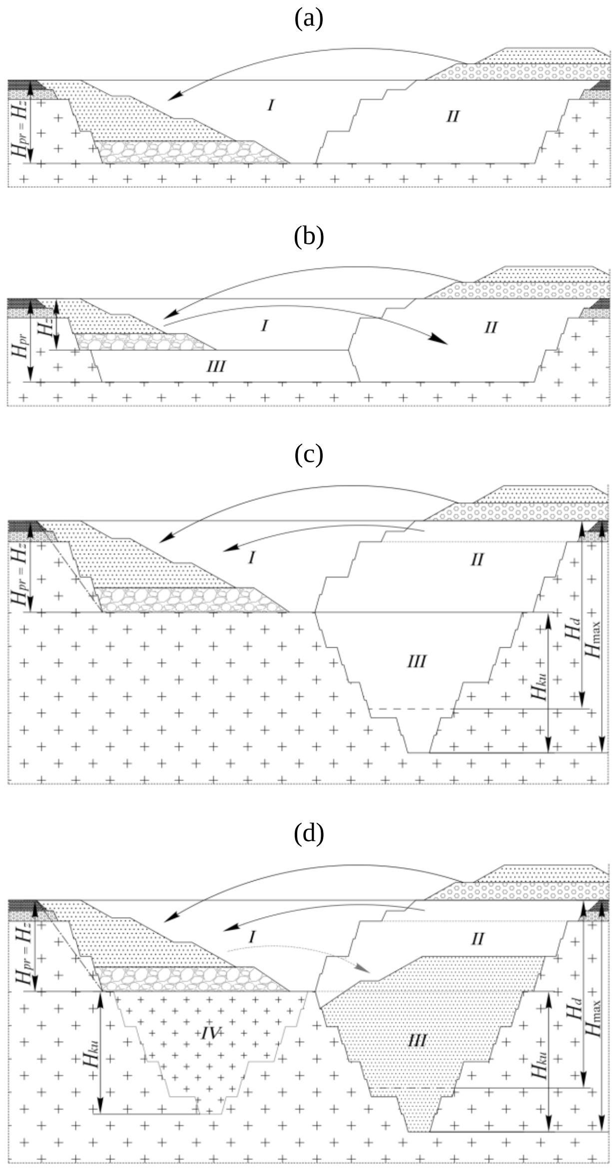

Figure 1. Schemes for mining the non-metallic quarries of building materials with dumping of overburden rocks: (a) at the design depth without deepening the quarry, "scheme A"; (b) above the design depth without deepening the quarry, "scheme B"; (c) at the design depth with the additional mining of the field in depth, "scheme C"; (d) below the design depth with the additional mining of the field in depth, "scheme D"; H_{des} – design depth of the quarry; H_{fill} – the depth of filling the dump; H_{exp} – expedient depth of mining the quarry; $H_{q(max)}$ – maximum depth of mining the quarry with deepening of mining operations; I, II, III, IV – stages of mining the quarry

Scheme C – this scheme provides for the mining of the deposit to the maximum possible depth, without push back of the flanks, and provides for internal dumping at the design level. After the completion of operations at the stage II, a significant area of the quarry bottom remains, where it is possible to conduct additional mining of reserves with their putting on the balance sheet, and then mine out these reserves.

Scheme D is similar to scheme C, but at the moment of reaching the maximum depth (stage III) the internal dump is re-laid on the lower horizons, after which the quarry is further additionally mined out at the end, where the internal dump was previously located.

The maximum depth of mining the granite quarries ($H_{\max}$) is determined taking into account the formation of an internal dump of overburden rocks, as well as its location (Fig. 2a, b).

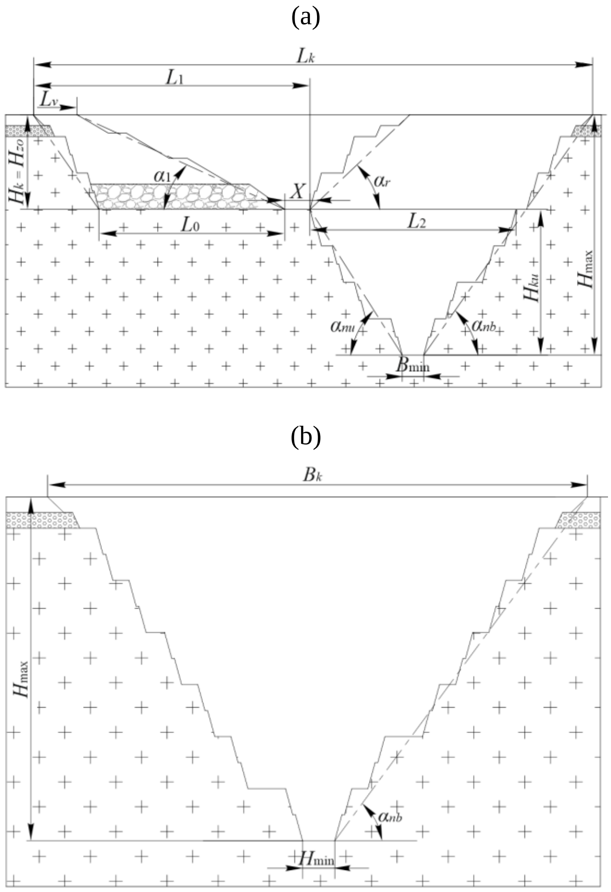

Figure 2. Scheme for determining the parameters of mining the quarry to the maximum depth: (a) by its length; (b) by its width

$$H_{\max} = \frac{H_{fill} + \left[L_q - \left(\frac{V_d}{B_d \cdot H_d} + \frac{H_d}{2} \times \left(ctg\alpha_{D.r} - ctg\alpha_N \right) + X + 2H_{fill} \cdot ctg\alpha_N \right) \right] - B_{\min}}{2ctg\alpha_r}, \text{ m}, \quad (1)$$

where:

H_{fill} – depth of dumping, m;

L_q – quarry field length, m;

V_d – internal dump volume, m^3;

B_d – internal dump width, m;

H_d – internal dump height, m;

$ctg\ \alpha_{D.r}$ – resulting slope angle of a dump, deg;

α_N – non-mining slope angle of a flank, deg;

X – safety platform from the dump to the upper edge of the deepened area, m;

$B_{\min}$ – minimum width of the quarry bottom, m;

A_r – resulting slope angle of a flank, deg;

The maximum depth of the quarry for scheme D [29], [47], [48] can be determined, if $L_o \geq L_2$, by the formula:

$$H_{\max} = H_{fill} + \frac{\left(\frac{V_d}{B_d \cdot H_d} + \frac{H_d}{2} \left(ctg\alpha_{D.r} - ctg\alpha_N \right) \right) - B_{\min}}{2ctg\alpha_r}, \text{ m}. \quad (2)$$

The maximum depth of mining across the width of the quarry field will be:

$$H_{\max} = \frac{B_q - B_{\min}}{2ctg\alpha_r}, \text{ m}. \quad (3)$$

3. Results and discussion

As a result of the performed calculations, the dependences of the maximum depth of mining ($H^q_{\max}$) on the depth of internal dumping (H_{fill}) have been determined. Analyzing the results obtained, it can be concluded that the depth of internal dumping to the greatest extent influences on the maximum depth of mining the quarries with low and medium thickness of overburden rocks. The optimal depth of internal dump location, taking into account the parameters of the quarry field, the design and expedient depth of mining the deposit, is:

– for deposits with a large area: with low and medium thickness of overburden rocks – the maximum depth does not depend on the depth of the internal dump location; with a large thickness of overburden rocks – 70-115 m;

– for deposits with a medium area: – 50-90 m;

– for deposits with a small area: – 50-85 m.

From the above, based on the research results, it can be stated that the design depth of the quarry (the maximum of estimated reserves) is rational to take as the depth of internal dumping.

The patterns of a change in the maximum depth of mining the basic deposits depending on the main parameters of the quarry field are studied with application of statistical processing according to systematized types of deposits on the basis of the developed methodology. The main parameters of deposits are processed using modern computer technologies with the methods of mathematical statistics. Using the least-squares method, correlation dependences have been determined of the maximum mining depth ($H^q_{\max}$) on the length (L_q), width (B_q), overburden rocks thickness (h_{over}) and the depth of internal dumping (H_{fill}) for typical deposits according to mining schemes C and D [29], [47], [48]:

1) for deposits with a large area:

– with a low thickness of overburden rocks:

$$H^q_{\max} = 17.04 - 0.98h_{over} + 0.02L_q + 0.43B_q - 0.12H_{fill}; \quad (4)$$

– with a medium thickness of overburden rocks:

$$H^q_{\max} = 13.85 - 1.88h_{over} + 0.01L_q + 0.46B_q + 0.33H_{fill}; \quad (5)$$

– with a large thickness of overburden rocks:

– *for the scheme C:*

$$H^q_{\max} = 250.07 + 0.72h_{over} + 0.19L_q + 0.45B_q - 0.38H_{fill}; \quad (6)$$

– *for the scheme D:*

$$H^q_{\max} = -4865.48 + 100.07h_{over} - 2.33L_q + 7.74B_q - 16.33H_{fill}; \quad (7)$$

2) for deposits with a medium area:

– with a low thickness of overburden rocks:

– along the length of the quarry field:

$$H^q_{\max} = 10.2 - 5.46h_{over} + 0.41L_q + 0.01B_q + 0.32H_{fill}; \quad (8)$$

– across the width of the quarry field:

$$H^q_{\max} = 7.97 + 0.01h_{over} - 0.01L_q + 0.49B_q + 0.12H_{fill}; \quad (9)$$

– with a medium thickness of overburden rocks:
– along the length of the quarry field:

$$H^q_{\max} = 31.96 - 5.35h_{over} + 0.35L_q - 0.02B_q + 0.72H_{fill}; \quad (10)$$

– across the width of the quarry field:

$$H^q_{\max} = 71.82 - 0.71h_{over} - 0.01L_q + 0.39B_q - 0.11H_{fill}; \quad (11)$$

– with a large thickness of overburden rocks:
– along the length of the quarry field:
– *for the scheme C:*

$$H^q_{\max} = 48.4 - 2.78h_{over} + 0.3L_q + 0.12B_q - 0.51H_{fill}; \quad (12)$$

– *for the scheme D:*

$$H^q_{\max} = -164.56 + 8.19h_{over} + 0.53L_q - 0.38B_q + 0.63H_{fill}; \quad (13)$$

– across the width of the quarry field:

$$H^q_{\max} = 543.74 - 3.0h_{over} - 1.07L_q + 1.41B_q + 11.67H_{fill}; \quad (14)$$

3) for deposits with a small area:
– with a low thickness of overburden rocks:
– along the length of the quarry field:

$$H^q_{\max} = 23.37 - 4.74h_{over} + 0.37L_q + 0.07B_q - 0.005H_{fill}; \quad (15)$$

– across the width of the quarry field:

$$H^q_{\max} = -4.01 + 0.59h_{over} + 0.003L_q + 0.5B_q + 0.02H_{fill}; \quad (16)$$

– with a medium thickness of overburden rocks:
– along the length of the quarry field:

$$H^q_{\max} = 53.45 - 4.86h_{over} + 0.34L_q - 0.03B_q + 0.25H_{fill}; \quad (17)$$

– across the width of the quarry field:

$$H^q_{\max} = -22.26 + 0.09h_{over} - 0.01L_q + 0.54B_q + 0.28H_{fill}; \quad (18)$$

– with a large thickness of overburden rocks:
– *for the scheme C:*

$$H^q_{\max} = -1.14 - 3.54h_{over} + 0.58L_q - 0.27B_q - 0.003H_{fill}; \quad (19)$$

– *for the scheme D:*

$$H^q_{\max} = 31.14 + 0.7h_{over} + 0.08L_q + 0.53B_q - 0.49H_{fill}. \quad (20)$$

Analyzing the obtained results, the dependences of the maximum mining depth ($H^q_{\max}$) on the main parameters of the quarry field (length, width and thickness of overburden rocks) and the depth of internal dumping (H_{fill}), it can be concluded that the maximum mining depth of typical deposits will be:

1) for deposits with a large area:
– with a low thickness of overburden rocks: 388 m;
– with a medium thickness of overburden rocks: 355 m;
– with a large thickness of overburden rocks: 327 m (385*);
2) for deposits with a medium area:
– with a low thickness of overburden rocks: 238 m;
– with a medium thickness of overburden rocks: 209 m;
– with a large thickness of overburden rocks: 217 m (258*);
3) for deposits with a small area:
– with a low thickness of overburden rocks: 158 m;
– with a medium thickness of overburden rocks: 155 m;
– with a large thickness of overburden rocks: 134 m (169*);

* maximum mining depth according to the scheme D.

After mining out of the approved reserves of the Liubymivske granite deposit and formation of the internal dump, a significant area remains of the quarry bottom, which is 78930 m^2. As a result of additional exploration and putting of the specified volumes of reserves on the balance sheet, their further extraction is possible (Fig. 3).

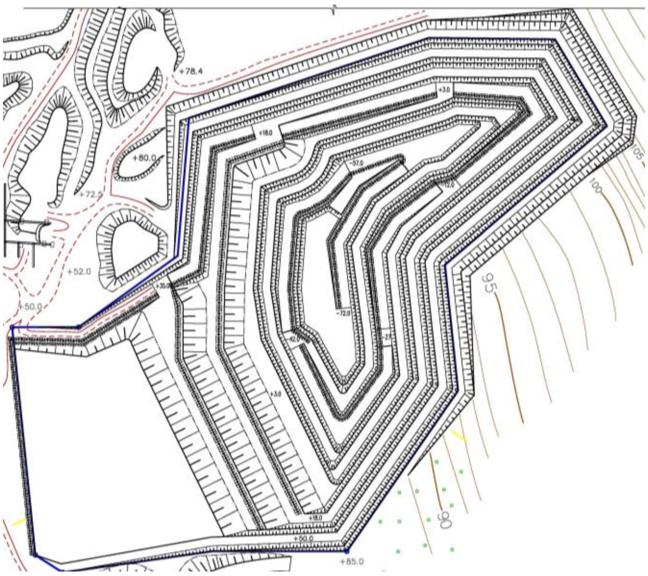

Figure 3. Setting the maximum depth of mining by the graphic method

Given that the minimum acceptable profitability of the enterprise should be not less than the bank rate on the deposit [49], the minimum acceptable "total cost" of the finished product will be – 290-340 UAH/m^3. Taking into account these indicators, the dependences of a change in the economically expedient depth of mining the typical deposits have been obtained (Fig. 4).

Based on the obtained dependences, the economically expedient depth of mining the typical deposits has been substantiated (Tables 1 and 2).

In order to implement the presented research results in non-metallic granite quarries, recommendations of the main provisions have been developed. The generalized essence of these recommendations is given using the example of the Liubymivske granite deposit, which is a rather typical representative of non-metallic deposits of Prydniprovia.

Analyzing the results obtained to substantiate the depth of mining the Liubymivske deposit using graphoanalytical and analytical methods, it can be concluded that the determining parameter in achieving the maximum depth of mining in this case is the width of the quarry field, resulting in the maximum depth of 160-172 m. Having studied the obtained results, it can be seen the error in different methods of solving the problem, namely: the developed methodology, the obtained correlation dependences and the graphical method is 2-7%. This error is insignificant given the spatial complexity of the quarry field shape.

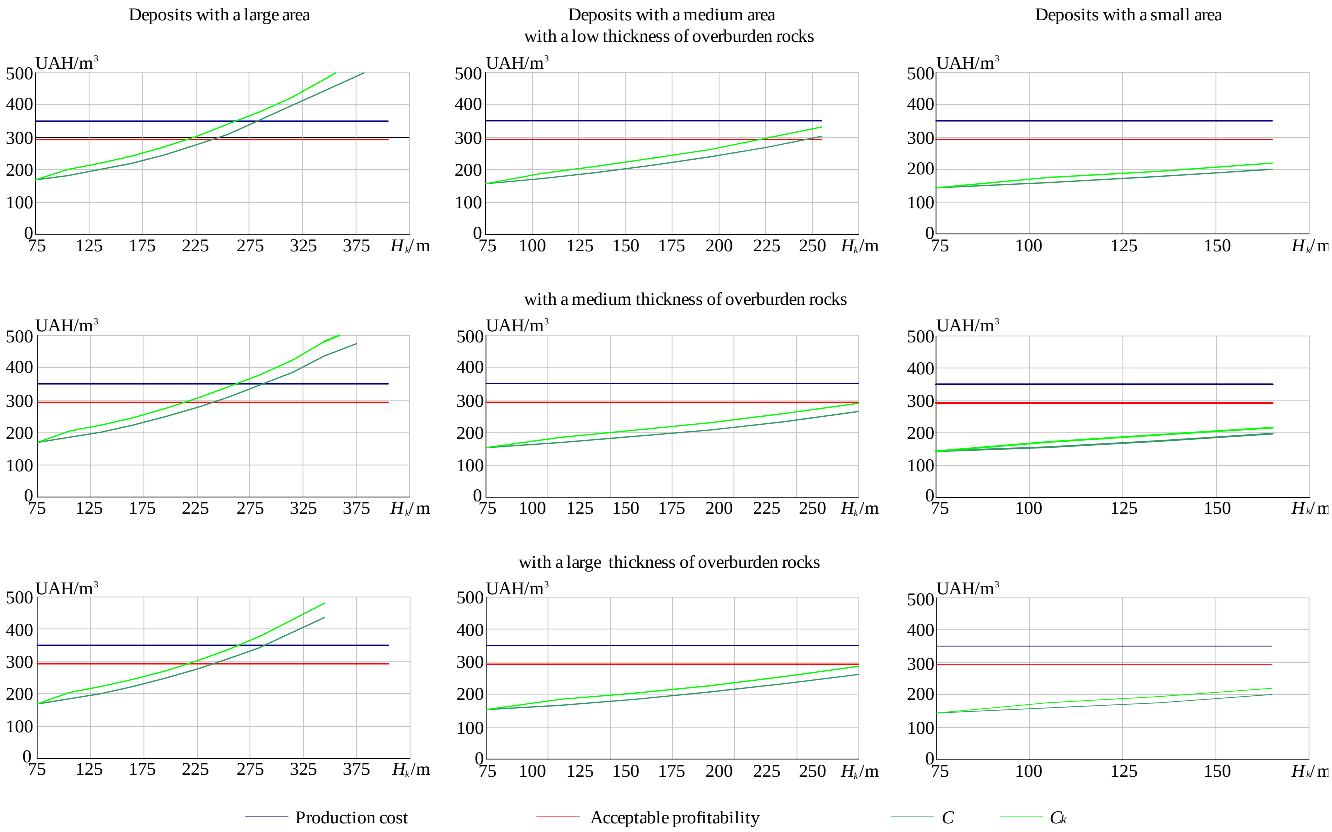

Figure 3. Substantiation of economically expedient depth of mining the typical deposits: C – total cost of production, C_k – total cost of production considering the coefficients that take into account the complexity of the production process conditions with increasing depth of the quarry and the time factor

Table 1. Economically expedient depth of mining according to the scheme C

A group of fields by spatial dimensions	Type of fields by thickness of overburden rocks	Quarry depth, m		Cost, *C*, UAH/m^3
		Maximum	Economically expedient	
With a large area	With a low thickness	388	220-240	290-300
	With a medium thickness	355	220-240	290-300
	With a large thickness	327	220-240	290-300
With a medium area	With a low thickness	238	225-238	280-290
	With a medium thickness	209	209	260-275
	With a large thickness	217	217	265-280
With a small area	With a low thickness	158	158	190-220
	With a medium thickness	155	155	185-215
	With a large thickness	134	134	170-190

Table 2. Economically expedient depth of mining according to the scheme D

A group of fields by spatial dimensions	Type of fields by thickness of overburden rocks	Quarry depth, m		Cost, *C*, UAH/m^3
		Maximum	Economically expedient	
With a large area	With a large thickness	385	200	290
With a medium area		258	230	290
With a small area		169	169	265

4. Conclusions

As a result of the research performed, it has been determined that the optimal depth of internal dumping, which provides the maximum depth of mining the deposit, is: for the deposits with a large area and with a large thickness of overburden rocks H_{fill} = 70-115 m; for the deposits with a medium area – H_{fill} = 50-90 m; for the deposits with a small area – H_{fill} = 50-85 m. In quarries of large area with small and medium thickness of overburden rocks, $H^q_{\max}$ does not depend on the depth of internal dumping. The design depth of the quarry is expedient to take as the depth of internal dumping.

Based on the obtained new dependences between the maximum mining depth and the main parameters of the quarry fields (length and width, thickness of overburden rocks and depth of internal dumping), the value of $H^q_{\max}$ has been determined for typical deposits of small, medium and large thickness of overburden rocks, respectively: large area – 388, 355, 327 (385) m; medium area – 238, 209, 217 (258) m; small area – 158, 155, 134 (169) m. At the same time, the value given in parentheses corresponds to the conditions of internal dumping with its repeated transfer to the mined-out space after additional mining of reserves.

It has been determined that the growth of the total cost of the finished products with the depth of mining operations is largely influenced by the cost of drainage and transportation of minerals to the Crushing and screening plant. The amount of water-removing costs for typical deposists increases from 1.9 to 12.45 UAH/m^3, and transportation costs – from 26 to 323 UAH/m^3.

Given that the profitability of the enterprise should be not less than the bank rate on the deposit (16%), it has been determined the minimum acceptable total cost of the finished product in the range of 290-340 UAH/m^3. Based on this, the developed methodology substantiates the economically expedient depth of mining the typical deposits, which is: for the deposits with a large area – 220-240 m; for the deposits with a medium area with low, medium and large thickness of overburden rocks – 225-238 m, 209 m, 217 (230) m, respectively; for the deposits with a small area with low, medium and large thickness of overburden rocks – 158 m, 155 m and 134 (169) m, respectively. At the same time, the depth value given in parentheses corresponds to the conditions of internal dumping with its repeated transfer to the mined-out space.

The substantiated depth of mining the non-metallic deposits of rocky minerals with stockpiling of overburden rocks in the mined-out space will allow as a result of additional exploration of mineral reserves their additional increment in the volume from 1 to 48 million m^3, which will ensure 5-40 years of sustainable operation of the mining enterprise.

The research results have been tested under the conditions of mining the Liubymivske granite deposit, which, according to the classification peculiarities, belongs to the deposits with a medium area and with a medium thickness of overburden rocks. It has been found that the maximum depth of the quarry will be 160-172 m.

The error of the obtained results by different methods does not exceed 7% relative to the data of the obtained correlation dependences. At the same time, the field development to the specified economically expedient depth will provide an increment of the additional mineral reserves in the volume of 2.8 million m^3, and increase the operational life of the quarry by more than 18 years.

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Обґрунтування ресурсозберігаючої технології розробки родовищ з виробництва щебеневої продукції

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Мета. Наукове обґрунтування доцільної глибини розробки нерудних родовищ скельних корисних копалин на основі математичних і статистичних методів, що забезпечить ресурсозбереження та раціональне використання природних ресурсів.

Методика. Для вирішення поставленої мети використані наступні методи: графо-аналітичний – при оптимізації максимальної глибини розробки родовищ будівельних матеріалів, а також метод математичного моделювання – для визначення максимальної глибини розробки нерудних родовищ із внутрішнім відвалоутворенням. Дослідження закономірностей зміни максимальної глибини розробки базових родовищ від головних параметрів кар'єрного поля виконано шляхом статистичної обробки за систематизованими типами родовищ.

Результати. Розроблена нова методика розрахунку граничної глибини гранітних кар'єрів, що відрізняється врахуванням внутрішньокар'єрного відвалоутворення, яке найбільше впливає на ефективність ведення гірничих робіт і величину економічних показників при забезпеченні максимального економічного ефекту з досягненням раціональної граничної глибини відпрацювання покладу. Створено нову, теоретично обґрунтовану, методику визначення граничної глибини розробки родовищ мінеральної сировини для виробництва щебеневої продукції із забезпеченням ресурсо- та землезбереження в процесі експлуатації карєрів.

Наукова новизна. Вперше для зазначених родовищ встановлена залежність їхньої граничної глибини відпрацювання від головних параметрів кар'єрного поля та місця формування внутрішнього відвала розкривних порід, що стало визначальним фактором доцільної розробки глибоких нерудних родовищ будівельних матеріалів із внутрішнім відвалоутворенням при мінімальному порушенні земель.

Практична значимість. Результати досліджень апробовані та впроваджені у робочих проектах розробки Любимівського, Чаплинського, Первомайського, Микитівського, Трикратського та Новоукраїнського родовищ гранітів; в результаті дорозвідки запасів корисної копалини можливе їх додаткове прирощення у обсязі від 1 до 48 млн м^3, що забезпечить 5-40 років сталого функціонування гірничодобувного підприємства.

Ключові слова: *неметалеві кар'єри, технологічна схема розробки, глибина формування відвалу, внутрішній відвал, максимальна глибина розробки*

Обоснование ресурсосберегающей технологии разработки месторождений по производству щебеночной продукции

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Цель. Научное обоснование целесообразной глубины разработки нерудных месторождений скальных полезных ископаемых на основе математических и статистических методов, что обеспечит ресурсосбережение и рациональное использование природных ресурсов.

Методика. Для решения поставленной цели использованы следующие методы: графо-аналитический – при оптимизации максимальной глубины разработки месторождений строительных материалов, а также метод математического моделирования – для определения максимальной глубины разработки нерудных месторождений с внутренним отвалообразованием. Исследование закономерностей изменения максимальной глубины разработки базовых месторождений от основных параметров карьерного поля выполнено путем статистической обработки по систематизированным типам месторождений.

Результаты. Разработана новая методика расчета предельной глубины гранитных карьеров, отличающаяся учетом внутрикарьерного отвалообразования, которое больше всего влияет на эффективность ведения горных работ и величину экономических показателей при обеспечении максимального экономического эффекта с достижением рациональной предельной глубины отработки месторождения. Создана новая, теоретически обоснованная, методика определения предельной глубины разработки месторождений минерального сырья для производства щебеночной продукции с обеспечением ресурсо- и землесбережения в процессе эксплуатации карьеров.

Научная новизна. Впервые для указанных месторождений установлена зависимость их предельной глубины отработки от главных параметров карьерного поля и места формирования внутреннего отвала вскрышных пород, что стало определяющим фактором целесообразной разработки глубоких нерудных месторождений строительных материалов с внутренним отвалообразованием при минимальном нарушении земель.

Практическая значимость. Результаты исследований апробированы и внедрены в рабочих проектах разработки Любимовского, Чаплинского, Первомайского, Никитовского, Трикратского и Новоукраинского месторождений гранитов; в результате доразведки запасов полезного ископаемого возможно их дополнительное приращение в объеме от 1 до 48 млн м^3, что обеспечит 5-40 лет устойчивого функционирования горнодобывающего предприятия.

Ключевые слова: *неметаллические карьеры, технологическая схема разработки, глубина формирования отвала, внутренний отвал, максимальная глубина разработки*