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Analysis of the regularities of basalt open-pit fissility for energy efficiency of ore preparation

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Abstract

Purpose. To identify dependence of specific rock mass fissility upon the bench height of basalt open pits based upon the analysis of basalt open-pit bench fissility.

Methods. Fractural tectonics of basalt open pits was studied experimentally. In addition to the specific fissility, the studies determined both shape and quantity of natural blocks within each bench meter; their geometry in terms of fissure frequency; and nature of changes in the fissure number as well as geometry of the blocks depending upon a bench height. Graphical analysis of the obtained results has helped determine the typical dependencies of fissure number upon the changes in the open-pit bench height.

Findings. It has been defined that the specific fissility of basalt benches is distributed irregularly in terms of an open-pit bench height. Field studies, involved three basalt open pits, have made it possible to identify that the 3rd degree polynomial is the most adequate approximation of the specific fissility dependence upon the bench height.

Originality. For the first time, the experiments have helped define that rock mass joints a share downward from the smaller to the larger ones following a parabolic law (according to a cubic expression). The obtained regularities help identify the percentage of shares of three sizes for each bench height meter.

Practical implications. Estimate of share percentage will make it possible to schedule rationally the drilling and blasting operations while selecting energy efficient parameters of production facilities for further basalt processing.

Keywords: *basalt, fissility, tectonics, bench, open pit, energy efficiency*

1. Introduction

Ukraine is rich in various minerals. Almost 90 of their types have been prospected; more than eight thousand deposits are being mined. Its subsoil assets depend upon the availability of diverse tectonic structures being filled with rocks of different origin and age during several billion years. Significant amounts of coal, iron and manganese ore, graphite, titanium and zirconium ores, germanium, nonmetallic metallurgical feed, stock for building materials, gas, oil etc. have been extracted [1]-[6]. The Ukrainian Shield, having unique structure, is connected with the majority of ore minerals as well as non-metallic ones being of magmatic and metamorphic origin (i.e. iron, nickel, and uranium ore; granite; basalt; labradorite; gneiss; and graphite) [7]-[10].

Volyn basalt is of the utmost interest as the useful building material as well as mineralization source. Volyn-Podillia Plateau, represented by igneous complexes in Volyn-Polissia Depression, allocates within the northwest bank of the Ukrainian Shield. Four series represent trappean occurrence structure of Volyn series. According to the stratigraphic sequence, their downward order is as follows: 50-195 m of Ratnenska basalt set with ribbons of lava-clastic breccias; levels of tuff; tuffite; and tuff-conglomerate; 90-235 m of Babynska tuff set with certain basalt flows; 0-345 m of Zabolotovska basalt set with tuff interlayers; and Horbashevsky gravelite-sandstone admixed with pyroclastic material and 15-60 m thickness. Currently, basalt is excavated. The mineral belongs to Ratnenska set; it is under Cretaceous deposits (i.e. marl stone-colour loam) and Quaternary unconsolidated deposits. Totally, they are 2-3 up to 5-7 m layer facilitating overburden operations.

Volyn basalt is interesting for researchers owing to its unique mineralogical and chemical characteristics. According to potassium-argon method, isotopic age of the mineral is 510-598 million years. There are two basalt types in the area. Type one is the aphanite basalt being of black and darkgray colour. Mainly, it is palagonite mineral which mineral composition is as follows: 36% of plagioclase; 33% of pyroxene; 19% of glass; 6% of palagonite; and 6% of metallic mineral. The basalt is outcropped in the open pits of such villages as Berestovtsy, Yanova Dolyna, Ivanchi, Polytsi etc. Type two is the almond-shaped basalt greenish gray close-grained rock with numerous amygdules which size is up to 15 mm. The mineral composition is as follows: plagioclase,

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metallic mineral (i.e. magnetite, and menaccanite); apatite; and volcanic glass. The key basalt blast is observed in the Styr River basin. Table 1 shows the rock density, and chemical composition of the basic basalt in the form of percent-denominated weight content [11].

Table 1. Chemical composition of the basic basalt types according to the open pits

Compositions of chemical elements, %	Outcropping areas	
	Villages of Khodosy, Hutwin, Yanova Dolyna, and Mydsk	Villages of Berestovtsy, and Yanova Dolyna (open pit 2)
SiO_2	45.04	49.50
TiO_2	2.54	2.85
Al2O_3	14.30	12.79
Fe_2O_3	6.03	3.36
FeO	6.46	10.63
MnO	0.4	0.21
MgO	8.47	6.19
CaO	6.58	9.38
Na_2O	2.42	2.78
K_2O	0.48	2.05
P_2O5	0.17	0.57
SO_3	0.30	0.20
CuO	0.03-1.20	0.22
H_2O	0.72	0.80
Others	1.88	2.41

Significant quantity of energy is required to disintegrate ore body and perform following extraction of the mineral [12]. Development of new procedures for rock mass processing and preparing involves use of natural characteristics of minerals saving power consumption for their disintegration and increasing ore breakdown and recoverability of the mineral [13], [14]. Hence, it becomes topical to analyze natural joints of different rocks within the basalt mass which may vary significantly both approaches and principles of technological influence on them for further disintegration and extraction of minerals.

In the late 19th and early 20th centuries, geologists showed interest and started analyzing structures within the rocks in the form of joints at macro- and mega-levels specified as autonomous blocks within the Earth's crust and fractures varying in their geometry [15]-[17]. In addition to vertical layers, the horizontal transversal ones were found commonly on a table. In this context, the fissures had regular arrangement; moreover, they were always vertical. Each their system is of the well-balanced course supporting the idea of the oriented tectonic forces passing through the table [18]-[21]. As a result of the problem consideration, K.F. Tiapkin denotes a system-based arrangement of the fractures shaping blocks with stable 140×140 km dimension. In turn, fractures divide the blocks into the smaller ones corresponding to a half, quarter etc. of the main block; i.e. they multiply 70; 35; 17.5; 9 km and less. Hence, dependence of double reduction in the geoblock geometry has been derived. Following the law, the joint, differing from a block size only in dimensions, should have similar dependence [22], [23]. In other words, it has to be penetrating for each rock size and type.

Relying upon the determined connection between a mechanism determining the oriented structure of enclosing rocks and their characteristics, paper [24] recommends the nature of mechanical effect during disintegration. For the first time, it has been defined that in the process of static load, failure behaviour of intrusive rocks depends upon the specific features of a microstructure, i.e. directedness of microfissures as well as of their orientation degree. In the context of dynamic load, failure behaviour is influenced by the rock mass macrostructure, i.e. orientation of macrofissures as well as their opening degree. A procedure, separating granite monoliths from the rock mass has been improved; percentage of the block output has been increased [25]-[27].

From the viewpoint of blockiness and fissility, analysis of basalt outcropping in Rafalivsky and Berestovetsky open pits has shown their high cleavage degree (face height is 15-20 m) and strongly marked joints limited by means of vertical and horizontal fissures.

Generally, the deposits, being mined, have non-uniform mineral composition. Hence, rational use of the resources at the initial stage of the mineral processing should involve information concerning specific features of the mined rock mass blockiness as well as study of fissure arrangement within it [28]-[30]. Stage one of ore preparation is disintegration of the mineral substance connected with ore bodies, and further division of the rock mass until a commercial product is obtained, within which useful component concentration achieves a level being sufficient for its profitable extraction. Following separation of ore bodies from the rock mass, containing useful components (waste rocks), is intended to increase its concentration in the commercial product. Hence, owing to mechanical treatment of a mineral, ore preparation is an auxiliary processing stage involving crushing and classification, thus being a medium between the mining practice and the preparation one.

Mechanical preparation system involves following operations [31]-[34]:

– advanced engineering analysis for strategic planning of useful component extraction;

– separation of technological ore types;

– ore disintegration into mineral aggregates;

– lump ore separation;

– ore averaging depending upon its grade by certain technological types;

– shaping of ore flows in the form of a commercial product for future preparation.

All the listed cases need the information concerning strength characteristics of the rock mass being processed. Namely, lumpiness effect on power intensity of ore preparation processes as well as on productivity is meant [35]-[37].

Development process of the considered method pays insufficient attention to the preliminary rock mass disintegration at the expense of fracturing both in the rock mass and in separate lumps [38]. The abovementioned should involve extensive statistics, i.e. the identified dependencies helping apply new principles to engineer ore processing since they take into consideration the developed micro- and macro-fissured network while reducing energy intensity of the schedules [39]-[41].

Currently, open-pit fields are mined under the conditions of insufficient information concerning fissility of rocks as well as their strength characteristics. Blasting destruction of an open-pit bench should be considered as the initial disintegration stage along with the primary breaking, crushing, and grinding; rather often, crushing and grinding are the parts of a mining method [42]-[44]. Fissility of the open-pit rocks, determining their blockiness, is among the most important characteristics to be used in the process ore preparation. The amount of fissures within the open-pit bench has been increased as a result of drilling and blasting operations; the amount is tectonic and technogenic total [45]-[47]. Hence, the field studies recorded a soil grid in the form fissure projection on the bench plane to determine the dimensions of blocks, their outcrop, and shapes.

The blocks or so-called joints represent behaviour of an open-pit bench [48]-[50]. Analysis of the available concept of rock joints, with the participation of the author, has shown that the joints, shaped in rock mass by means of tectonic fissures, take place at macro- and mega-levels in sedimentary, metamorphic, and ingenious rocks. They form large blocks in the Earth's crust as a result of tectonic disturbances [51]-[53]. It has been determined that fractures shape the blocks with stable 140×140 km dimensions; it turn, the latter are separated by means of fractures in their own system. Distances between them correspond to a half, quarter etc. of the main block [54]-[56]. Consequently, the blocks multiplying 70; 35; 17.5; 9 km and less have been identified. As defined by S.S. Schulz, the fissility is of the planetary nature and of regular orientation; it disintegrates rocks into the regular-shaped blocks. While analyzing the problem of blockiness formation, authors of [57]-[59] have defined a number of regularities. For instance, K.F. Tiapkin and later M.A. Sadovski have identified that such a common characteristic of solid substances (i.e. rocks) is as follows: in the process of their disintegration into joints by fissures as well as in the process of consolidation of the joints into large blocks, dimensional distribution of the arising lumps forms hierarchic sequence of the 'preferential' sizes. Moreover, the characteristic is typical for large geoblocks as well as for smaller objects [60]-[62] (up to a microlevel) which can be considered as a very important argument for the development of methods to mine and process minerals.

A premining technology of a basalt deposit needs large quantities of data even at the design stage of an enterprise. An operating open pit with its developed infrastructure is the specific feature of Rafalivsky deposit as one of those being potentially productive from the holistic extraction perspective. Despite the fact that the open pit extracts basalt for gravel, the performed research part is based upon the facts, represents specific geological and mineralogical characteristics to increase accessibility of the resources, and influences heavily the decisions concerning extraction operations in the context of full-field development [63]-[68].

It is known [69]-[71] that increase in a bench height results in the prolonged period of the blast effect on the structure. The abovementioned factors into its more intensive disintegration and fissility. However, while describing the results of studies, no scientific source mentions the nature of dependence of fissure frequency changes in a face after blast in terms of height; what block geometry prevails; outcrop of the blocks and their sizes. Nevertheless, the data characterize drastically the rock mass blockiness over the exposed bench surface [72]-[74]. Thus, the research should study and analyze bench fissility of basalt open pits to derive dependencies of specific fissility upon the bench heights of the basalt open pits. For the purpose, it is required to analyze rock mass fissility and determine regularities of fissure penetration.

2. Methods

Field studies of fissure tectonics took place in Rafalivsky open pit extracting basalt of Ratnenska suite to produce top-grade gravel; it contains heavy percentage of native copper. Mining schedule includes drilling and blasting operations as well as the blasted rock mass loading and transporting to the facility for further crushing and vibrational screening on grain-size categories [74]-[77]. Since overburden operations are performed in advance being small in their amount, the performed research concerning the open-pit bench fissility helps make the deposit more accessible at the design stage owing to the improved quality and efficiency of drilling and blasting operations. The matter is that drilling and blasting increase significantly the amount of fissures within an open-pit bench; hence, the research took into consideration both the tectonic fissures and the technogenic ones (i.e. failures, faults, and fissures as a result of explosion load). A soil grid in the form a fissure projection on a plane was recorded. Specific features of the rock mass blockiness were analyzed on the basis of large-scale measurements performed uniformly along the studied area. The data of a fissility analysis of the exposed 10×10 m bench face, carried out using a well-known technique, turned out to be the most reliable. In this context, a height started to be measured from a bench floor since its upper share has weathering fissures. It is the softened bench part where fissures do not form regularities developing instead by the available fissure networks; in such a way, the fissures complicate their framework, shaping additionally more frequent grid. Hence, the upper part of the bench was not analyzed after 10 m height from its floor.

The obtained fault and fracture 10 m grid across the face width was analyzed one every meter. In such a way, specific fissility was recorded since the amount of macroscopic well-defined cracks, falling at a linear meter of the exposed rock plane, was calculated. Vertical lines were determined with the help of projecting edges of columnar joints separating the rock mass into polygonal prisms being typical for basalt. Columnarity is perpendicular to a lava flow; it is vertical; and distance between edges is up to a meter. Prismatic joint of the open pit as well as columnar one has five or six ends in cross sections; and width is 0.8 up to 1.0 m. In addition to the specific fissility, the research also defined the shape of natural blocks as well as their number per each meter; their geometry (using fissure frequency); and nature of changes in the amount of fissures as well as sizes of blocks (units) on the bench height. The assumed simplified methods to take account of fissility [78], [79] facilitates the research task. Moreover, it is not intended to solve geological problems of a site. It helps identify the face conditions to improve or select mining technique, parameters of processing equipment, blasting pattern, and amount of explosives.

The officially accepted methods have been applied to study and determine the specific fissility blockiness nature of the exposed bench face within the 10x10 m site. A fissility pattern varies depending upon the face advance. Hence, the methods involve following procedure. It is known that increase in the open-pit bench height as well as in the well length results in the increased period of the blast effect on the rock mass; consequently, it results in its more intensive disintegration and fissility. In this context, the following is understudied: dependence of fissure frequency changes in face throughout the height after blast; and geometry of blocks and distribution of joints throughout the bench height. At the same time, the data help make a decision as for the adjustment of face preparation. That is why, the research marked each face site with 10×10 m dimensions; the specific fissility of each bench height meter within the studied area was determined; moreover, percentage of (< 300), 300-700 and 700-1000 mm joints was identified. In this context, the count started from a bench floor as its upper share had weathering fissures. It is the softened bench part where fissures do not form regularities developing instead by the available fissure networks; in such a way, the fissures complicate their framework, shaping additionally more frequent grid. Hence, the upper part of the bench was not analyzed after 10 m height from its floor. Total height of the bench is 18-20 m where overburden layer is 2-3 up to 5-7 m. The latter consists of sandy and chalk deposits. The obtained failure and fracture grid across the 10 m width of the face was analyzed after each meter; in such a way, the specific fissility was recorded. It should be mentioned that only macroscopic well-defined cracks, falling at a linear meter of the exposed rock plane, were taken into consideration. Vertical lines were determined with the help of projecting edges of columnar joints separating the rock mass into polygonal prisms being typical for basalt. The columnarity is perpendicular to a lava flow; it is vertical; and distance between edges is 0.8-1.0 m.

3. Results and discussion

Table 2 demonstrates the results of basalt fissility research in three open pits making it possible to understand significant changes in the fissure amount in terms of a bench height as well as the shaped joints.

Graphical analysis of the results obtained for the three open pits has shown similar nature of the dependence of the fissure amount upon an open-pit bench height. High fissility density within the upper share of a bench decreases the rock mass blockiness; and significant increase in block dimensions within lower share of the bench is observed. In addition, the blocks within the lower share are oversized from the viewpoint of a large crusher feeding. Geometry of joints (blocks) listed in the Table specified for the analysis depends upon the sizes of receiving openings of primary gyratory cone crushers, secondary cone crushers as well as jaw breakers.

Figure 1 demonstrates the dependence of the specific fissility upon a bench height. Lines 1, 2, and 3 show the derived experimental fissility dependencies upon such open-pit heights as Rafalivsky, Berestovetsky, and open pit in the village of Yanova Dolyna respectively.

Table 2. The results of fissility research of benches of the basalt open pits

Top to bottom bench height, m	The specific fissility	Maximum lump geometry, mm. Pecentage		
		< 300	300-700	700-1000
Rafalivsky basalt open pit				
1	18	100	–	–
2	17	100	–	–
3	13	97	3	–
4	10	94	6	–
5	10	88	11	1
6	8	86	12	2
7	8	74	16	10
8	6	65	17	18
9	5	38	32	30
10	3	15	45	40
Berestovetsky basalt open pit				
1	17	100	–	–
2	15	100	–	–
3	13	98	2	–
4	12	97	3	–
5	11	95	4	1
6	9	90	7	3
7	9	77	15	8
8	6	62	30	8
9	5	55	36	9
10	4	40	50	10
Basalt open pit (village of Yanova Dolyna)				
1	12	95	5	–
2	10	94	6	–
3	8	92	8	–
4	7	90	8	2
5	6	80	12	8
6	5	45	15	30
7	4	25	30	45
8	4	15	35	50
9	3	8	44	48
10	2	2	55	43

Similar nature of the dependencies for the three open pits denotes potential genelarity of the accepted engineering solutions as for basalt extraction, crushing, classification, and grinding in the process of their development and prepararion. Since the fillsity defines geomentry of joints within the rock mass then, according to percentage classification, shown in Figures 2-4, rock mass lumpiness in terms of sizes of the pieces (joints) are < 300; 300-700 and 700-1000 mm for the analyzed basalt faces in the three open pits.

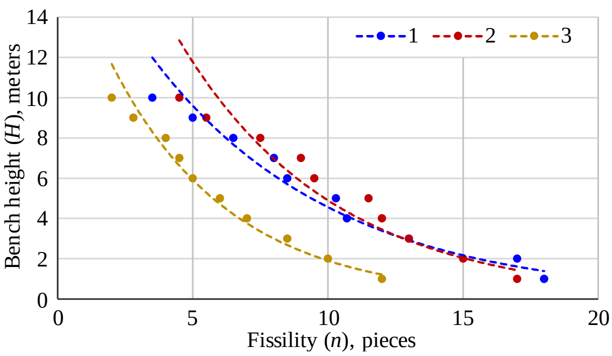

Figure 1. Changes in the specific fissility depending upon the open-pit bench: 1 – Rafalivsky open pit; 2 – Berestovetsky open pit; 3 – open pit in the village of Yanova Dolyna

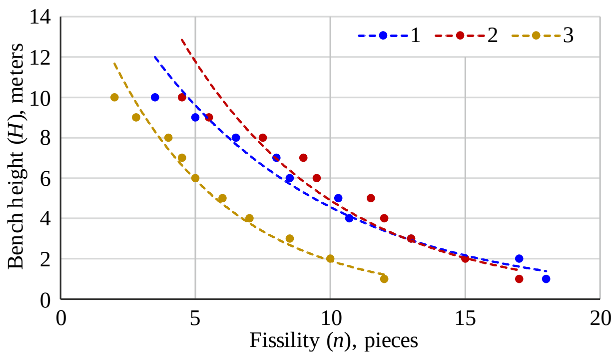

Figure 2. Dependence of the amount (in terms of percentage point) of (−300) mm joints upon the open-pit height: 1 – Rafalivsky open pit; 2 – Berestovetsky open pit; 3 – open pit in the village of Yanova Dolyna

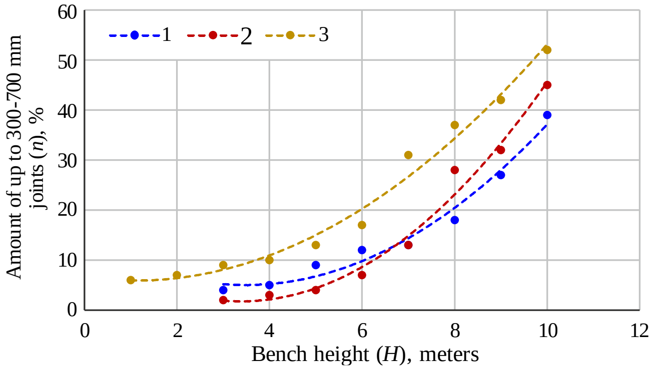

Figure 3. Dependence of the amount (in terms of percentage point) of (300-700) mm joints upon the open-pit height: 1 – Rafalivsky open pit; 2 – Berestovetsky open pit; 3 – open pit in the village of Yanova Dolyna

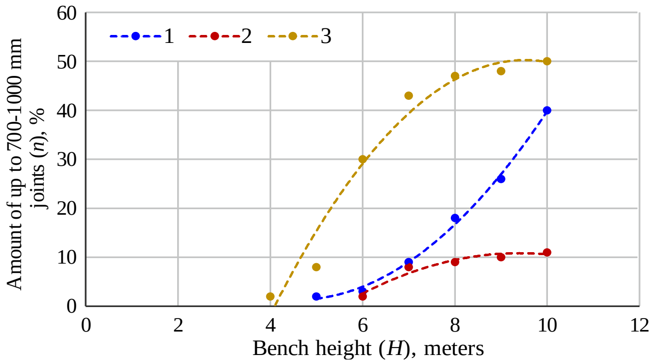

Figure 4. Dependence of the amount (in terms of percentage point) of (700-1000) mm joints upon the open-pit height: 1 – Rafalivsky open pit; 2 – Berestovetsky open pit; 3 – open pit in the village of Yanova Dolyna

Graphical analysis of the research results helps understand distribution density of the joints, varying in size, throughout the bench height making it possible to forecast the disintegrated ore before blast and specify approximate distances between the blastholes to avoid mutual basalt regrinding as a result of blasting effect. Nevertheless, it becomes necessary to quantify preliminary the lumpiness.

More accurate determination of lumpiness involved the development of a technique to calculate analytical dependence according to the available experimental data. For the purpose, dependence of the specific fissility indices of basalt open-pit bench is studied first and the maximum lump geometry upon a bench height.

Specify as follows: x is the bench height and y is the analyzed index.

The research results are represented like this:

$$X = \{x_1, x_2, \dots, x_n\},\quad Y = \{y_1, y_2, \dots, y_n\}. \tag{1}$$

The problem is to determine the dependence:

$$\hat{y} = f(A, x), \tag{2}$$

where:

$A = \{a_0, a_1, \dots, a_m\}$ are the function parameters.

To derive f function, apply the least-squares method which criterion is:

$$F = \sum_{i=1}^{n}\left(y_i - f(A, x_i)\right)^2 \to \min . \tag{3}$$

To minimize F criterion, set to zero its derivatives using the required parameters:

$$\frac{\partial F}{\partial a_0} = 0,\quad \frac{\partial F}{\partial a_1} = 0, \dots,\quad \frac{\partial F}{\partial a_m} = 0. \tag{4}$$

Solve the equation system relative to the required parameters of the function. Since the function choice may use different dependencies (i.e. polynomial and nonlinear ones), the determination coefficient R^2 is calculated to select the best approximation for each dependence. The dependence, in terms of which the determination coefficient is maximum one, is assumed.

In the context of polynomial dependence, the equation system is obtained straight from the initial variables. For instance, for such a parabolic dependence as $\hat{y} = f(A, x) = a_0 + a_1 x + a_2 x^2$, the equation system is as follows:

$$\begin{cases} a_0 + a_1\dfrac{\sum x_i}{n} + a_2\dfrac{\sum x_i^2}{n} = \dfrac{\sum y_i}{n}, \\ a_0\dfrac{\sum x_i}{n} + a_1\dfrac{\sum x_i^2}{n} + a_2\dfrac{\sum x_i^3}{n} = \dfrac{\sum y_i x_i}{n}, \\ a_0\dfrac{\sum x_i^2}{n} + a_1\dfrac{\sum x_i^3}{n} + a_2\dfrac{\sum x_i^4}{n} = \dfrac{\sum y_i x_i^2}{n}. \end{cases} \tag{5}$$

Determine parameters of a_0, a_1, a_2 function while solving the equation system.

If the required function is not defined by m^{th} order polynomial but by a nonlinear expression of another type then it should be linearized by means of substitution of the variables before using the least-squares method. For instance, assume that $\hat{y} = f(A, x) = a_0 \cdot a x^{a_1}$ is an exponential function.

Perform logarithmation:

$$\ln y = \ln a_0 + a_1 \ln x . \tag{6}$$

Specify $Y = \ln y$, $A_0 = \ln a_0$, $X = \ln x$.

The linear model is obtained:

$$Y = A_0 + a_1 X . \tag{7}$$

Calculation of its parameters A_0 and a_1 by means of the least-squares method results in following equation system:

$$\begin{cases} A_0 + a_1\dfrac{\sum X_i}{n} = \dfrac{\sum Y_i}{n}, \\ A_0\dfrac{\sum X_i}{n} + a_1\dfrac{\sum X_i^2}{n} = \dfrac{\sum Y_i X_i}{n}. \end{cases} \tag{8}$$

The required dependence coefficients A_0 and a_1 are obtained from the equation system solving. Definitely, we have $a_0 = \exp(A_0)$.

To calculate determination coefficient R^2, define two variation criteria:

– total variation $\Delta = \sum_{i=1}^{n}(y_i - \bar{y})^2$;

– trend variation $\delta = \sum_{i=1}^{n}(\bar{y} - f(A, x_i))^2$.

Hence, determination coefficient is:

$$R^2 = \frac{\delta}{\Delta}. \tag{9}$$

Table 3 represents options of the most adequate approximating function with the sample data of different dependencies. The determination coefficient helps understand that the 3rd degree polynomial yields the best approximation.

Table 3. Determination of the dependence function of the specific fissility upon a bench height

Types of functions	Open pit
	Rafalivsky open pit
Linear	$y = 18.533 - 1.588x$; $R^2 = 0.9472$
Parabolic	$y = 20.617 - 2.6295x + 0.0947x^2$; $R^2 = 0.9688$
Cubic	$y = 22.8 - 4.566x + 0.514x^2 - 0.025x^3$; $R^2 = 0.977$
Logarithmic	$y = 19.71 - 6.561\ln x$; $R^2 = 0.948$
Power	$y = 24.265x^{-0.6844}$; $R^2 = 0.8181$
Exponential	$y = 23.033e^{-0.1785x}$; $R^2 = 0.9491$
	Berestovetsky open pit
Linear	$y = 17.867 - 1.4121x$; $R^2 = 0.9857$
Parabolic	$y = 18.2 - 1.5788x + 0.0152x^2$; $R^2 = 0.9864$
Cubic	$y = 18.93 - 2.22x + 0.15x^2 - 0.0085x^3$; $R^2 = 0.987$
Logarithmic	$y = 18.603 - 5.6295\ln x$; $R^2 = 0.9183$
Power	$y = 22.166x^{-0.5836}$; $R^2 = 0.7191$
Exponential	$y = 21.581e^{-0.1554x}$; $R^2 = 0.9546$
	Open pit of Yanova Dolyna Village
Linear	$y = 11.733 - 1.0242x$; $R^2 = 0.9521$
Parabolic	$y = 13.483 - 1.8992x + 0.0795x^2$; $R^2 = 0.9889$
Cubic	$y = 14.76 - 3.037x + 0.32x^2 - 0.015x^3$; $R^2 = 0.996$
Logarithmic	$y = 12.596 - 4.3009\ln x$; $R^2 = 0.9841$
Power	$y = 15.517x^{-0.7045}$; $R^2 = 0.8673$
Exponential	$y = 14.496e^{-0.1811x}$; $R^2 = 0.9776$

Table 4 shows the results of the function selection to calculate the specific fissility as well as output of geometry of lumps (joints).

Table 4. Determination of a function type to calculate the output depending upon the size

Joint size, mm	Open pit
	Rafalivsky open pit
up to 300	$y = 105.7 - 5.978x + 1.506x^2 - 0.182x^3$; $R^2 = 0.994$
300-700	$y = 2.8667 - 2.0758x + 0.5909x^2$; $R^2 = 0.9532$
700-1000	$y = 1.9333 - 1.2591x - 0.0781x^2 + 0.0598x^3$; $R^2 = 0.9924$
	Berestovetskyopen pit
up to 300	$y = 95.4 + 4.6667x - 1.0303x^2$; $R^2 = 0.9885$
300-700	$y = 2.033 - 1.669x + 0.25x^2 + 0.0404x^3$; $R^2 = 0.987$
700-1000	$y = -0.9 + 0.0773x + 0.1136x^2$; $R^2 = 0.9117$
	Open pit of Yanova Dolyna Village
up to 300	$y = 82.67 + 12.54x - 1.89x^2 - 0.419x^3 + 0.041x^4$; $R^2 = 0.9822$
300-700	$y = 7.3833 - 2.9492x + 0.7386x^2$; $R^2 = 0.9866$
700-1000	$y = 7.593 - 6.68x - 0.066x^2 + 0.554x^3 - 0.045x^4$; $R^2 = 0.9788$

The basalt percentage size output for the three controlled classes is calculated on the derived dependencies in the context of the studied open pits within each bench height meter.

4. Conclusions

The research has shown that bench fissility of basalt open pits is distributed irregularly through its height. The analysis has helped understand that the obtained rock mass joints are distributed downwards from smaller to larger ones (according to the 3rd degree polynomial). The determined regularity makes it possible to identify percentage of joints of three types for each meter of a bench height. The forecast of the parameters helps schedule efficiently the drilling-and-blasting operations and select instrumental conditions for further basalt processing. The total (i.e. tectonic and technogenic) fissility of a basalt open-pit bench should be involved while developing an energy-saving ore preparation technique of ore preparation.

It has been identified that the specific fissility is distributed irregularly through the open-pit (face) bench. The field studies, carried out within three basalt open pits, have helped define that the most adequate approximation of the specific fissility dependence upon a bench height results from the use of the 3rd degree polynomial, i.e. three types of joints (up to 300; 300-700 and 700-1000 mm) have been obtained downwards from smaller to larger ones following the law. It has been determined that fissility degree of an open-pit face influences heavily the intensity of mineral mining operations, efficiency of machinery, and production of eligible end product. In addition, fissility defines nature of rock blockiness, geometry of blocks, and their amount and shape which should be taken into consideration while selecting both equipment and mining schedule.

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Дослідження закономірностей тріщинуватості базальтових кар'єрів для забезпечення енергоефективності рудопідготовки

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Мета. Встановити залежність питомої тріщинуватості гірського масиву від висоти уступа базальтових кар'єрів на основі вивчення тріщинуватості уступів базальтових кар'єрів.

Методика. Дослідження тріщинної тектоніки базальтових кар'єрів проводилися експериментальним шляхом. У процесі досліджень, крім питомої тріщинуватості, визначалися форма і кількість (на кожному метрі висоти) природних блоків, їх розмір (за частотою тріщин), характер зміни кількості тріщин та розмірів блоків (окремостей) за висотою уступу. За допомогою методів графічного аналізу отриманих результатів по базальтових кар'єрах визначалися характерні залежності кількості тріщин від зміни висоти уступа кар'єра.

Результати. Встановлено, що питома тріщинуватість базальтових уступів нерівномірно розподіляється по висоті уступу (вибою) кар'єра. Польовими експериментальними дослідженнями на трьох базальтових кар'єрах встановлено, що залежність питомої тріщинуватості від висоти уступу найбільш адекватно апроксимується у вигляді многочлена третього порядку.

Наукова новизна. В результаті проведення експериментальних досліджень вперше встановлено, що окремості гірського масиву розподіляються від менших до більших зверху вниз за параболічним законом (у відповідності до многочлена 3-го порядку). Отримані закономірності дають змогу визначати відсотковий вміст окремостей трьох типорозмірів для кожного метра висоти уступа.

Практична значимість. Прогноз процентного вмісту окремостей дозволить раціонально планувати буропідривні роботи та обирати енергоефективні параметри технологічного обладнання з подальшої переробки базальтів.

Ключові слова: *базальт, тріщинуватість, тектоніка, уступ, кар'єр, енергоефективність*