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EXPLORING THE EFFICIENCY OF APPLYING FRACTAL ANALYSIS FOR THE PROCESS OF DECORATIVE STONE QUALITY CONTROL

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Розроблено методику фр кт льного н лізу з кономірностей формув ння тріщинув тості для різних родовищ, як б зується н співст вленні зн чень фр кт льних розмірностей роз тріщинув тості. Вст новленні з кономірності зміни фр кт льної розмірності н різних структурних рівнях. Вст новлений вз ємозв'язок між фр кт льною розмірністю зони буріння шпурів т продуктивністю процесу. Розроблен методик оцінки просторової мінливості продуктивності процесу буріння шпурів

Ключові слов : фр кт льний н ліз, фр кт л, декор тивний к мінь, тріщини, розломи, мікротріщінув тість, блочність, продуктивність буріння, геост тистичний н ліз, кл сифік ція родовищ

Р зр бот н методик фр кт льного н лиз з кономерностей формиров ния трещинов тости для р зных месторождений или их уч стков, котор я б зируется н сопост влении зн чений фр кт льных р змерностей роз трещинов тости. Уст новлены з кономерности изменения фр кт льной р змерности н р зных структурных уровнях. Уст новленн вз имосвязь между фр кт льной р змерностью зоны бурения шпуров и производительностью процесс . Р зр бот н методик оценки простр нственной переменчивости производительности процесс бурения шпуров

Ключевые слов : фр кт льный н лиз, фр кт л, декор тивный к мень, трещины,р зломы, микротрещинов тость, блочность, производительность бурения, геост тистический н ліз, кл ссифик ция месторождений

1. Introduction

A basic problem in defining technological parameters for developing blocking stone is determining the direction for developing mining operations and the reliability of predicting the change in the orientation of the planes of cracks. High efficiency in solving similar problems is characteristic for the method of analogues, that is, the prediction of parameters of a system of cracks and the assessment of effectiveness of technological decisions, used in the deposit, similar to the given one in the conditions of formation. It should be noted that the orientation of cracks may be formed in the rock array at different orientation of axes of the main normal stresses, but most planes of cracks are parallel to the axis of the main vector of stress. It is also known that the spatial orientation of cracks is determined by the stressed state of rock formations in the area of a well and the changes, caused by the distribution of stresses. Considering the above mentioned facts, we can conclude that the orientation of systems of cracks characterizes the spatial orientation of stress tensors in this array, so it is logical to assume that in the deposit with the same configurations of tensors of stresses, the process of cracks formation will be characterized by the same regularities. Different methods of mathematical processing are used in studying fracturing, among which the methods of cluster and fractal analysis can currently be considered as the most promising. The methods of cluster analysis, applied in previous studies [1, 2], revealed low effectiveness in the cases of generalization of results of fracturing measurements at different structural levels. Results of research of various authors prove the fractal properties of fracturing at different structural levels, which makes exploring the fractal nature of fracturing and using the obtained regularities for controlling the technological processes in mining natural decorative stones a relevant scientific and applied task.

2. Literature review and problem statement

An apparent breakthrough in studying fracturing is the proof of its fractal nature and application of the methods of fractal analysis to its studying. It should also be noted that this approach to studying fracturing is characteristic for its different levels, starting with microfracturing and finishing with tectonic splits. In paper [3], on the basis of the method of fluoroscopic flaw detection, the procedure of determining fractal characteristics of fracturing of rock formation was established. Continued research into this area allowed authors in article [4] to develop a new computer simulation model of the cracks dynamics in the system of iterative functions of fractal Brownian motion that makes it possible to predict the change in qualitative characteristics of a decorative stone deposit. In paper [5], the difference in the laws of distribution of fractal characteristics of cracks of various classes was established and parameters of approximating equations were defined. In article [6], the surface of natural cracks and non-homogeneity of their spatial distribution are assessed on the basis of using a set of fractal characteristics of rocks fracturing.

A number of researchers [2, 3, 6] distinguish three structural levels of fracturing: split tectonics, fracturing of deposit and microfracturing. The above mentioned factors make relevant the search for the relationship between the procedure of structural disruptions and fractal dimensionality of fracturing.

In article [7], it was proved that with an increase in the intensity of fracturing, the values of fractal dimensionality increase, as a result, low, medium, high, very high and critical levels of fracturing development were distinguished, for which the corresponding values of fractal dimensionality were set.

Results of the above mentioned studies prove the effectiveness of fractal dimensionality for the assessment of intensity, spatial orientation, linear dimensions, shapes of separate cracks and of natural separatenesses, formed by them, and the establishment of regularities of fracturing development.

The regularities of developing fracturing in decorative building stone and their impact on quality were established in paper [8].

Article [9] explored the process of measuring the elements of location of natural cracks in stone quarries of blocking stone and studied the influence of fracturing on the productivity of mining processes. Results of the studies demonstrated the effectiveness of considering regularities of formation of fracturing in the deposit for assessing qualitative characteristics.

Studies [10] explored the impact of fracturing on the efficiency of blocking stone exploration.

Article [11] explored the efficiency of using a georadar for assessing spatial variability of quality indexes of decorative stone, which gave the opportunity to significantly increase the accuracy of prediction. This variant should be considered promising when combined with natural measurements of fracturing, which will greatly increase efficiency of the interpretation of results of georadar imaging. The obtained results were used for assessing spatial variability of deposit fracturing and evaluating of its quality. The shortcomings of this study include a lack of research into evaluation of regularities of formation of deposit fracturing and estimation of the impact of geostructural indicators on qualitative characteristics of a deposit.

After summarizing the outcomes of the studies, which were implemented in articles [1–11], it is possible to distinguish the following parameters that can be used for quality control of the blocking products: geostructural (orientation of fracturing, linear dimensions of cracks, depth of cracks location, shape of natural separatenesses, blockiness) and technological (anisotropy of deposit properties, orientation of monoliths in relation to the faces of the natural separatenesses, the speed of drilling and diamond rope cutting of a fractured array).

As a result of the performed research, in paper [12], the effectiveness of using the photogrammetric methods in studying blockiness and fracturing was proved, at the same time, the influence of the above mentioned indices on the qualitative characteristics of a deposit was not investigated.

The effectiveness of punch drilling of high-strength rocks was investigated in [13], and paper [14] proved that fracturing of rock array can affect the performance of the drilling process. It should be noted that the result of the executed research did not contain estimations of the influence of fracturing intensity on the performance of drilling. The spatial variability in drilling productivity was not explored either, which does not allow obtaining effective evaluation of the quality of the array of decorative stone and predicting the effectiveness of drilling operations. At the same time, the existence of influence of fracturing on the quality of drilling was proved, which makes it possible to implement the process of controlling the quality of blocking stone on the basis of choosing optimal technological parameters of the drilling process.

Generalization of results of the completed research allows us to emphasize the relevance of developing new approaches to using the fractal analysis apparatus in the process of quality control of non-ore building materials and assessing its effectiveness when predicting spatial variability of geostructural and technological indices of a deposit.

3. The aim and tasks of the study

The aim of the study is to estimate efficiency of using the fractal analysis apparatus for the process of quality control of decorative stone.

To achieve the set goal, the following tasks were to be solved:

– to develop the methods of fractal analysis of regularities of the fracturing formation for various deposits or their sections;

– to establish the patterns of change in fractal dimensionality at different structural levels and to develop methodological basis for their prediction;

– to develop a technique for the estimation of spatial variability of the productivity of blast-holes drilling process and to implement it for particular production conditions.

4. Materials and methods of the study

Fractal dimensionality is appropriate to define using the method of “coverage”, which is implemented in the majority of papers [3–7] and is characterized by high performance and precision. The essence of the method lies in applying a crack on a model with simultaneous calculation of the minimum number of cells N (r_i), which cover the fractal (crack) by dependence which is derived from the Hausdorff dimension:

$$\ln N(r_i) = \ln C - d_f \ln r_i, \tag{1}$$

where r_i is the dimension of a square grid center, which is applied to the rose diagram; N (r_i) is the number of cells that cover the rose diagram; C is the constant value.

Using the existence of linear regressive relationship between r_i and $N(r_i)$, the estimation of fractal dimension of the image is expedient to perform based on the following expression:

$$D_F = \frac{n\left(\sum_1^i N_i \ln r\right) - \left(\sum_1^i \ln r\right)\left(\sum_1^i N_i\right)}{n\left(\sum_1^i \ln r) - \left(\sum_1^i \ln r\right)^2\right)}, \qquad (2)$$

for i=1–n, where n is the number of iterations.

The fracturing roses from 14 labradorite deposits in Zhytomyr Oblast (Ukraine) were taken as the object of study. The construction was performed with increment 10° (which is the most common when examining fracturing) in the software package SteroNett v2.6. Initial data for the construction were the results of geological exploration and direct measurement of the elements of orientation of cracks in mining faces. The total number of measurements of fracturing was 640, and the minimum number of measurements for one deposit was 32.

For their preliminary processing, we used adaptive binarization, based on the Christian method:

$$T = (1-k)m + kM + \frac{ks(m-M)}{R}, \qquad (3)$$

where k is the constant, k=0,5; M is the minimum value of gradations of grey for the entire image; R is the maximum mean square deviation of gray value in a local window; m is the value of gradations of grey for the current pixel.

Results of the performed operations are shown in Fig. 1.

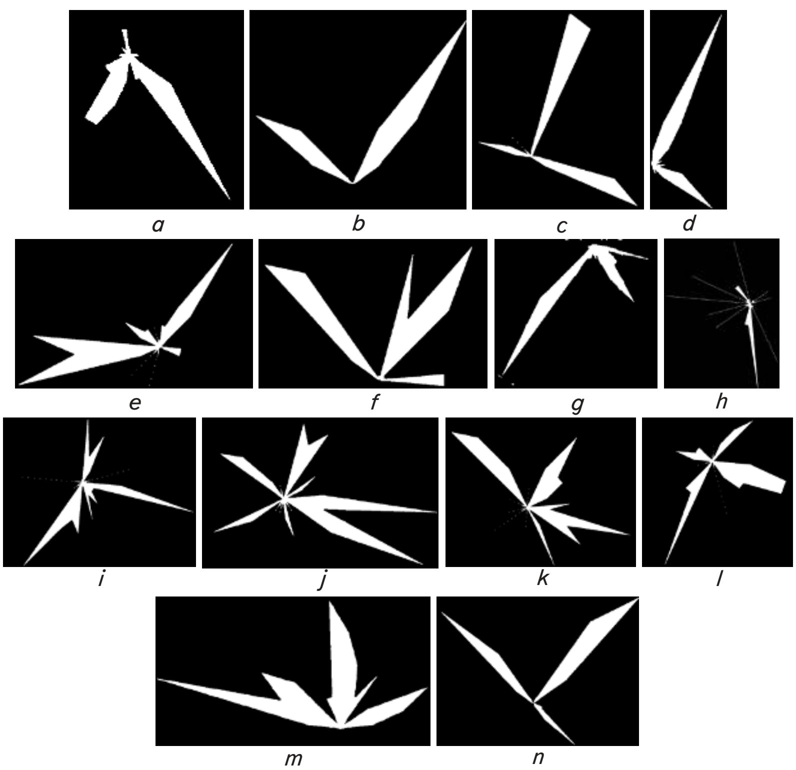

Fig. 1. Roses of fracturing of labradorite deposits in Zhytomyr Oblast after binarization: *a* — Andriyivskiy; *b* — Brazhenskiy; *c* — Verkholuzkiy; *d* — Golovinskiy; *e* — Guta–Dobrinskiy; *f* — Dobrinskiy; *g* — Kamianobridskiy; *h* — Korchiivskiy; *i* — Mykivskiy; *j* — Fedorivskiy; *k* — Olegivskiy; *l* — Neverivskiy; *m* — Ocheretyanskiy; *n* — Osnitskiy

For the estimation of geospatial variability of fractal dimensionality of fracturing roses in labradorite deposits of Zhytomyr Oblast, we used the interpolation method Inverse Distance to a Power (the degree of the inverse distance).

Quite an important factor that can affect comparability of the obtained results for different deposits of decorative stone is the different amount of data (Fig. 2).

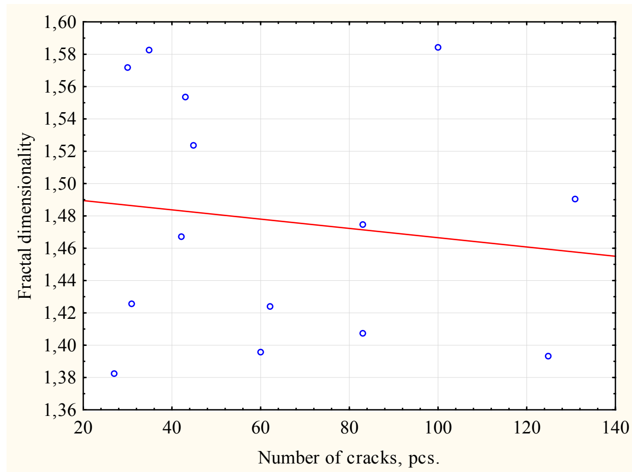

Fig. 2. Dependence of fractal dimensionality on the number of cracks

This assumption is disproved by insignificant coefficient of correlation between the indicator of fractal dimensionality and the amount of data (correlation coefficient is 0,134).

In the study we distinguished 3 structural levels: the first is the level of tectonic splits (length exceeds 1 km), the second level is fracturing of the entire deposit (length exceeds 1 m) and the third level is microfracturing (length is 0,1 mm – 100 mm). Distinguishing the levels of fracturing was concluded on the basis of analysis of practical effectiveness of research into fracturing.

In the course of studying the influence of the level of structural disruption on fractal dimensionality, we also used the method of coverage, in this case, the dimension of a cell size of a square grid, which is applied on the fracturing plan, was designated as r_i, and the number of cells that cover fracturing plan was designated as $N(r_i)$.

In the study of regularities of fracturing formation at the first structural level, we examined the change in fractal dimensionality for copying from the tectonic map in scale of 1:500 000, the center of copying corresponds to the location of the gabbro deposit of Luhove. The procedure of studying involved scanning tectonic maps, further vectorization of the image using the KOMPAS-3D v16 software and processing the obtained images by the software package ImageJ 1.47 v. The dimensions of the examined zone were 5000××5000 m and were gradually growing by 1000 m. 20 iterations were explored. An example of the implementation of this approach for one of the iterations is shown in Fig. 3.

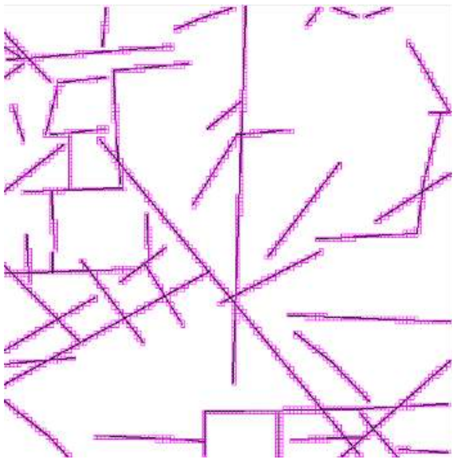

Fig. 3. Determining fractal dimensionality of the deposit location area

The next stage of the study was determining fractal dimensionality of fracturing for the entire deposit by the plan of fracturing on scale 1:500. Similarly to the previous case, the initial zone with dimensions of 50×50 m, which was consistently growing by 10 m, was secured in the geometrical center of the deposit (Fig. 4).

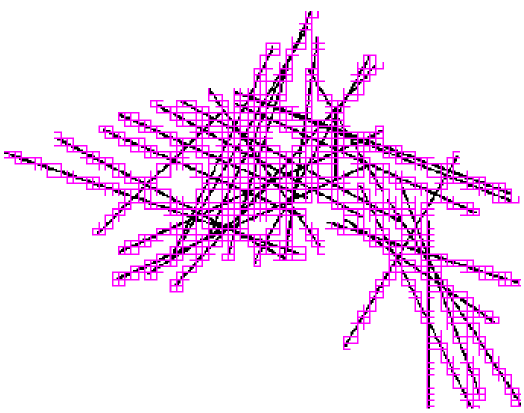

Fig. 4. Determining fractal dimensionality of fracturing at the Luhove gabbro deposit (Zhytomyr Oblast, Ukraine)

And the last stage of the study was to determine fractal dimensionality of microfracturing of 176 samples, which were selected in this deposit. The scheme of sampling is shown in Fig. 5.

The samples were selected by separating the sections with dimensions of 260×100 mm at the surface of the ledge, where the diamond rope cutting plant was installed. In case of absence of the saw cut surface of the array, some sections with the similar dimensions were sanded with the help of hand sanding machine. A total number of selected samples was 88. After that, the fault detecting solutions HELLING NORD-TEST U87, U88, U 89 were applied on the saw cut surface or on the sanded surface. Then the surfaces were scanned by the portable scanner IRISCan Executive Book 3 with resolution of 600 dpi. Further processing of the obtained image was carried out by the software program ImageJ 1.47 v. From every selected band at dimensions of 260×100 mm, two fragments with dimensions of 100×100 m were chosen. Image processing was performed similarly to the previous cases.

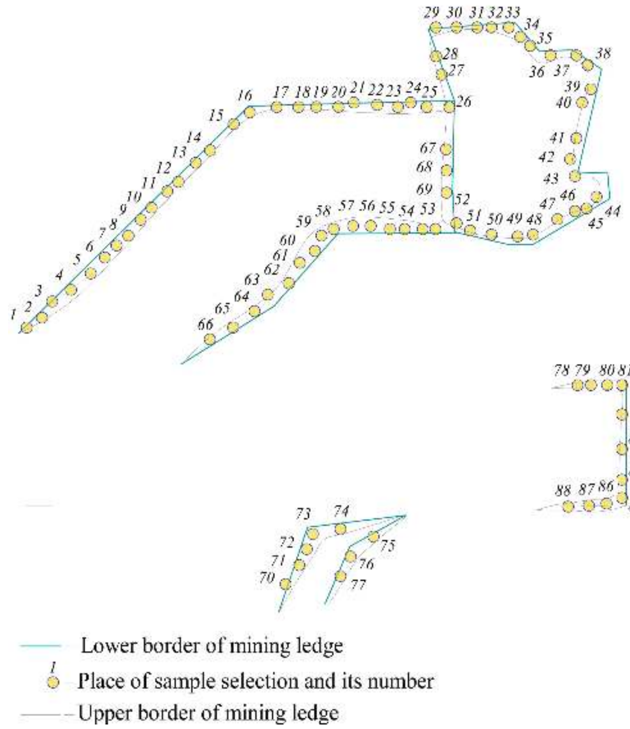

Fig. 5. Scheme of sampling

To study the influence of fracturing on the drilling productivity, we developed a new procedure for determining the predicting performance of blast-hole drilling process depending on the fractal dimensionality of the zone of blast-hole drilling. One-shot photogrammetric imaging of the area parallel to the drilling area was used in this procedure (Fig. 6). The image taking parameters: camera Canon PowerShot G12; focal distance 25 mm; 4.34375 lumens; diaphragm 4.5; shutter speed 1/250 s. In the obtained image, we distinguished cracks by ImageJ 1. 47 v on the basis of using approaches to recognition and identification of cracks, described in papers [1, 7]. The section with identified cracks was evenly divided into zones. The width of the examined zone for each blast-hole was selected equal to 1 m relative to the blast-hole axis. With the help of ImageJ 1. 47 v, the fractal dimensionality of the image of each selected area was determined. Drilling performance of the drilling machine COMANDO 110 was determined on the basis of timing the duration of blast-hole drilling with the stopwatch CASIO SGW-l500H with accuracy to 0,01 s and by measuring length of the drilled blast-hole after the separation of monolith using the 20-meter long roulette with accuracy to 0,01 m.

The obtained methods for determining the predicting performance of the blast-hole drilling process depending on fractal dimensionality of the zone of blast-hole drilling can be used for the prediction of spatial variability of the given index. For this purpose, the following sequence of actions is proposed:

1) with the help of a double-sided scotch tape, the measuring tape is attached to the sides of the monolith (at least two), which are currently uncovered by the diamond rope saw plant;

2) imaging of the rock array is performed;

3) during the image processing, the lines, along which fractal dimensions of the expected zone of blast-holes drilling will be determined, are drawn after each 1 meter;

4) in the conditional system of coordinates, in which a common side of two planes is accepted as zero, the coordinates of each line are defined;

5) fractal dimensionality of the predicted zone of blast-holes drilling is defined for each line;

6) according to results of the previous research, analytical dependence between the values of fractal dimensionality of the zone of blast-holes drilling and drilling performance is established;

7) predicting value of the drilling performance is determined;

8) spatial interpolation of the change in productivity is performed (the interpolation method Inverse Distance to a Power (the extent of the inverse distance) is recommended);

9) the areas, which are characterized by the expected minimum capacity of drilling performance, are determined.

Table 1

Results of determining fractal dimensionality of the roses of fracturing

Deposit	Fractal dimensionality, D_F	Number of data	Blocks yield, %
Andriyivskiy	1,4254±0,0106	31	28,7
Brazhenskiy	1,4745±0,0077	83	32,3
Verkholuzkiy	1,4074±0,0087	83	31
Golovinskiy	1,4907±0,0083	131	31,5
Guta-Dobrinskiy	1,5533±0,0073	43	32,0
Dobrinskiy	1,5720±0,0073	30	31,5
Kamianobridskiy	1,3934±0,0081	125	34,0
Korchiivskiy	1,3821±0,0074	27	33,27
Mykivskiy	1,4241±0,0078	62	34,7
Neverivskiy	1,4670±0,0099	42	27,2
Olegivskiy	1,5234±0,0075	45	32,0
Osnitskiy	1,3956±0,0076	60	33,2
Ocheretyanskiy	1,5823±0,0075	35	31,5
Fedorivskiy	1,5842±0,0101	100	31,4

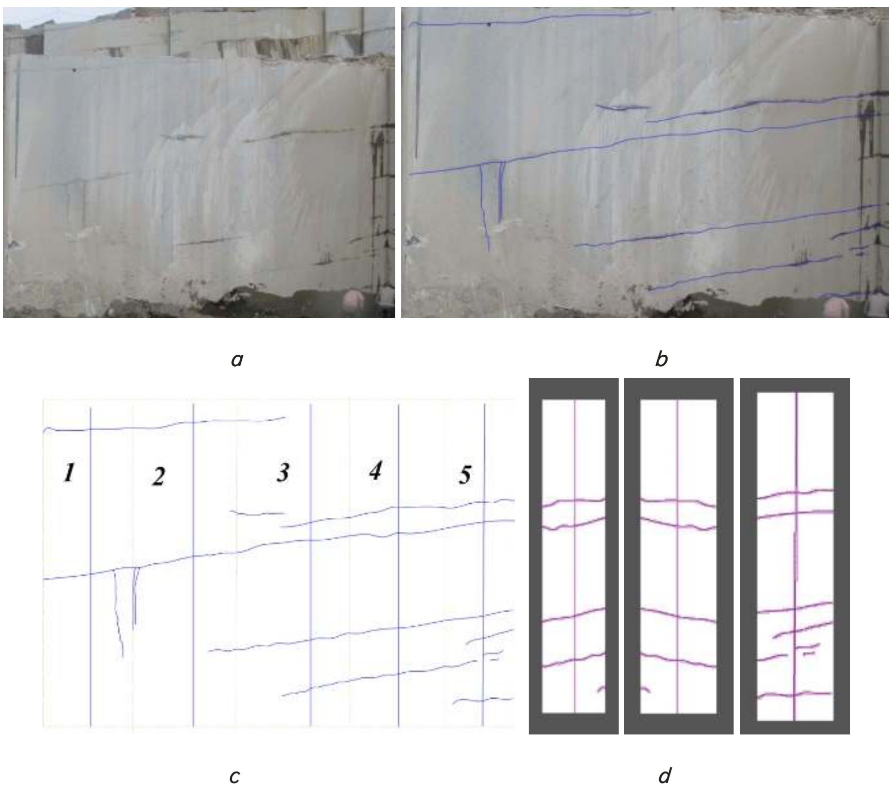

Fig. 6. Determining fractal dimensionality of fracturing in the zone of blast-holes drilling: *a* — imaging of array; *b* — cracks identification; *c* — blast-holes projection onto ledge plane; *d* — determining fractal dimensionality of fracturing in the zone of blast-holes drilling

By the index of fractal dimensionality, the grouping of deposits, based on the use of the Sturgess formula, was performed and, as a result, 5 groups were distinguished:

D_F=1,38–1,42 (Verkholuzkiy, Korchiivskiy, Osnitskiy, Kamianobridskiy);

D_F=1,43–1,46 (Andriyivskiy, Mykivskiy);

D_F=1,47–1,50 (Brazhenskiy, Golovinskiy, Neverivskiy);

D_F=1,51–1,54 (Guta-Dobrinskiy, Olegivskiy);

D_F=1,55–1,59 (Fedorivskiy, Ocheretyanskiy, Dobrinskiy).

Close values of fractal dimensionality in each group are explained by the common nature of forces that affect the crack formation, the most significant of which are rotational.

Performed correlation analysis of dependence of fractal dimensionality of cracks on the number of cracks (correlation coefficient 0,19) revealed a lack of connection between these two indices. The groups of labradorite deposits, distinguished by index of fractal dimensionality, make it possible to improve the accuracy of predicting fracturing of both separate sections and entire deposits based on the substantiated use of the method of analogies.

Performed studies allow us to create the map of spatial variability of fractal dimensionality of fracturing in the labradorite deposits in Ukraine (Fig. 7), which will make it possible to select promising sections for searching for new deposits and to establish regularities of fracturing development in the deposits that are already being developed.

As a result of studies, carried out in article [7], it was found that changes in fractal dimensionality correspond to structural reconstructions of fracturing network, that is, it is possible to tell about relative deformations, as well as about

5. Results of studying effectiveness of the quality control process of blocking raw materials based on fractal analysis

An attempt to compare the indices of fracturing requires substantiation of the basic criteria, by which a comparative analysis will be run. As such an index, we propose fractal dimensionality of the so-called rose diagrams, the length of rays of which in different directions are proportional to the amount or sum of the lengths of lines of the given intervals of propagation.

Results of calculations, performed by the given method, are given in Table 1.

stages of the destructive process, which preceded the formation of a large split, by the values of fractal dimensionality of the gaps of different hierarchical levels.

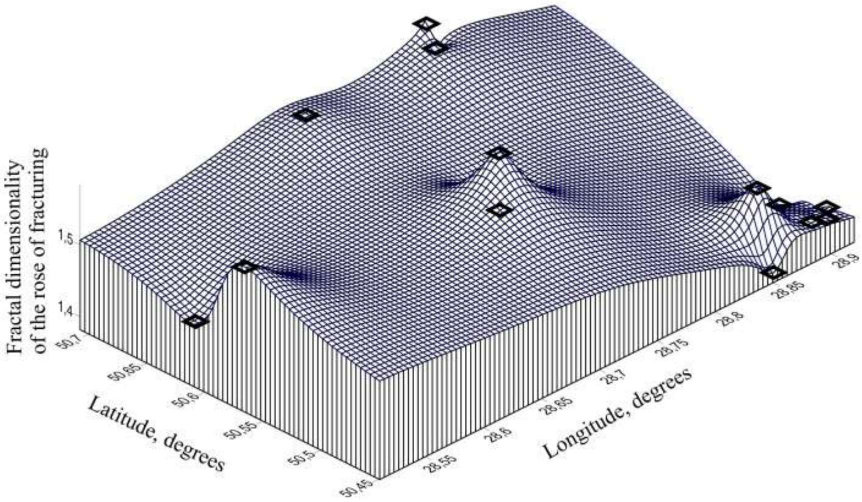

Fig. 7. Three-dimensional map of fractal dimensionality of the roses of fracturing in the labradorite deposits in Ukraine, where ◻ is the location of a labradorite deposit

Taking into account the results of the previous studies, in this work we performed research into a change of patterns in the development of fractal dimensionality of fracturing with a decrease in the hierarchical level and, accordingly, an increase in fracturing. Results of the study are given in Table 2.

Table 2

Results of determining fractal dimensionality at the first (for splits) and second (for fracturing of a deposit) structural levels

For splits		For fracturing of a deposit	
No.	D_F	No.	D_F
1	1,38610998	1	1,55507864
2	1,34512904	2	1,53470913
3	1,39928557	3	1,49829277
4	1,3805061	4	1,5508104
5	1,39179974	5	1,58535242
6	1,33445361	6	1,54609094
7	1,35173688	7	1,54138819
8	1,38673166	8	1,50196096
9	1,39231966	9	1,53818092
10	1,34801259	10	1,45739958
11	1,34274679	11	1,54822714
12	1,38221192	12	1,54256276
13	1,39186458	13	1,53157871
14	1,36253832	14	1,55264536
15	1,38620236	15	1,48077471
16	1,39719206	16	1,50288886
17	1,39008415	17	1,56359026
18	1,41698312	18	1,53157226
19	1,36195534	19	1,4931499
20	1,34654384	20	1,55213623
Mean value	1,374720±0,023382	Mean value	1,530420±0,031460

An analysis of the obtained results demonstrated that the mean value of fractal dimensionality at the given structural level is D_F=1,374720 with 0,023382 dispersion.

Results of the study are given in Table 3. Analysis of the obtained results revealed that the mean value of fractal dimensionality for fracturing of the entire deposit is D_F=1,530420 with 0,031460 dispersion.

Results of the experiment are presented in Table 3. The resulting sample is characterized by mean value D_F= =1,854490 with 0,027914 dispersion.

As a result of the performed research, dependence of fractal dimensionality on the order of structural disruption, which is characterized by correlation coefficient 0,91, was established (Fig. 8).

It is proposed to describe this dependence analytically by polynomial of the second degree in the following form:

$$D_F = 0{,}0842L^2 - 0{,}0969L + 1{,}3874, \quad (4)$$

where L is the order of structural disruption (for splits L=1, for fracturing of a deposit L=2, and for microfracturing of a deposit L=3).

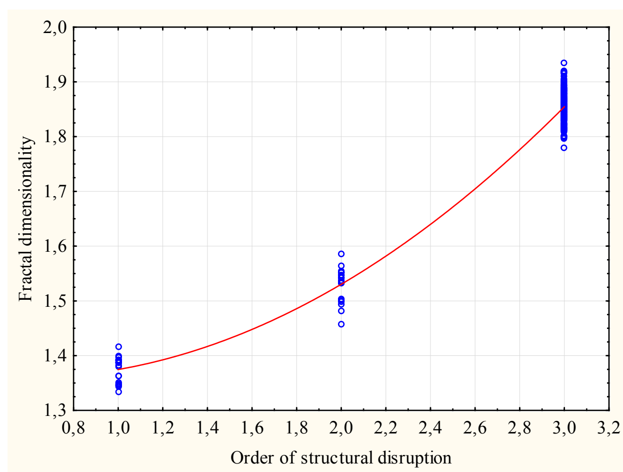

Fig. 8. Dependence of fractal dimensionality on the order of structural disruption

A relevant task was to study the influence of fractal dimensionality of the zone of blast-hole drilling on the drilling performance. The studies that have been performed using the above given method, demonstrated the existence of fairly close correlation connection between the above described parameters, which is characterized by correlation coefficient 0,83. As a result of regression analysis, we obtained analytical expression for evaluating productivity of the blast-hole drilling process depending on fractal dimensionality of the zone of blast-hole drilling in the form of linear dependence (Fig. 9) in the following form:

$$P = 0{,}0287 + 0{,}5541 D_F^d, \quad (5)$$

where D_F^d is the fractal dimensionality of blast-hole drilling zone.

Table 3

Determining fractal dimensionality of microfracturing of deposits

No.	D_F	No.	D_F	No.	D_F	No.	D_F
1	1,83210022	45	1,85507933	89	1,86723115	133	1,85453028
2	1,80776398	46	1,85053168	90	1,88794324	134	1,84017853
3	1,83293296	47	1,85247929	91	1,87036965	135	1,8339415
4	1,86509277	48	1,88494883	92	1,88091465	136	1,86395212
5	1,87003491	49	1,88661329	93	1,84137646	137	1,86390477
6	1,85323659	50	1,87108643	94	1,85106241	138	1,84300548
7	1,82074906	51	1,81624859	95	1,82871656	139	1,82192323
8	1,8663224	52	1,89247932	96	1,88717354	140	1,81515909
9	1,88404101	53	1,79915781	97	1,89241272	141	1,86527244
10	1,87477258	54	1,86682569	98	1,83146832	142	1,86964251
11	1,85969173	55	1,80997528	99	1,83343829	143	1,81528736
12	1,88019202	56	1,84539196	100	1,86902439	144	1,86551281
13	1,88381276	57	1,79948883	101	1,86938281	145	1,83886154
14	1,85718585	58	1,83539893	102	1,84606292	146	1,8246782
15	1,81963767	59	1,85641133	103	1,86013322	147	1,82379654
16	1,86236265	60	1,85676053	104	1,77971761	148	1,86876925
17	1,86057774	61	1,8635064	105	1,82440332	149	1,83136067
18	1,86683442	62	1,8314707	106	1,85169302	150	1,85449909
19	1,8103429	63	1,84831011	107	1,8304967	151	1,88964043
20	1,83672433	64	1,87977627	108	1,88301347	152	1,86517896
21	1,89221187	65	1,82395146	109	1,89963535	153	1,84862649
22	1,90687358	66	1,87940373	110	1,7976736	154	1,84431831
23	1,86581593	67	1,8484978	111	1,81428045	155	1,88340575
24	1,87062966	68	1,89533259	112	1,83379383	156	1,83903496
25	1,81317253	69	1,88402806	113	1,80072412	157	1,85577517
26	1,83672435	70	1,93385604	114	1,85278301	158	1,84897271
27	1,85781612	71	1,85701315	115	1,86859761	159	1,87236704
28	1,84154954	72	1,84502613	116	1,87087668	160	1,87794774
29	1,87344409	73	1,87593089	117	1,8358641	161	1,85790906
30	1,86840209	74	1,85533468	118	1,88338019	162	1,87704622
31	1,87330037	75	1,83352825	119	1,85858812	163	1,87836346
32	1,9041495	76	1,83710845	120	1,88743283	164	1,86291521
33	1,88300919	77	1,8404379	121	1,85608124	165	1,84591548
34	1,84913739	78	1,86483888	122	1,84621007	166	1,81338882
35	1,81578788	79	1,83580874	123	1,9175184	167	1,91733077
36	1,84544029	80	1,82227191	124	1,85698953	168	1,8390879
37	1,81804876	81	1,84035585	125	1,84706988	169	1,80179173
38	1,81448714	82	1,81221995	126	1,87026453	170	1,88859608
39	1,84670553	83	1,83660887	127	1,83833934	171	1,85803823
40	1,815978	84	1,91650611	128	1,85976576	172	1,84309202
41	1,89768464	85	1,88830317	129	1,82233462	173	1,86550882
42	1,85988228	86	1,8342084	130	1,92004427	174	1,85106828
43	1,90987811	87	1,86621086	131	1,88014137	175	1,83650407
44	1,88661758	88	1,87808454	132	1,8143104	176	1,85453028

Using the above given technique, a change in productivity of the blast-holes drilling for the horizon 180 at Ltd. "Polissky Labradorite" (town-type settlement Volodarsk-Volynskyi, Zhytomyr Oblast, Ukraine) was explored (Fig. 10).

The obtained model of spatial variability in the drilling productivity for the horizon 180 at Ltd. "Polissky Labradorite" demonstrated the existence of productivity drops to 0,10 m/min, which is equivalent to the loss in shift productivity in the range of 4.8 m/per shift. Taking into account the established patterns of the change in productivity of the blast-hole drilling will allow choosing the optimal locations for blast-hole drilling and obtaining a reliable predicting assessment of the efficiency in decorative stone mining.

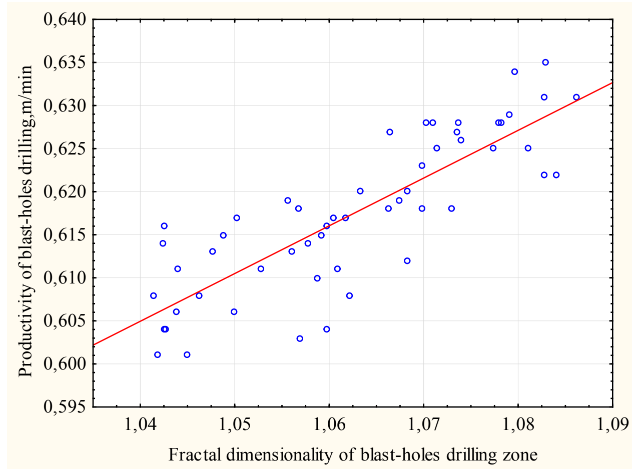

Fig. 9. Dependence of productivity of blast-holes drilling on fractal dimensionality of blast-holes drilling zone

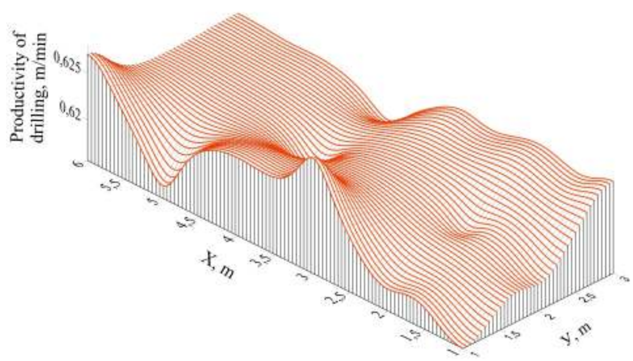

Fig. 10. Evaluation of spatial variability of productivity of drilling for the horizon 180 at Ltd. "Polissky Labradorite"

6. Discussion of results of examining effectiveness of the fractal analysis methods when controlling technological processes of decorative stone extraction

The obtained results may be implemented for obtaining a model of deposit array of non-ore building materials for the optimization of control process over mining of useful raw minerals. As objective function of optimal management process over technological processes, we should take function of geostructural (orientation of fracturing, linear dimensions of cracks, depth of cracks location, shape of natural separatenesses, blockiness) and technological (anisotropy of deposit properties, orientation of monoliths relative to the faces of natural separatenesses, speed of drilling and diamond rope cutting of fractured array) indices. In this case, it is expedient to select quality indices for objective function individually for each deposit taking into account the geological and technological features. In this study, objective function of the optimal process for controlling technological processes contains orientation of fracturing, linear dimensions of cracks and speed of drilling fractured mass.

The performed research allow us to predict the values of fractal dimensionality of fracturing at different structural levels, ensuring significantly lower volume of field observations compared with other methods of studying fracturing. The shortcomings of the performed studies include the fact that their implementation is limited to the deposits of gabbro rocks. In further studies, it is advisable to explore regularities of change in fractal dimensionality, depending on the structural level, for a larger number of deposits to prove a hypothesis about the globality of this pattern. The technique of samples selection for determining microfracturing, which is quite labor intensive, also needs improving.

A search for the methods of determining fractal dimensionality of microfracturing by a photographic image of the face surface is also relevant. The basis of such a study may be formed by the establishment of correction coefficients for different cases of curvature in the samples selection plane.

The analytical dependence for the assessment of productivity of the process of blast-holes drilling, depending on fractal dimensionality of the zone of blast-holes drilling, is obtained for particular conditions at Ltd. "Polissky Labradorite", which makes it relevant to continue the studies into effectiveness of predicting the drilling efficiency with the help of the developed methods for other enterprises. Establishing global relationship between the above presented parameters for a whole group of deposits is becoming increasingly important. The obtained results allow increasing the efficiency of control over technological processes in the course of extracting decorative stones through increasing reliability in the prediction of productivity of the drilling process. The obtained methods will make it possible to improve the performance efficiency of drilling equipment due to the optimization of selecting location for blast-hole drilling taking into account the map of drilling productivity.

As a result of the performed research, we proved high productivity and reliability of predicting the spatial variability of geostructural and technological indices of a deposit using the proposed assessment of fractal dimensionality of the indices.

7. Conclusions

1. To analyze the regularities in the formation of fracturing of decorative stones deposits, a new technique, which is based on the comparison of values of fractal dimensionality of the roses of fracturing, was developed. The application of this methodology allowed us to select a group of labradorite deposits in Ukraine according to regularities of the fracturing formation. In addition, the result of applying this technique together with classic approaches of geostatistical analysis allowed us to obtain a three-dimensional map of spatial variability of fractal dimensionality of labradorite deposits in Ukraine that will make it possible to optimize geological explorations in searching for new deposits, as well as to increase efficiency of establishing the regularities of the fracturing formation for particular mining horizons.

2. The methods for predicting regularities of change in fractal dimensionality at the different structural levels were developed. An existence of correlation between fractal dimensionality at the different structural levels was revealed. The analytical expression of dependence of the value of fractal dimensionality on the order of structural level in the form of a polynomial of the second order was obtained for the gabbro deposit "Luhove".

3. The method for determining the predicting productivity of the blast-holes drilling process, depending on fractal dimensionality of the blast-holes drilling zone, was developed. The implementation of this method allowed us to establish the relationship between fractal dimensionality of the blast-holes drilling zone and productivity of the drilling process and to describe it analytically by empirical dependence for predicting assessment. This method combined with geostatistical analysis allowed creating a method for the assessment of spatial variability of productivity in the blast-holes drilling process. The obtained results were implemented under production conditions to evaluate spatial variability of the drilling performance for the horizon 180 at Ltd. "Polissky Labradorite".

4. The results of the performed research prove high effectiveness of using the fractal analysis apparatus for the process of quality control over non-ore building materials. We proved high efficiency of using, as objective function of the optimal process of controlling technological processes, the function of fracturing orientation, linear dimensions of cracks and speed of drilling the fractured array, which were assessed by generalizing index of fractal dimensionality.

References

1. Sobolevskyi, R. Cluster analysis of fracturing in the deposits of decorative stone for the optimization of the process of quality control of block raw material [Text] / R. Sobolevskyi, N. Zuievska, V. Korobiichuk, O. Tolkach, V. Kotenko // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 5, Issue 3 (83). – P. 21–29. doi: 10.15587/1729-4061.2016.80652
2. Sobolevskyi, R. Using cluster analysis for planning mining operations on the granite quarries [Text] / R. Sobolevskyi, I. Korobiichuk, M. Nowicki, R. Szewczyk // 16 th International Multidisciplinary Scientific GeoConference Science and Technologies in Geology, Exploration and Mining, Book 1. – 2016. – Vol. 2. – P. 263–270.
3. Osipov, I. Issledovanie harakteristik raspredeleniya treschin v obraztsah gornyih porod sposobom lyuminestsentnoy defektoskopii [Text] / I. Osipov // Dobyicha, obrabotka i primenenie prirodnogo kamnya. – 2008. – Vol. 1. – P. 228–232.
4. Latyishev, O. Metodika izucheniya fraktalnyih harakteristik treschinovatosti gornyih porod [Text] / O. Latyishev, V. Syinbulatov, I. Osipov // Dobyicha, obrabotka i primenenie prirodnogo kamnya. – 2008. – Vol. 1. – P. 217–227.
5. Osipov, I. Opredelenie fraktalnyih razmernostey treschin primenitelno k gornyim porodam Severouralskih boksitovyih mestorozhdeniy [Text] / I. Osipov // Izvestiya UGGU. Materialyi Uralskoy gornopromyishlennoy dekadyi, 2008. – P. 109–110.
6. Eremizin, A. Zakonomernosti izmeneniya fraktalnyih harakteristik treschinnoy strukturyi pri nagruzhenii gornyih porod [Text] / A. Eremizin // Izvestiya vuzov. Gornyiy zhurnal. – 2012. – Vol. 2. – P. 155–161.
7. Vallejo, L. Fractal Analysis of the Cracking and Failure of Asphalt Pavements [Text] / L.Vallejo // Geotechnical and Structural Engineering Congress, 2016. – P. 1176–1185. doi: 10.1061/9780784479742.098

8. Sousa, L. Influence of fracture system on the exploitation of building stones: the case of the Mondim de Basto granite (north Portugal) [Text] / L. M. Sousa, A. S. Oliveira, I. M. Alves // Environmental Earth Sciences. – 2016. – Vol. 75, Issue 1. – P. 1–16. doi: 10.1007/s12665-015-4824-6
9. Pershin, G. Enhanced stone production in quarries with complex natural jointing [Text] / G. Pershin, M. Ulyakov // Journal of Mining Science. – 2015. – Vol. 51, Issue 2. – P. 330–334. doi: 10.1134/s1062739115020167
10. Mosch, S. Optimized extraction of dicepеднixion stone blocks [Text] / S. Mosch, D. Nikolayew, O. Ewiak, S. Siegesmund // Environmental Earth Sciences. – 2011. – Vol. 63, Issue 7-8. – P. 1911–1924. doi: 10.1007/s12665-010-0825-7
11. Luodes, H. Evaluation and modeling of natural stone rock quality using ground penetrating radar (GPR) [Text] / H. Luodes, H. Sutinen // Geological Survey of Finland. Special Paper. – 2011. – Vol. 49. – P. 83–90.
12. Kalenchuk, K. Characterizing block geometry in jointed rock masses [Text] / K. Kalenchuk, M. Diederichs, S. McKinnon // International Journal of Rock Mechanics and Mining Sciences. – 2006. – Vol. 43, Issue 8. – P. 1212–1225. doi: 10.1016/j.ijrmms.2006.04.004
13. Repin, A. A. Downhole High-Pressure Air Hammers for Open Pit Mining [Text] / A. A. Repin, B. N. Smolyanisky, S. E. Alekseeev, A. I. Popelyukh, V. V. Timonin, V. N. Karpov // Journal of Minig Science. – 2014. – Vol. 50, Issue 5. – P. 929–937. doi: 10.1134/s1062739114050123
14. Saeidi, O. A stochastic penetration rate model for rotary drilling in surface mines [Text] / O. Saeidi, S. Torabi, M. Ataei, J. Rostami // International Journal of Rock Mechanics and Mining Sciences. – 2014. – Vol. 68. – P. 55–65. doi: 10.1016/j.ijrmms.2014.02.007

Розроблено структуру контролер фікс ції п с жиропотоку гром дського тр нспорту, лгоритм його функціонув ння, специ лізов не прогр мне з безпечення для ре ліз ції функцій контролер т модель н основі мереж Петрі, як д є змогу дослідити дин міку роботи системи. Розроблено т ре лізов но технічне з безпечення контролер н б зі однопл тного комп'ютер Raspberry Pi, що з безпечує низьку ціну проектного рішення т є оптим льним рішенням з широкими функціон льними можливостями

Ключові слов : "Розумне" місто, контролер фікс ції п с жиропотоку гром дського тр нспорту, мережі Петрі, Raspberry Pi

Р зр бот н структур контроллер фикс ции п сс жиропоток общественного тр нспорт , лгоритм его функциониров ния, специ лизиров нное прогр ммное обеспечение для ре лиз ции функций контроллер и модель н основе сетей Петри, котор я д ет возможность исследов ть дин мику р боты системы. Р зр бот но и ре лизов но техническое обеспечение контроллер н б зе однопл тного компьютер Raspberry Pi, что обеспечив ет низкую цену проектного решения и является оптим льным решением с широкими функцион льными возможностями

Ключевые слов : "умный" город, контроллер фикс ции п сс жиропоток общественного тр нспорт , сети Петри, Raspberry Pi

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DEVELOPING A CONTROLLER FOR REGISTERING PASSENGER FLOW OF PUBLIC TRANSPORT FOR THE "SMART" CITY SYSTEM

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1. Introduction

We live in a period of wide scale implementation of computer systems and intelligent technologies in all spheres of human life, one of which is the Smart City system [1–4]. Smart City is a complex system designed to provide up-to-date quality of life of residents through the use of new technologies, which involve economic and ecological use of the urban subsystems of life activity. Accordingly, for the implementation of such a system, "smart" solutions in all its subsystems, in particular in transport, are required [5]. The solutions can be: "smart" management of the transportation