Mining of Mineral Deposits
Volume 18 (2024), Issue 3, 114-125

JOURNAL / MINING.IN.UA

https://doi.org/10.33271/mining18.03.114

Change in the qualitative composition of non-metallic mineral raw materials as a result of blasting operations

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Abstract

Purpose. The research purpose is to study the change in the qualitative composition of granite before and after blasting operations to determine its compliance with the criteria of marketable products.

Methods. X-ray phase and X-ray structural research methods are used to study changes in the mineral composition of granites before and after blasting operations. To separate magnetic and non-magnetic fractions of the selected granite samples, a three-roller RST magnetic separator is used. X-ray phase research is conducted using a DRON-3 diffractometer. Additionally, an analysis of the unit cell dimensions of the quartz crystal lattice was conducted, and the dislocation density along the corresponding crystallographic planes was studied.

Findings. It has been determined that after blasting operations, granite mass is redistributed from coarse fractions of 1-20 mm to small fractions of 0-1 mm with an increase in the latter by 4.2%. It has been found that the biotite content decreases naturally and consistently, and the quartz content increases correspondingly in products in the following series: magnetic separator drum (90%, 2%) → lower roller (72%, 14%) → upper roller (55%, 31%) → non-magnetic product (48%, 34%) before blasting operations. Therefore, despite significant differences in the magnetic favorability of these two mineral phases, they are present in all magnetic separation products (with the exception of quartz in the non-magnetic product): magnetic separator drum → lower roller → upper roller.

Originality. It has been established that along the crystallographic directions 101 and 211, the maximum gradient of dislocation density increase in the quartz crystal lattice in granite samples before blasting operations is observed during the transition from the lower roller product to the upper roller product, amounting to $1.55 \cdot 10^{10}$ and $6.63 \cdot 10^{10}$ cm^{-2}, respectively. After blasting operations, in granite samples along the same directions, the maximum gradient of dislocation density increase is observed between the upper roller product and the non-magnetic product, amounting to $3.01 \cdot 10^{10}$ and $4.67 \cdot 10^{10}$cm^{-2}. As a result of the thermodynamic impact of blasting operations, the weighted average dislocation density value along crystallographic planes 101 and 211 in the quartz crystal lattice increases by 47.21 and 25.72%, respectively.

Practical implications. Understanding the quality characteristics of marketable products after blasting operations will contribute to optimizing the stages of further processing of non-metallic mineral raw materials (two-, three- or four-stage crushing) and expanding the scope of granite applications. This increases its competitiveness in the building materials market by reducing the costs for additional processing with a reduction in the labor intensity of the process.

Keywords: *non-metallic mineral raw materials, granite, magnetic separation, quartz, crystal lattice*

1. Introduction

The development of the mining industry, in particular in the field of mining non-metallic mineral raw materials, is becoming increasingly important. In the context of the war in Ukraine, the armed conflict has had a significant impact on all sectors of the economy, including mining and processing of minerals [1]. However, the mining industry remains one of the key sectors in supporting the country's economic sustainability and reconstruction [2]. Several mining and processing enterprises have been damaged or destroyed as a result of the hostilities, especially in regions where there are active hostilities. This has significantly reduced production volumes and increased the need to modernize and rebuild damaged facilities. One of the consequences of the war is the widespread destruction of buildings, infrastructure and other facilities, which has increased the demand for building materials, stimulating the development of non-metallic mineral mining to meet the needs of restoration and reconstruction of destroyed facilities [3]-[5].

The prospective development of the mining industry plays a key role in providing construction, industrial and infrastructure projects with the necessary materials [6], [7]. Non-metallic minerals, such as limestone, sand, clay, crushed stone, are used in many sectors of the economy, including construction, cement production, glass and ceramic products, as well as

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Received: 14 May 2024. Accepted: 16 September 2024. Available online: 30 September 2024

Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

in the chemical industry [8], [9]. Urbanization, infrastructure development and the implementation of major government projects stimulate the development of this sector, while the introduction of modern technologies in the mining and primary processing of non-metallic raw materials makes it possible to increase production efficiency [10], [11], reduce costs and minimize the negative impact on the environment [12]-[14].

Mining policy determines licensing conditions, taxation, environmental standards and other important aspects that are prerequisites for the development of the building materials industry [15]. The development of the mining industry depends on a number of economic, technological, political, environmental and social factors [16]-[18]. It should be noted that the cost of minerals on world markets has a direct impact on the mining industry profitability [19], [20]. High prices stimulate investment in exploration and mining of new mineral deposits [21], while falling prices can lead to a reduction in production [22]. Important factors are also the lack of investment and the level of tax burden on mining enterprises, which can slow down the development of the industry [23].

Taxation in mining of mineral resources in Ukraine is regulated by the Tax Code of Ukraine (TCU), which determines the procedure for taxation of this industry [24]. This taxation is an important tool for regulating the use of natural resources and aims to ensure that the economic benefits of mineral mining are equitably shared between the state and enterprises.

When analyzing the Tax Code of Ukraine, it should be noted that the object of taxation is the volume of marketable products – mined minerals (mineral raw materials), including those that have passed the stage of primary processing (beneficiation). In this case, primary processing (beneficiation) includes raw materials that have undergone a set of operations of accumulation, crushing or grinding operations, drying, classifying (sorting), briquetting, beneficiation by physical-chemical methods (without qualitative change in the mineral forms of minerals, their aggregate-phase state, crystal-chemical structure). It may also include processing technologies that are special types of mining operations (underground gasification and smelting, chemical and bacterial leaching, dredge and hydraulic mining of placer deposits, hydraulic transport of rocks from the bottom deposits of water bodies) [25]-[28]. Primary processing does not include raw materials beneficiated by a physical-chemical method with a qualitative change in the mineral forms of minerals, their aggregate-phase state, crystal-chemical structure, and products that have undergone ore sintering/lumping operations with heat treatment, sintering and beneficiation by physical-chemical methods [29], [30].

Marketable products are mineral raw materials that can be used or sold after mining, including those that have undergone the initial stages of processing [31]. An important issue to consider is the transportation of raw materials, which plays a critical role in ensuring the efficiency of the supply chain and the overall economic viability of mining operations [32]-[36]. Additionally, geodynamic monitoring is essential for the safe and sustainable development of mining activities [37]-[39]. By employing modern geodetic instruments and repeated observations, geodynamic monitoring helps track subsidence, displacement, and other structural changes in the earth's surface, ensuring that mining does not lead to adverse environmental impacts or compromise the safety of surrounding infrastructure [40]-[43].

Thus, the research purpose is to study the change in the qualitative composition of granite before and after blasting operations in order to determine its compliance with the criteria of marketable products. According to the purpose set, the following interrelated tasks should be solved: characterize the research problem and analyze the mining-geological research objects; determine the granulometric composition of granite samples taken before and after blasting operations; classify the components of the research samples based on their magnetic properties; study the influence of blasting operations on the change in qualitative composition of granite.

2. Study area

The Syniavske granite deposit is situated in the Rokitnyansky District of the Kyiv Oblast, approximately 120 kilometers southwest of Kyiv, Ukraine's capital. The deposit lies on the right bank of the Ros River, a major tributary of the Dnipro River, in close proximity to the northern outskirts of the urban-type settlement of Syniava. The area is under the jurisdiction of the Syniava Village Council, which oversees land use and environmental management in the region. The deposit is part of a geologically rich zone characterized by significant granite formations that have long been of interest for extraction and use in construction. Surrounding the deposit, the landscape is dominated by rolling hills, agricultural lands, and forested areas, with the Ros River contributing to the local hydrology and ecosystem.

The region is accessible via a network of local roads connecting it to nearby towns and villages. Additionally, its proximity to the Ros River makes it an important site for evaluating potential impacts on local water resources and environmental sustainability. The deposit itself is within the Precambrian Ukrainian Shield, known for its vast granite reserves, which have been the focus of various geological studies and mining activities in the past (Fig. 1).

Syniavske granite deposit is mined by ALC Rokytnianskyy Spetskarier. The final product formed as a result of technological mining and processing operations is crushed hard rock. This product is a mixture of quarrystone and crushed stone with a lump size of 0-1000 mm. Due to the absence of a valid DSTU for this type of product, ALC Rokytnianskyy Spetskarier has developed its own TU U08.1-05408680-001:2019. "Amendment No. 1 Crushed hard rock for the production of crushed stone for construction operations. Technical conditions." It states that the physical-mechanical parameters comply with the current DSTU BV.2.7-210:2010, DSTU BV.2.7-241:2010, DSTU BV.2.7-204:2009 and DSTU BV. 2.7-75-98. But in terms of quantitative composition, such a mixture does not correspond to any of the above DSTU in a number of parameters. Therefore, this product should be sent for further processing at a crushing and screening plant into quarrystone and/or crushed stone of different grain-size classes, as well as screening.

In compliance with the Tax Code of Ukraine, ALC Rokytnianskyy Spetskarier conducts primary processing of mineral raw materials to the state of industrial "crushed hard rock" product according to TU U08.1-05408680-001:2019.

From the point of view of the change in the qualitative parameters of the crushed hard rock, namely, the qualitative change in the mineral forms of minerals, their aggregate-phase state, crystal-chemical structure, it is necessary to conduct research with the purpose to determine such changes before and after blasting operations [44]-[49].

Figure 1. Location of Syniavske granite deposit: (a) view of ALC Rokytnianskyy Spetskarier; (b), (c), (d) views of rock

Syniavske granite deposit belongs to the intrusive formations of the Uman Ultrametamorphic Complex. Based on geological observations, as well as mineralogical and petrographic data, taking into account, first of all, the textural and structural characteristics of rocks, undoubtedly reflecting geological and thermodynamic conditions of their formation, four large sequentially formed rock associations have been identified as part of the Uman Complex, each of which, with some convention, can be linked to a certain phase of its formation.

The determining factor for the identification of the products of each of these phases is their belonging to one of the common here petrotypes of granites, between which there are stable relationships. These petrotypes, according to all data, were formed in the following age sequence:

1st phase. Predominantly gray fine- to medium-grained, uniformly grained granites.

2nd phase. Pink-gray and pink medium-coarse-grained implicitly porphyric granites.

3rd phase. Light gray, pinkish-light gray, coarse porphyroblastic granites.

4th phase. Aplite-pegmatoid and pegmatoid granites.

The first phase (Antoniv). The Antoniv phase includes a rock association of granites and biotite migmatites, sometimes with muscovite, uniformly grained.

In many places (near the villages of Olshanytsia, Busheve, Yurpil) undeniable facts have been revealed of active action of the later porphyric granites of the Uman Complex on uniformly grained granites.

The second phase (Bohuslav). This phase, in terms of the spread of the rocks formed, is determinant in the Uman Complex formation. As already noted, this phase includes pink-gray and pink medium-coarse-grained implicitly porphyric and porphyric biotite granites and migmatites, as well as amphibole-biotite migmatites and granodiorites, which are considered to be products of processing of high-basicity plagiogranitoids of the Tethyan Complex by potassic granites of the Uman Complex.

The third phase (Olshanytsia). Granitoids of the Olshanytsia phase are clearly defined visually by the presence of regular tabular porphyroblasts of potassium feldspar up to 3-4·1.2-1.8 cm in size. These rocks do not form separate masses, but form small areas with vague boundaries and smooth mutual transitions among granites of other phases in Uman, Bohuslav and smaller masses.

The fourth phase. Aplite-pegmatoid and pegmatoid granites form veins, veinlets, vein-like and nest-like irregularly shaped bodies, mostly of insignificant thickness (from centimeters to a few meters), which are found in almost all more or less extended outcrops, mapping and structural prospecting wells. Contacts with other Uman Complex granitoids often have the nature of a gradual transition. By penetrating into more ancient rocks, they form bodies with clear contacts: either cross rectilinear or adapted to structural forms. In terms of structural and textural peculiarities, these formations are very different: aplitoid, aplite-pegmatoid, pegmatoid from coarse- to hard-grained, coarse-grained and graphic pegmatites. There are pegmatites with zonal structure with quartz core.

Visually, granites are pink, reddish-pink, pinkish-gray, medium-grained porphyric massive rocks, with different content of hornblende and biotite (from essentially hornblende with insignificant biotite admixtures to almost devoid of amphibole – biotite), similar in composition to rapakivi granites. These granites are characterized by a wide development of graphic aggregate structures, porphyric precipitates of potassium feldspar (up to 1-2 cm), often fringed with plagioclase, and the predominance of ovoids over porphyry precipitates in the composition of rocks. Microcline is mostly lattice and non-lattice perthitic. Plagioclase in the center of grains corresponds to No. 30, at the edges – No. 10, it is often albitized and sericitized. According to chemical analysis data, these are high-alumina, subalkaline rocks of the potassium series with a marked predominance of potassium over sodium. Granites are predominantly medium-grained, implicitly porphyric, with poikilopegmatitic, poikilaplitic, and, less commonly, hypidiomorphic-grained microstructure.

The main rock-forming minerals, which differ macroscopically, are pink-red, less frequently pink-gray, and sometimes milky-white feldspars, smoky-gray quartz and dark-brown biotite flakes. The granite color is predominantly pinkish-red to red.

The rock structure is hypidiomorphic-grained, micropegmatitic, medium-grained; the texture is massive. The main rock-forming minerals are potassium feldspar, plagioclase, quartz, and biotite. Minor and accessory minerals are pyroxene, ilmenite, zircon, epidote, sericite, ore mineral, sphene and hornblende. Secondary minerals are sericite, epidote, chlorite, chlorite-serpentine, iron hydroxides, hydromica, pelitic products of feldspar destruction. The weathering of feldspars is noticeable; iron hydroxides penetrate through fractures into the rock and sometimes color the pelitic destruction products. Feldspars and quartz form mutual aggregates, and larger quartz grains form individuals with angular outlines.

Mineral composition, (%): potassium feldspars – 30-70 (on average – 60-65), plagioclase – 2-30 (2-5), quartz – 20-35 (25-35), biotite – up to 8 (1-2), hornblende – up to 2, ore mineral – up to 1, chlorite – up to 1. Physical-mechanical parameters of the mineral from Syniavske granite deposit are given in Table 1.

Table 1. Physical-mechanical parameters of the mineral from Syniavske granite deposit

Name of quality parameters, units of measurement	Granite quality indicators			
	unchanged		disturbed by weathering	
	from-to	average	from-to	average
Actual density, g/cm^3	2.61-2.74	2.67	2.65-2.73	2.71
Average density, kg/m^3	2.60-2.73	2.68	2.63-2.69	2.64
Water absorption, %	0.09-0.57	0.24	0.31-0.71	0.49
Total porosity, %	0.27-1.73	0.75	0.31-1.88	1.24
Ultimate compressive strength, kgf/cm^2:				
– in an air-dry state	1607	1838	1135-1215	1175
– in a water-saturated state	1100-1881	1488	997-1197	1070
Strength reduction coefficient when saturated with water	0.86-0.97	0.90	0.86-0.93	0.89
After 50 cycles of freezing:				
– ultimate compressive strength, kgf/cm^2:	1044-2077	1620	966-1327	1150
– loss in strength, %	3.5-8.7	6.4	8.3-8.7	7.2
– stone brand		F100		F100
Quarrystone brand by TU 21-10-69-89	1000-1400	1400	800-1200	1000

Potassium feldspars are represented by perthitic grains of orthoclase and lattice microcline. Both potassium feldspar varieties are significantly pelitized and acquire an intense brown coloration in translucent sections.

Plagioclase (oligoclase) is present in smaller quantities than potassium feldspars, and contains a significant amount of fine-flacky sericite in its composition, which allows almost unmistakable diagnosis of plagioclase. In some plagioclase grains, a fine polysynthetic twin structure is observed.

Biotite occurs in leaflet aggregates, characterized by sharp pleochroism from light brown (P Ng) to dark green (P Ng). Its flakes are altered, chloritized, sometimes transformed into chlorite, and sometimes accompanied by fine-flacky hydromica-type formations.

Ilmenite occurs in grains confined to altered biotite. Its color is gray, with a metallic sheen in reflected light, creating separateness bounded by fractures in three directions.

Monoclinic pyroxene is observed as relics of yellowish-green grains immersed into a mass of fine-flacky formations, which obviously belong to serpentine. Zircon occurs as characteristic elongate-prismatic grains up to 0.1 mm long, which gravitate towards clusters of altered biotite aggregates.

Secondary formations are represented by pelitic products of the feldspar destruction, by sericite, chlorite, epidote and iron hydroxides. Among the minor and accessory minerals, apatite, zircon, sphene, and pyroxene are sometimes found.

3. Research methods

To study the change in the mineral composition of granites before and after blasting operations, the authors of the research use the X-ray phase and X-ray structural research methods. The X-ray phase research method, based on X-ray diffraction (XRD), determines the phase composition of the material, that is, the presence and amount of different crystal phases. The X-ray structural research method is also based on X-ray diffraction, but its purpose is to determine the exact atomic structure of crystals.

Before conducting the research, samples were collected at two sampling sites. The first sample was taken at the site of blasting operations. The second sample was taken at the site after crushing the granite by blasting operations. Photo-fixation of samples for research is given in Figure 2.

(a)

(b)

Figure 2. Photo-fixation of the selected samples before (a) and after (b) blasting operations

Once the samples are collected, they are thoroughly dried to constant weight to eliminate any residual moisture that can affect the research results. This process is critical to ensure measurement accuracy, as moisture can distort the physical-chemical characteristics of materials. After drying, the samples are subjected to quartering, which consists in dividing the material into equal parts to reduce its volume without loss of representativeness. Further, the sample averaging is performed to ensure more accurate and more generalized results. Finally, samples are taken from each batch of samples for further granulometric analysis to assess the particle size distribution. This step is important to understand the physical properties of material, in particular its porosity, density, and behavior during further processing.

After this, a subsample is taken from each sample for magnetic separation, which is one of the key steps in preparing materials for subsequent analysis. Magnetic separation allows dividing a sample into fractions based on its magnetic properties. This method is widely used to isolate iron-containing minerals or other components with magnetic activity. During the process, the samples are exposed to a magnetic field of varying intensity to separate the magnetic and non-magnetic fractions. A roller RST magnetic separator is used as a device for magnetic separation (Fig. 3). Separation of the magnetic fraction is an important step for further research such as chemical analysis, determination of mineral composition or preparation for further industrial processing. The study of magnetic and non-magnetic fractions makes it possible to assess the quality of the material and its potential use in technological processes, including metallurgy or other manufacturing industries.

Figure 3. General view of the roller RST electromagnetic separator

The X-ray structural research method includes the analysis of granite samples using a DRON-3 X-ray diffractometer in monochromatized Co-K-α radiation (I = 1.7902 Å). Samples taken before/after blasting operations and subjected to magnetic separation are examined. Therefore, 4 types of samples have been identified by fractions:

1) fraction from the magnetic separator drum;
2) fraction from the lower roller;
3) fraction from the upper roller;
4) non-magnetic fraction.

Identification of mineral compounds (phases) is performed manually by comparing the interplanar distances (d, Å) and relative intensities (I otn-I/I 0) of the experimental curve with the PCPDFWIN electronic file database. All X-ray phase studies are conducted at angles of 10-90°, with a step of 0.1° and a holding period of 5 s.

After conducting an X-ray structural research, the size of the quartz crystal lattice unit cell and the dislocation density along the crystallographic planes 101 and 211 (D_{101} and D_{211}) are calculated for all samples, as well as the dislocation density of the biotite crystal lattice along the 001 and 112 (D_{001} and D_{112}) crystallographic planes.

The sizes of quartz crystallites along crystallographic planes 101 and 211 (L_{101} and L_{211}), as well as the sizes of biotite crystallites along crystallographic planes 001 and 112 (L_{001} and L_{112}) are calculated using the Selyakov-Scherrer formula [50], [51]:

$$L = \frac{K\lambda}{\Delta B\cos\theta}, \tag{1}$$

where:

λ – the radiation wavelength;

K – the Scherrer constant (taken from 0.9 to 1, depending on the shape of crystals);

$\Delta B = \sqrt{B_o^2 - B_e^2}$;

B_o and B_e – the line widths of the sample and the standard, respectively;

θ_{HKL} – the diffraction angle, deg.

The total sizes of crystallites (L) and the degree of microstresses (M) of the quartz and biotite are calculated using two lines that correspond to X-ray reflections from the main crystallographic planes of these minerals (101 and 211 for quartz and 001 and 112 for biotite, respectively) by solving a system of Equations:

$$L = \frac{0.94\lambda}{\Delta B\cos\theta_{HKL}}; \tag{2}$$

$$\frac{\Delta d}{d} = \frac{\Delta a}{a} = \frac{\Delta B}{4tg\theta_{HKL}} = M \quad . \tag{3}$$

Since quartz and biotite monofractions are the most important constituents of the granites from Syniavske granite deposit, a pairwise sequential comparison and analysis of the shape characteristics of the X-ray diffractograms of biotite and quartz along the corresponding crystallographic planes make it possible to assess general and distinctive features in the selected granite samples before and after blasting operations.

4. Results and discussion

According to the conducted research, changes in the grain-size class of samples have been analyzed before and after blasting operations (Table 2).

Table 2. Granulometric analysis of samples before and after blasting operations

Grain-size class, mm	Sample before blasting operations	
	Yield, g	Yield, %
1-20 mm	6803	87.3
0-1 mm	990	12.7
In total	7793	100.0
	Sample after blasting operations	
1-20 mm	5904	83.1
0-1 mm	1196	16.9
In total	7100	100.0

After blast, the number of particles of the 1-20 mm grain-size class decreases by 4.2%, indicating that a part of the material has been crushed under the influence of the explosive force. Accordingly, the number of fine particles has increased by this figure. The blasting operations has resulted in the redistribution of mass from coarse to fine fractions, which is the expected result of such a process.

After conducting research on determining the granulometric composition, the samples are prepared for the next research stage – magnetic separation – separation of the sample components based on their magnetic properties. In order to obtain the minimum necessary and sufficient amount of monomineral phases, the samples are exposed to a magnetic field of varying intensity. This approach allows magnetic minerals, including iron-containing ones, to be isolated from non-magnetic components. As a result of separation, the samples are divided into several fractions, which allows further more accurate analysis of the mineral composition of each of them. This ensures high research accuracy and improves the quality of the data obtained for subsequent X-ray phase and X-ray structural analyses. These samples are divided into four products:

1. Strongly magnetic particles of iron-containing minerals (fraction from the magnetic separator drum).
2. Product consisting of weakly magnetic biotite and plagioclase grains from the upper roller of the magnetic separator.
3. Product consisting of weakly magnetic biotite and plagioclase grains from the lower roller of the magnetic separator.
4. A product consisting predominantly of quartz is a non-magnetic product.

Photo-fixation of samples from Syniavske granite deposit after magnetic separation is given in Figure 4.

***Figure 4.** Photo-fixation of samples from Syniavske granite deposit after magnetic separation*

The magnetic separation of the granite samples resulted in four separate products, each corresponding to a specific level of magnetic induction. Separation of monomineral particles is achieved by using a magnetic field with induction in the separation zone ranging from 0.45 to 1.8-2.0 T. This wide range of magnetic induction allows the separation of different mineral components from the sample, particularly magnetically active phases and weakly magnetic particles.

The separation process provides high selectivity, since at lower induction levels (0.45 T) minerals with low magnetic susceptibility are isolated, while at higher levels (1.8-2.0 T) minerals with high magnetic sensitivity can be isolated. This allows accurate identification and separation of monomineral particles for further research, improving the quality of chemical and mineralogical analysis results. As a result of the conducted research, X-ray diffractograms of total granite samples before and after blasting operations have been constructed, which are given in Table 3.

The analysis of the data presented indicates that the biotite content naturally and consistently decreases, and the quartz content increases in products from the following series: magnetic separator drum → lower roller → upper roller → non-magnetic product. Despite the known significant differences in the magnetic susceptibility of these two mineral phases, they are present in significant quantities in all magnetic separation products (except for quartz in the non-magnetic product). Given the size of individual grains of biotite, quartz and the granulometric composition of the fraction (-0.16 + 0.1), this fact cannot be explained by the effect of the presence of aggregates of these minerals. In turn, this indicates that there is a significant variability in the parameters of their fine crystal structure, which affects their magnetic properties.

After that, based on the X-ray structural research data for all samples, the sizes of the quartz crystal lattice unit cell and the dislocation density along the crystallographic planes 101 and 211 (D_{101} and D_{211}), as well as the dislocation density of the biotite crystal lattice along the 001 and 112 (D_{001} and D_{112}) crystallographic planes, are calculated. The research results of the parameter *a* size of the quartz crystal lattice unit cell for all products are shown in Figure 5.

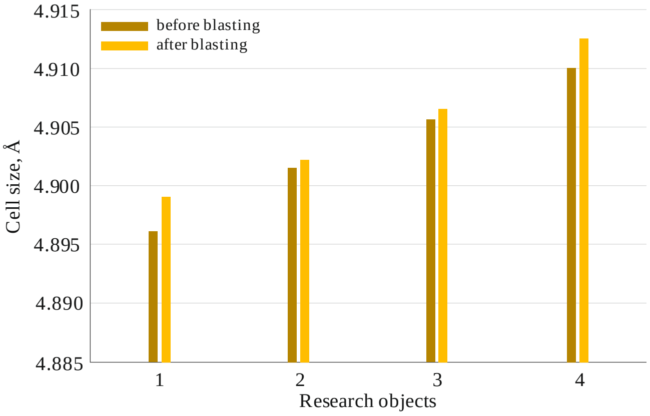
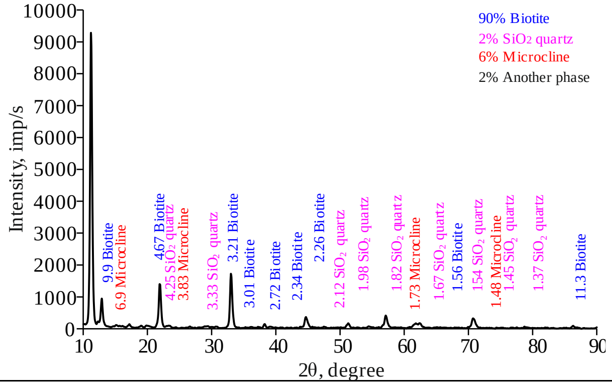
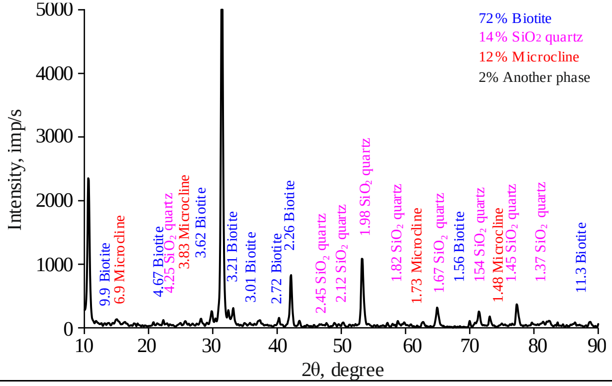
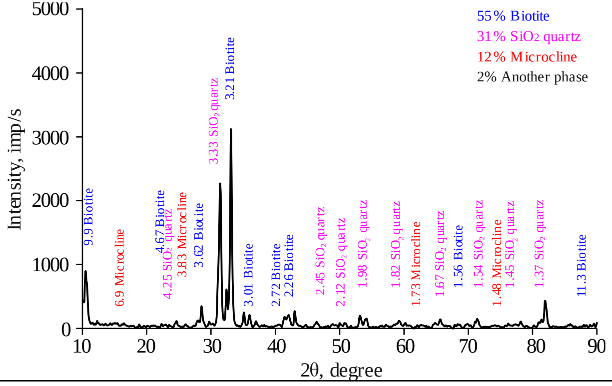
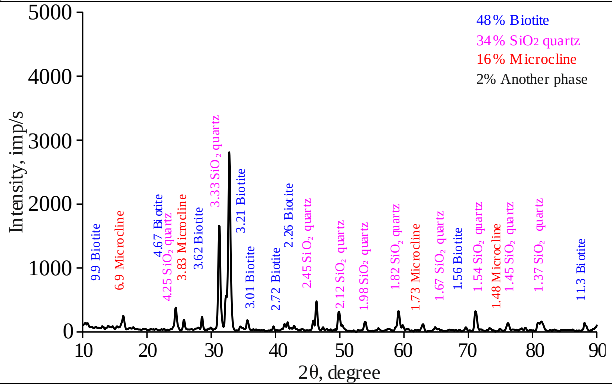
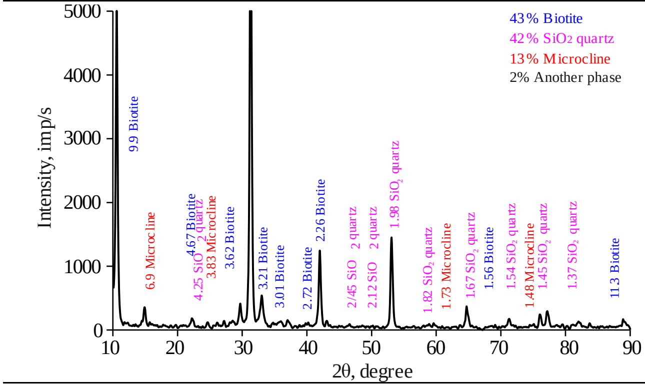
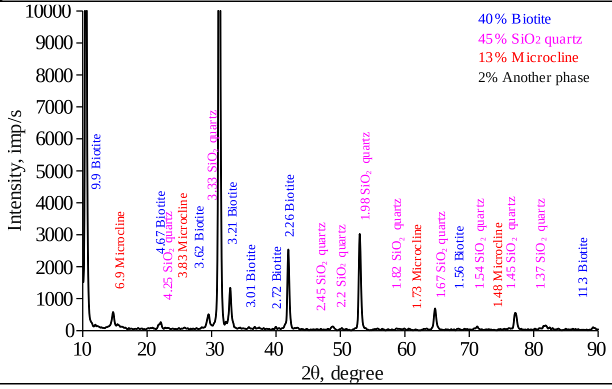
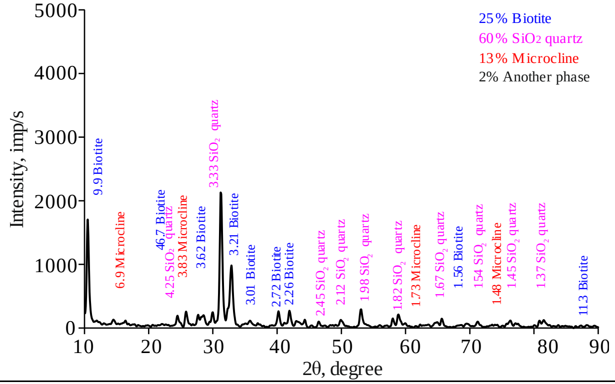
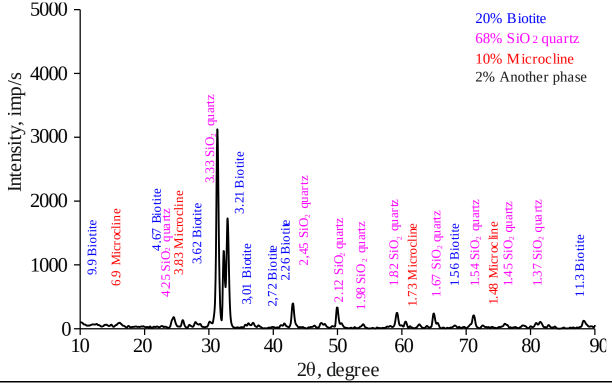


***Figure 5.** Unit cell size according to parameter a of the quartz crystal lattice: 1 – magnetic separator drum product; 2 – lower roller product; 3 – upper roller product; 4 – non-magnetic product*

Figure 5 clearly shows an almost linear increase in the *a* parameter of the quartz crystal lattice unit cell in the series of products: magnetic separator drum → lower roller → upper roller → non-magnetic product, which occurs in granite quartz, both before and after blasting operations. However, a comparison of this parameter values for same-name products shows that in all cases its value is slightly higher in granites after exposure to blasting operations.

The results of research on the parameter *c* size of the quartz crystal lattice unit cell for all products are given in Figure 6. This Figure also clearly shows an almost linear increase in the *C* parameter of the quartz crystal lattice unit cell in the series of products: magnetic separator drum → lower roller → upper roller → non-magnetic product, which occurs in granite quartz, both before and after blasting operations. As in the previous case, a comparison of this parameter values for same-name products shows that in all cases its size is slightly higher in granite quartz after exposure to blasting operations.

Table 3. X-ray diffractograms of granite samples before and after blasting operations

Before blasting operations	After blasting operations
Magnetic separator drum product	
	
Upper roller product	
	
Lower roller product	
	
Non-magnetic product	
	

The conducted research on the unit cell sizes (parameters *a* and *c*) of the quartz crystal lattice from each product of magnetic separation of granites before and after blasting operations resulted in determining the phenomenon of their growth, which occurs under the thermodynamic influence of blasts carried out during the mining of Syniavske granite deposit.

The research results of the quartz crystallite size along crystallographic planes 101 and 211 in all products of magnetic separation of granites sampled from Syniavske deposit before and after blasting operations are shown in Figure 7, respectively.

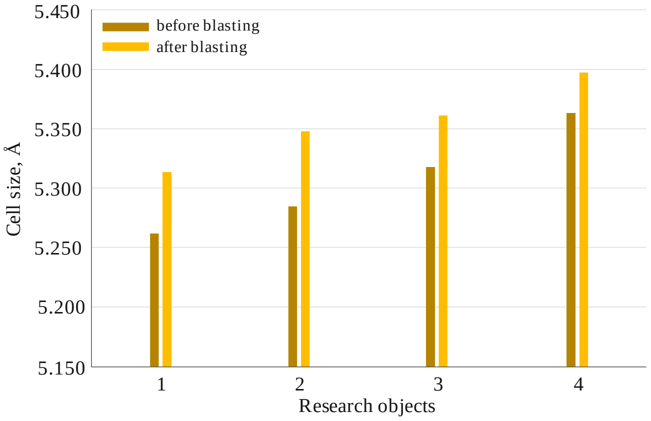


***Figure 6.** Unit cell size according to parameter c of the quartz crystal lattice: 1 – magnetic separator drum product; 2 – lower roller product; 3 – upper roller product; 4 – non-magnetic product*

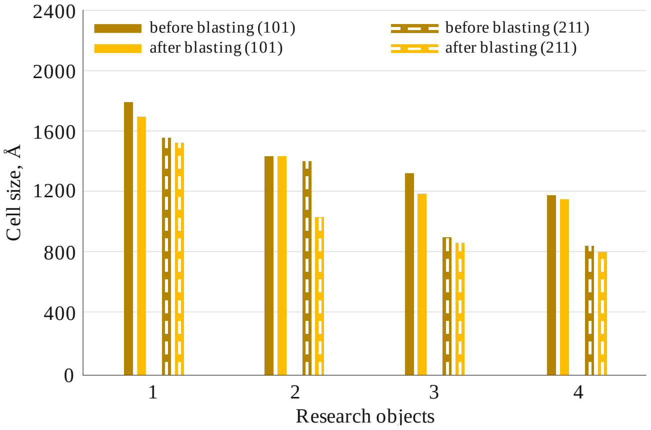


***Figure 7.** Quartz crystallite size along the 101 and 211 crystallographic planes: 1 – magnetic separator drum product; 2 – lower roller product; 3 – upper roller product; 4 – non-magnetic product*

In both cases, a significant decrease is observed for both granites before and after blasting operations in the series: magnetic separator drum → lower roller → upper roller → non-magnetic product, but its dynamics are significantly different.

In the first case, the maximum gradient of crystallite size decrease is observed between quartz from granite samples taken before blasting operations between the magnetic separator drum – lower roller products (351 Å decrease in crystallite size) and between quartz from granite samples after blasting operations between the magnetic separator drum – lower roller products (265 Å decrease in crystallite size). In the second case, the maximum gradient of crystallite size decrease is observed between quartz from granite samples taken before blasting operations, but between the lower roller – the upper roller products (504 Å decrease in crystallite size) and between quartz from granite samples after blasting operations between the magnetic separator drum – lower roller products (491 Å decrease in crystallite size).

Between the sizes of quartz crystallites along both crystallographic planes in the same-name magnetic separation products, their decrease is observed in granites after blasting operations. But this decrease is different, which in turn makes it possible to assert that during the primary processing of granites from Syniavske deposit, namely during blasting operations, the overall anisotropy of the quartz crystal lattice structure increases significantly. This is evidenced by the difference between the sizes of crystallites in different crystallographic planes of granites from samples taken before and after blasting operations in the same magnetic separation products.

The analysis of selected granite samples, using the example of Syniavske deposit, shows that in both cases there is a significant decrease in both granite samples before and after blasting operations in the series: magnetic separator drum → lower roller → upper roller → non-magnetic product, but its dynamics are significantly different.

Between the sizes of quartz crystallites along crystallographic planes 101 and 211 in the same-name magnetic separation products, their decrease is observed in granites after the thermodynamic influence of blasting operations. During the primary processing of granites from the Syniavske deposit, namely during blasting operations, the overall anisotropy of the quartz crystal lattice structure increases significantly.

Figure 8 shows the peculiarities of the change in the total quartz crystallite size for different magnetic separation products of granites from Syniavske deposit before and after blasting operations. The analysis of the presented data of X-ray structural research clearly shows a consistent and natural decrease, which has an almost linear nature in the total sizes of crystallites, as in the magnetic separation products of the series: magnetic separator drum → lower roller → upper roller → non-magnetic product, so between identical products from granite samples taken before blasting operations to granite samples taken already after blasting operations.

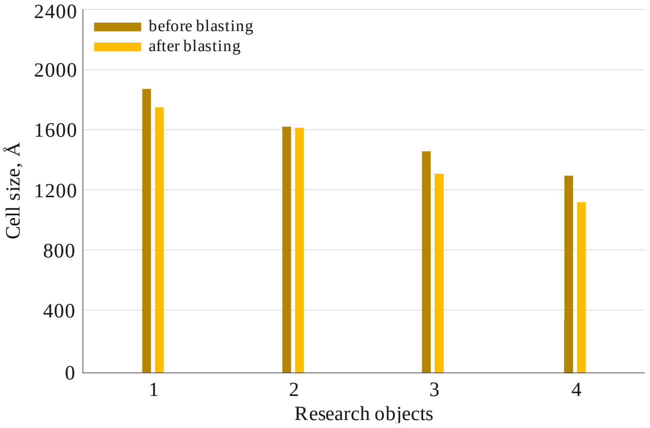


***Figure 8.** Total quartz crystallite size: 1 – magnetic separator drum product; 2 – lower roller product; 3 – upper roller product; 4 – non-magnetic product*

It should be noted that the total quartz crystallite size in different magnetic separation products of granites from Syniavske deposit before and after blasting operations changes. These changes are almost linear in nature and correspond to a decrease in the total quartz crystallite size, on the one hand, between the same-name magnetic separation products from granites before blasting operations to granite samples after blasting operations, and on the other hand, a decrease in this parameter is observed between the products in the series: magnetic separator drum → lower roller → upper roller → non-magnetic product.

Figure 9 shows the results of calculations of existing quartz crystal lattice microstresses for all granite samples from Syniavske deposit before and after blasting operations, as well as the products of their magnetic separation.

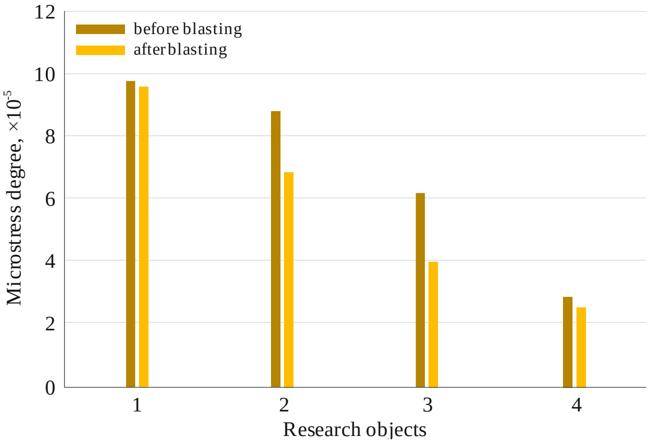


Figure 9. Microstress degree of quartz crystal lattice: 1 – magnetic separator drum product; 2 – lower roller product; 3 – upper roller product; 4 – non-magnetic product

As a result of research, a sharp decrease in this parameter is recorded between magnetic separation products in the series: magnetic separator drum → lower roller → upper roller → non-magnetic product, and somewhat less, but also natural decrease in the quartz crystal lattice microstresses in the direction from granite samples taken before blasting operations to granite samples taken already after blasting operations. In this case, the greatest gradient of reduction of the quartz crystal lattice microstresses in samples taken before blasting operations is observed in the area between magnetic separation products: upper roller – non-magnetic product, while in the samples taken already after blasting operations, it is observed between magnetic separation products: magnetic separator drum – lower roller.

As a result of the research, a decrease in the existing quartz crystal lattice microstresses between the magnetic separation products in the series: magnetic separator drum → lower roller → upper roller → non-magnetic product is recorded, and a natural decrease in the quartz crystal lattice microstresses in the direction from granite samples taken before blasting operations to granite samples taken already after blasting operations.

The results of research on the quartz crystal lattice dislocation density along crystallographic planes 101 and 221 are presented in Figure 10.

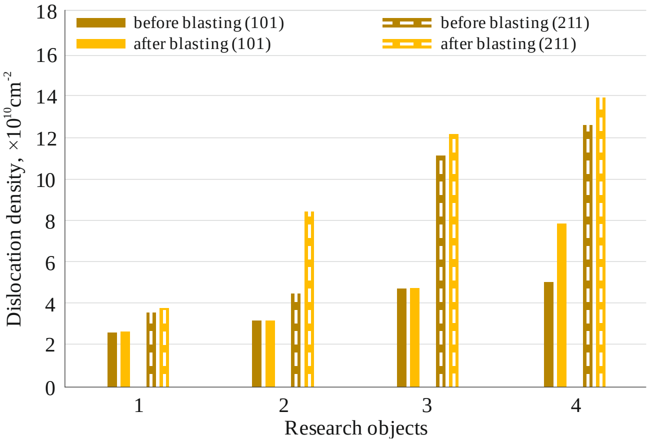


Figure 10. Quartz crystal lattice dislocation density along crystallographic planes 101 and 211: 1 – magnetic separator drum product; 2 – lower roller product; 3 – upper roller product; 4 – non-magnetic product

In both cases, there is an increase in the density of dislocations:

1) between magnetic separation products in the series: magnetic separator drum → lower roller → upper roller → non-magnetic product;

2) in the direction from granite samples taken before blasting operations to granite samples taken already after blasting operations.

Along the crystallographic plane 101, the maximum gradient of quartz crystal lattice dislocation density growth in granite samples taken before blasting operations is noted during the transition from the lower roller product to the upper roller product and is $1.55 \cdot 10^{10}$ cm^{-2}, while in the granite samples taken after blasting operations in the same crystallographic direction, the maximum gradient of dislocation density growth is fixed between the upper roller product and non-magnetic product and is $3.01 \cdot 10^{10}$ cm^{-2}. Given the yield percentages of each of the magnetic separation products, the weighted average dislocation density value along the crystallographic plane 101 in the quartz crystal lattice in granite samples taken before blasting operations is $4.64 \cdot 10^{10}$ cm^{-2}, while in the granite samples taken after blasting operations – $6.84 \cdot 10^{10}$ cm^{-2}. Thus, the weighted average dislocation density value along the crystallographic plane 101 in the quartz crystal lattice increases by 47.41% as a result of the thermodynamic influence of blasting operations.

Along the crystallographic plane 211, the maximum gradient of quartz crystal lattice dislocation density growth in granite samples taken before blasting operations is noted during the transition from the lower roller product to the upper roller product and is $6.63 \cdot 10^{10}$ cm^{-2}, while in the granite samples taken after blasting operations in the same crystallographic direction, the maximum gradient of dislocation density growth is fixed between the magnetic separator drum product and lower roller product and is $4.67 \cdot 10^{10}$ cm^{-2}. Given the yield percentages of each of the magnetic separation products, the weighted average dislocation density value along the crystallographic plane 211 in the quartz crystal lattice in granite samples taken before blasting operations is $10.64 \cdot 10^{10}$ cm^{-2}, while in the granite samples taken after blasting operations – $13.38 \cdot 10^{10}$ cm^{-2}. Thus, the weighted average dislocation density value along the crystallographic plane 211 in the quartz crystal lattice increases by 25.72% as a result of the thermodynamic influence of blasting operations.

5. Conclusions

The conducted research has shown that during blasting operations primary processing of granites is performed that gives an opportunity to classify the obtained material as a marketable product. This means that blasted granite can be used in production without the need for additional processing, which greatly increases its economic value.

Research on quartz crystal lattice dislocation density along crystallographic planes 101 and 211 has revealed a significant increase in this density under the influence of thermodynamic processes caused by blasting operations. In particular, the analysis has shown that the dislocation density gradually increases in a series of magnetic separation products: magnetic separator drum → lower roller → upper roller → non-magnetic product. This indicates that magnetic separation influences the distribution of dislocations in quartz, which is a result of changes in its crystal structure after blast.

Special attention is drawn to the comparison of dislocation density in granite samples taken before and after blasting operations. It has been revealed that the weighted average value of the dislocation density along the crystallographic plane 101 in the quartz crystal lattice after blasting operations increases by 47.21%. Similarly, the weighted average value of the dislocation density along the crystallographic plane 211 increases by 25.72%. This increase indicates the intense thermodynamic impact of blasting operations on the quartz crystal structure, which may have significant consequences for the further use of the obtained products. Changes in dislocation density can affect the physical-mechanical properties of the material, such as strength and ability to be further processed, making this knowledge important for optimizing production processes and increasing the efficiency of using granites as marketable products.

The prospect for further research is the creation of mathematical models to predict changes in the crystal structure and properties of materials depending on the conditions of blasting operations. Such models could provide a basis for optimizing the process of mining non-metallic mineral raw materials to achieve the desired material characteristics.

Author contributions

Conceptualization: PS; Data curation: VI, OC; Formal analysis: OD, OA; Funding acquisition: PS; Investigation: PS, VI; Methodology: OD; Project administration: PS; Resources: OD; Supervision: PS; Validation: OC; Visualization: OA; Writing – original draft: PS, OA; Writing – review & editing: OD, VI, OC. All authors have read and agreed to the published version of the manuscript.

Funding

This study is supported by the National Research Foundation of Ukraine (Project No. 2022.01/0107, “A resource-saving technology development for mining and processing of non-metallic mineral raw materials in the war and post-war periods” for the call “Science for the Recovery of Ukraine in the War and Post-War Periods”).

Acknowledgements

The authors express their gratitude to the editor and the anonymous reviewers for their valuable suggestions and recommendations, which were taken into consideration during the revision.

Conflicts of interests

Author PS declared that he was an editorial board member of the Mining of Mineral Deposit journal at the time of submission. This had no impact on the peer review process and the final decision. The remaining authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Зміна якісного складу нерудної мінеральної сировини в результаті вибухових робіт

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Мета. Дослідження зміни якісного складу граніту до та після проведення вибухових робіт для визначення його відповідності критеріям товарної продукції.

Методика. Для дослідження змін мінерального складу гранітів до та після вибухових робіт використовували методи рентгенофазових і рентгеноструктурних досліджень. Для виділення магнітних та немагнітних фракцій відібраних проб граніту використовували магнітний сепаратор РСТ. Рентгеноструктурні дослідження виконували на дифрактометрі ДРОН-3. Додатково було проведено аналіз розмірів елементарної комірки кристалічної ґратки кварцу, а також вивчено щільність дислокацій по відповідних кристалографічних площинах.

Результати. Визначено, що після проведення вибухових робіт відбувається перерозподіл маси граніту з крупних фракцій 1-20 мм у дрібні 0-1 мм зі збільшенням останніх на 4.2%. Встановлено, що вміст біотиту закономірно й послідовно зменшується, а вміст кварцу, відповідно, зростає у продуктах в ряду: барабан магнітного сепаратора (90%, 2%) → нижній ролик (72%, 14%) → верхній ролик (55%, 31%) → немагнітний продукт (48%, 34%) до вибухових робіт. Тому, незважаючи на суттєві відмінності у магнітній сприятливості цих двох мінеральних фаз, вони присутні у всіх продуктах магнітної сепарації (за винятком кварцу у немагнітному продукті): барабан магнітного сепаратора → нижній ролик → верхній ролик.

Наукова новизна. Встановлено, що по кристалографічних напрямках 101 та 211 максимальний градієнт зростання щільності дислокацій у кристалічній ґратці кварцу в пробах граніту до проведення вибухових робіт спостерігається під час переходу від продукту нижнього ролику до продукту верхнього ролику і становить, відповідно, $1.55 \cdot 10^{10}$ та $6.63 \cdot 10^{10}$ см$^{-2}$. Після вибухових робіт у пробах граніту за тими ж напрямками максимальний градієнт зростання щільності дислокацій відзначається між продуктами верхнього ролику та немагнітного продукту і становить $3.01 \cdot 10^{10}$ та $4.67 \cdot 10^{10}$ см$^{-2}$. У результаті термодинамічного впливу вибухових робіт середнє зважене значення щільності дислокацій по кристалографічних площинах 101 та 211 у кристалічній ґратці кварцу зростає на 47.21 та 25.72% відповідно.

Практична значимість. Розуміння якісних характеристик товарної продукції після ведення вибухових робіт сприятиме оптимізації стадій подальшої переробки нерудної мінеральної сировини (дво-, три- або чотиристадійне дроблення) та розширенню сфер застосування граніту. Це підвищує його конкурентоспроможність на ринку будівельних матеріалів за рахунок зменшення витрат на додаткову переробку зі скороченням трудомісткості процесу.

Ключові слова: *нерудна мінеральна сировина, граніт, магнітна сепарація, кварц, кристалічна гратка*

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