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TECHNOLOGY OF BLOCK STONE EXTRACTION IN COMPLEX STRUCTURED CARBONATE DEPOSITS

It was established that the carbonate deposits of the Russian Platform are mainly semi-consolidated massifs with a complex spatial network of vertical endogenetic cracks and bedding, expressed in the separation of limestone formations into strata and intermediate layers. Together, they determine the block structure of the massif. The geological structure is dominated by deposits (about 85 %) of small-stone blocks from 0.2 to 0.9 m^3 with a 15 %–25 % yield of commercial-grade stone blocks. All this, together with the increased demand for white stone for construction and restoration, places increased demands on the quality of blocks extracted and supplied for stone-working, which cannot be achieved using conventional blasting techniques of pre-excavation of natural massifs.

A promising blast-free technology for extracting limestone and dolomite blocks that improves their quality is proposed. The technology, based on the use of a hydraulic excavator and a bar cutting machine, takes into account, as much as possible, the natural features of the complex structured carbonate deposits. It was established that for the majority of carbonate deposits of the Russian Platform limestone block mining is possible as a "by-product extraction" with the integrated use of all the productive strata of carbonates. To implement this technology, it is proposed to create a mine site for block stone production integrated into the working area of a large quarry which mines the carbonate massif, with the formation of several goods flows of different types of raw materials. Technological solutions for screening block excavation sites from the working area of the main quarry were considered.

Keywords: limestone blocks, jointing, bedding, blast-free technology, hydraulic excavator, bar cutting machine.

Limestone and dolomites of the Russian Platform occupy an important position in the building materials sector. This is primarily due to the long history of their use in the construction of white-stone buildings that first appeared in Vladimir-Suzdal Russia at the turn of 15th-16th centuries [1–5].

Today, white rock is once more in demand. The ecological purity, historical value, and low cost of limestone and dolomite give them an unbeatable advantage compared to marble and granite from domestic and foreign deposits. The use of inexpensive local materials is increasingly attractive not only for the restoration of religious and historical buildings, but also for new construction [6–9].

Carbonate deposits of the Russian Platform are mainly semi-consolidated massifs with a complex spatial network of vertical endogenetic cracks, formed as a result deposit lithification, and bedding, expressed in the separation of limestone formations into layers (strata and intermediate layers). Together, they determine the size of geological structures or block structure of the massif. The geological structure of the Russian Platform deposits is dominated (about 85 %) by small-stone blocks from 0.2 to 0.9 m^3 with a 15–25 % yield of commercial-grade stone blocks.

Therefore, despite the fact that limestone is a widespread mineral within the Russian Platform, manifestations and areas of high-quality limestone blocks are rare natural anomalies. There are only two limestone deposits on the balance sheet which fall into the "Natural decorative stones" category — Korobcheevskoe in Moscow Region and Molokovskoe in Tver Region [10–15].

The main suppliers of white stone are quarries which use conventional blasting techniques for pre-excavation of natural massifs. As a result, stone processing companies receive so-called boulder blocks with explosive-induced micro-jointing and irregular geometric shape. The use of such materials reduces the product yield, worsens its quality characteristics, and, as a result, it makes the limestone stone-working process ineffective.

This confirms that the justification for advanced block stone extraction technologies, taking into account as much as possible the natural characteristics of the carbonate massifs, is a very relevant task.

To assess the possibility of creating specialized areas (quarries) for the extraction of block stone, the economic stripping ratio is proposed as a criterion [16]:

$$K_b = \frac{C_p - C_o}{C_s}, \tag{1}$$

where C_p is the cost of mineral deposit production by underground mining;

C_o is the cost of mineral deposit production by open-pit mining;

C_s is the total cost for 1 m^3 (1 t) of stripping work.

The calculation scheme K_{pr} for exposed reserves of productive strata and the presence of residual quarry workings is given in Fig. 1.

It should be mentioned that we are not talking about placing a border zone between open-cut and underground mining, it is only about the ratio of the overburden formation to productive strata at which open-cut mining becomes efficient.

Considering K_b as an output function of (ρ) product from 1 m^3 of commercial-grade blocks and the output of blocks from massif (b), as well as the value of this type of basic material (M_ρ), after some simple mathematical transformations, we obtain the following:

$$K_b = \frac{\left(\dfrac{M_\rho}{f_\rho} - C_\rho\right)\cdot\rho - C_{m_\rho} - \dfrac{C_m}{b}\cdot f_g}{C_s \cdot f_g}. \tag{2}$$

From here we can determine the ultimate capacity of formations of exposed carbonate rocks lying over the productive strata:

$$H_s^{pr} = \frac{\left(\dfrac{M_\rho}{f_\rho} - C_\rho\right)\cdot\rho - \dfrac{C_m}{b}\cdot f_g}{C_s \cdot f_g \cdot H_c}, \tag{3}$$

where H_c is the productive layer thickness, m;

C_{m_ρ} is the cost of delivery of block stone to the stone-processing company, RUB/m^3;

C_ρ is the cost of cutting out 1 m^2 of product from the stone block, RUB/m^2;

ρ is the commercial-grade product output from the "raw" stone block, m^2/m^3;

M_ρ is the market price of the finished product made from natural stone, RUB/m^2;

b is the output of commercial-grade stone block from the massif;

C_s is the total development cost per 1 m^3 of overburden rock, RUB/m^3;

f_g is the quarry profitability ratio;

C_m is the cost of excavating 1 m^3 of stone block, RUB/m^3;

f_ρ is the profitability ratio of the stone processing company.

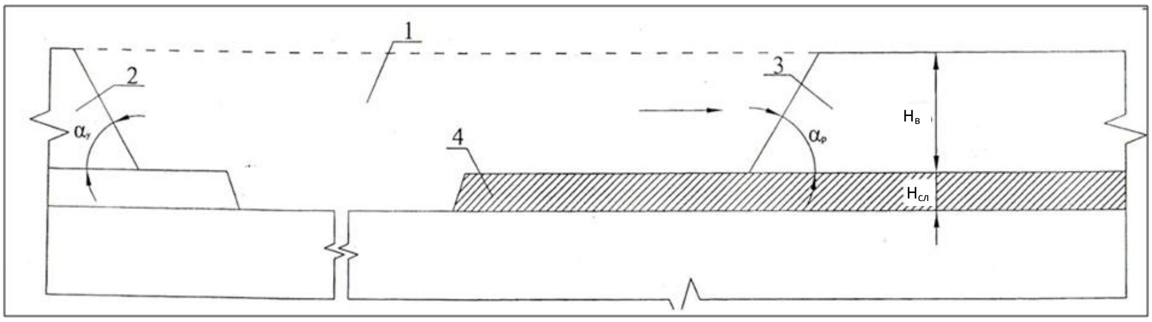

Fig. 1. The calculation scheme for the maximum stripping ratio under the conditions of exposed reserves of productive strata and the presence of residual quarry workings:
1 – exposed quarry space; *2* – fixed border; *3* – stripping bench; *4* – productive layer.

The main variables that affect H_s^{pr} are the output of slab (20-mm thick) from 1 m^3 (ρ), market price of the product (M_ρ), and output of blocks from the productive layer (b).

For limestones and dolomites of the Russian platform, the abovefigures vary in the following ranges: $\rho = 7...23$ m^2/m^3; $M_\rho = 44\ldots57$ c.u./m^2; $b = 0,1...0,5$.

For these variables, the calculated value of H_s^{pr} ranges from 3 to 7 m. With the average capacity of the productive stratum of 0.5 ... 0.6 m, this corresponds to an economic stripping ratio of 6 to 14 m^3/m^3.

If the actual thickness of stripped rocks lying over the productive stratum is higher than the value calculated by the formula (3), stone block can be extracted using by-product excavation where the overlying formation of carbonate is not taken out to the dump, but processed to obtain various kinds of commercial-grade products (gravel, slaked lime, crushed stone, cement raw materials, calcareous stone for the glass industry, lime flour, etc.). The profitability of processing host rock can be low. At this point it is important to decrease the C_s value.

Once again, it should be noted that the obtained H_s^{pr} values that determine the area and the possibility of creating independent sites (quarries) are valid when exposed geologic outcrops are present which were formed by quarries previously excavated in order to develop this deposit. When it comes to new deposits, initial capital costs associated with their development are an additional factor that seriously complicates the creation of an independent quarry in the deposit.

Analysis of the geological occurrence mode of productive limestone strata in the deposits of the Russian Platform allows us to conclude that limestone block development is only possible for the vast majority of carbonate deposits using "by-product excavation" with the integrated use of all productive strata of carbonates.

This allows us to formulate the following basic principles of block stone excavation for most carbonate deposits of the Russian Platform:

– the block stone mining site should be integrated into the working area of a large quarry, concentrated on carbonate massif, with multiple flows formed of different types of raw materials;

– nonconditioned blocks (up to 90% of extracted volume) from the block stone mining site should be efficiently processed into other types of products;

– rocks, enclosing productive strata of limestone, on a dedicated block limestone mining site should be developed using the blast-free method, and the site itself must be shielded from the main working area of the quarry.

When designing blast-free technology for block limestone and dolomite extraction, the natural characteristics of carbonate deposits of the Russian Platform (developed system of endogenetic cracks, stratification, small capacity of the productive strata) should be used as much as possible.

By virtue of these characteristics, as well as due to the fact that the productive horizons are located on the middle and lower hypsometric levels of the developed natural massif, it is highly unadvisable to use diamond-cutting rope [17–19]. Moreover, the majority of quarries use dependent development systems with a fixed sequence of stripping, mining and development operations. In addition, long-term reserves available for stripping are limited.

The geological structure of carbonate deposits of the Russian Platform are best suited for block limestone development technology based on the use of hydraulic excavator and bar cutting machines [20–21].

A process flow diagram of open mining is shown in Fig. 2.

Stripped loose soil and rocks are mined by excavators from the main quarry.

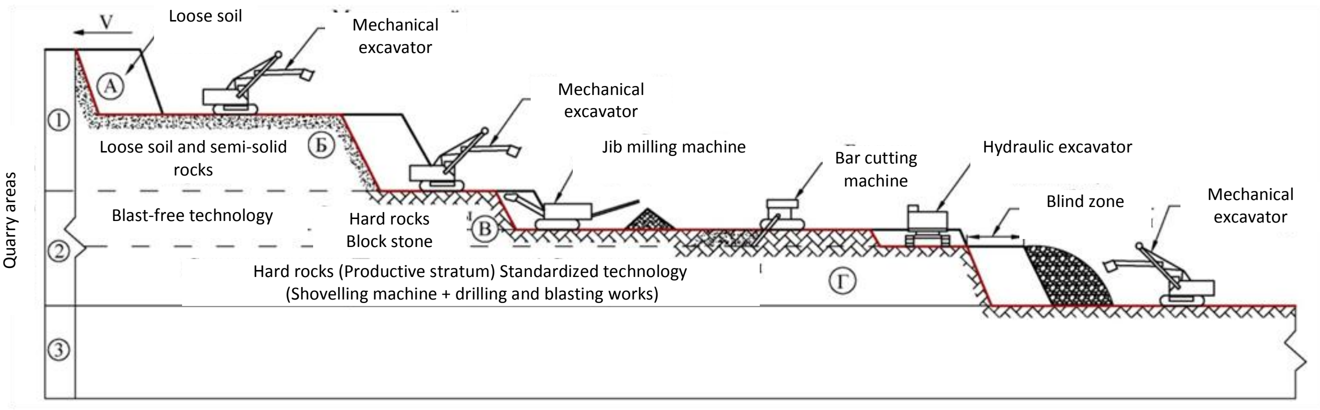

Fig. 2. Process flow diagram of the site allocated to process limestone into blockstone within complex mining of the deposit.

Fig. 3. Bar cuts in the Myachkovskiy stratum of limestone (Afanasyevsky quarry).

Because productive strata must be mined using the blast-free method to preserve their integrity, it is proposed to mine these strata using jib milling machines. Jib milling machines, but not auger milling machines [22] or machines with rotary wheels, should be used when mining rocks on the carbonate deposits of the Russian Platform due to the fact that jib machines do not require a large working face, which is very important for CSM-class machines.

Bar cutting machines produce vertical cuts to a depth equal to the thickness of the stratum. The bar cutter should function in such a way that the cuts are located perpendicular to the direction of the strike of endogenetic cracks (Fig. 3).

This allows rectangular blocks to be made and increases their output. The distance between the bar cuts should result in block sizes that can be loaded onto trucks. When the bar cutter works, cutting and chain vibration lead to weakening of the links between geological structures and emergence of anthropogenic weakness planes, which in turn leads to diminished effort of hydraulic excavator, thereby increasing its performance.

While using the bar cutters to prepare productive strata for extraction, it is important to perform geometrization of the massif, which makes it possible to determine the direction of the strike of the main endogenetic cracks that divide productive stratum into separate geological structures [23, 24]. The bar cutter makes it possible to cut taking into account the regularities of changes in the frequency and direction of endogenetic cracks, thereby increasing the chances that "actual" blocks will be formed.

Cracks in carbonate massifs of the Russian Platform form a complex three-dimensional network (Fig. 4). They arise due to a reduction in the volume of rocks during sediment diagenesis. These cracks are called endogenetic or primary cracks of desiccation or jointing. Such cracks are perpendicular to the stratification and form several systems that, together with stratification, predetermine the separation of the massif into geological structures with certain dimensions (Fig. 5).

Endogenetic cracks do not extend beyond the boundaries of the stratum. They are confined to the stratification planes.

The next process step is the breakdown of productive stratum into geological structures using three systems of weakening planes, namely, along the contours of stratification, vertical endogenetic cracks, and technological planes of weakening. The load should be applied to the individual geological structures from the bottom to the top (from the contact lying on the bottom lamination plane to the top of the productive stratum). Implementation of such an excavation process scheme is most suitable in terms of kinematic and power parameters for the use of front hydraulic shovels with breakout force of 17 … 27 t·H [25, 26].

The massif is excavated by the front hydraulic shovel by embedding the bucket into the cracks between the separate geological structures (along surface of the plane) and by breaking the blocks. The excavator operator sees the face, chooses the place of weakening, and breaks down the massif. For a backhoe excavator, the operator does not see the surface of the face and contact areas of rocks between different formations.

The experience of breaking carbonate rock into separate geological structures shows that the mechanical strength of the separate structures (it can even reach 110 ... 150 MPa) has little effect on the breaking efficiency. The most important factor here is the cohesion force between the extracted block and the underlying formation, and the separating forces occurring along the natural cracks that form contours of geological separate structures (blocks). The digging force for such rocks should be very high, since loading productivity is of secondary importance.

One of the major components of the proposed block stone extraction technology is shielding block extraction sites from the quarry's working area where mining operations are performed using standard blasting methods of massif pre-mining. Screening should be carried out along the three profile lines (Fig. 6). Two of them – AB and CD – cut off the block stone extraction site (F) from the working area at a height of the entire zone of rocks. The lower profile line AC AC cuts off section F from the group of lower quarry horizons.

An alternative option may be considered when, instead of shielding along $BACD$ contour, a section is temporarily preserved from mining operations (Fig. 6). However, this option may not be regarded as economically advantageous, because it assumes preservation of mining operations in the 40 ... 50 m band, which increases capital and operating expenditures incurred for creating a specialized area for block stone extraction. However, it can be used when the quarry has reserves that allow, without damaging the primary production, land stretching 250 ... 300 meters to be allocated on the flanks or in the center of the working area for blast-free block stone extraction.

The most effective method of shielding the block extraction sites in the carbonate massifs is presplitting. To be used as a means of shielding, the basic parameters of blasting works should be justified: well diameter, distance between the drill (blast) holes, alignment of the contour blast hole lines, charge design in the hole.

The application of the proposed technological solutions for mining limestone blocks in Afanasyevsky field in Moscow region and Maleevskoe field in Ryazan region showed their high efficiency.

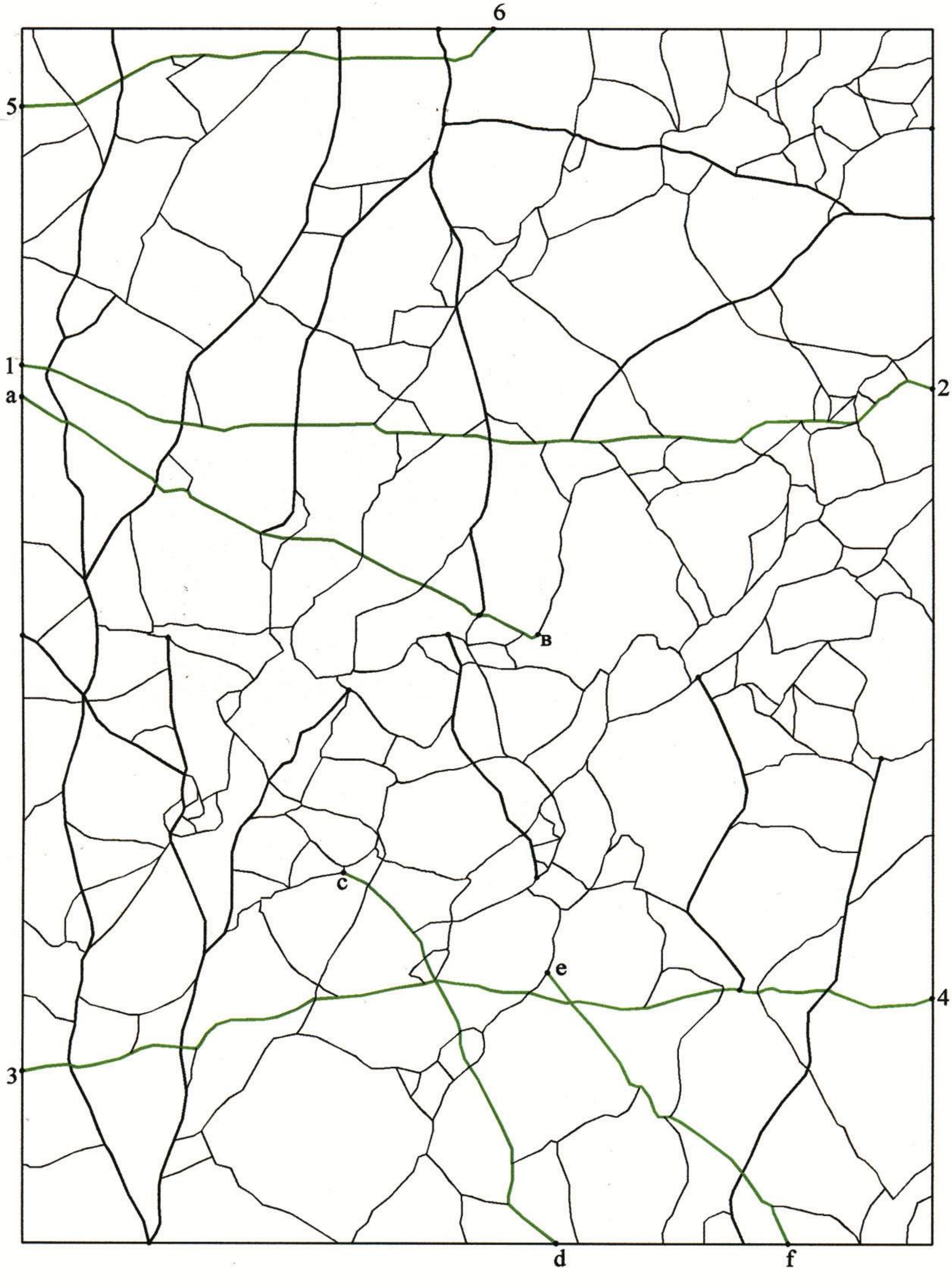

Fig. 4. Propagation pattern of endogenetic vertical cracks (cut along the top of carbonate massif stratum):
1–2, *3–4*, *5–6* – primary system cracks;
a–b, *c–d*, *e–f* – secondary system cracks.

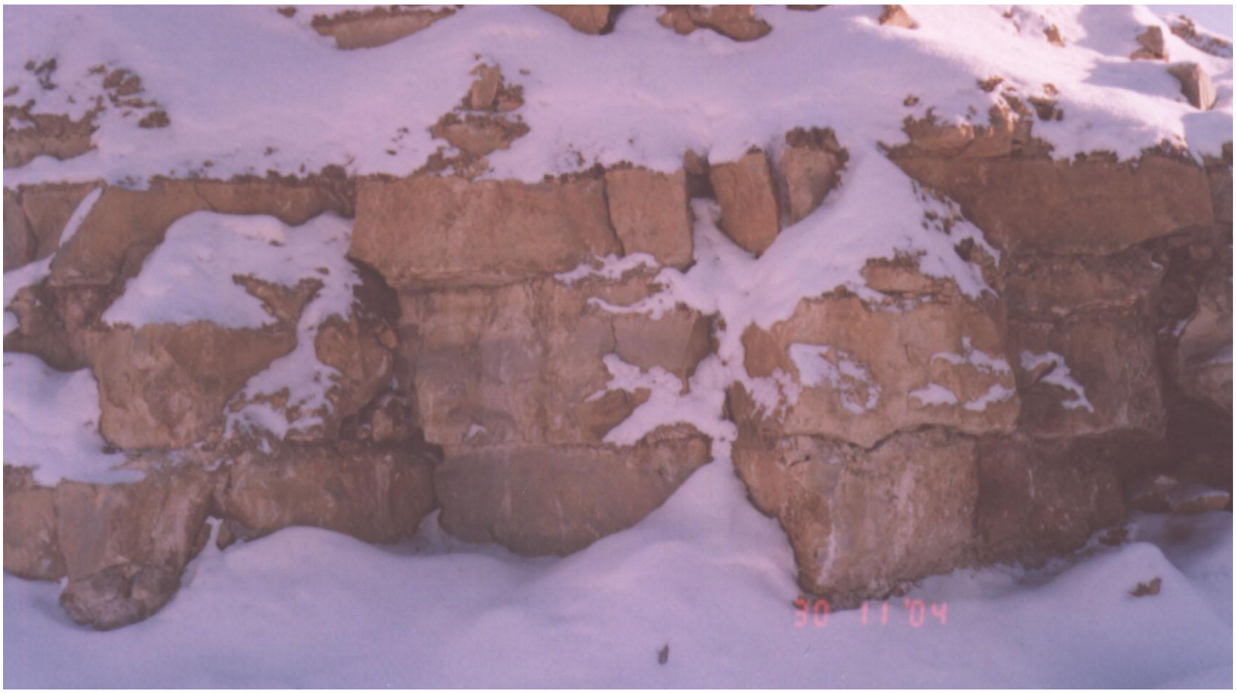

Fig. 5. Productive strata broken by vertical endogenetic cracks into separate geological structures.

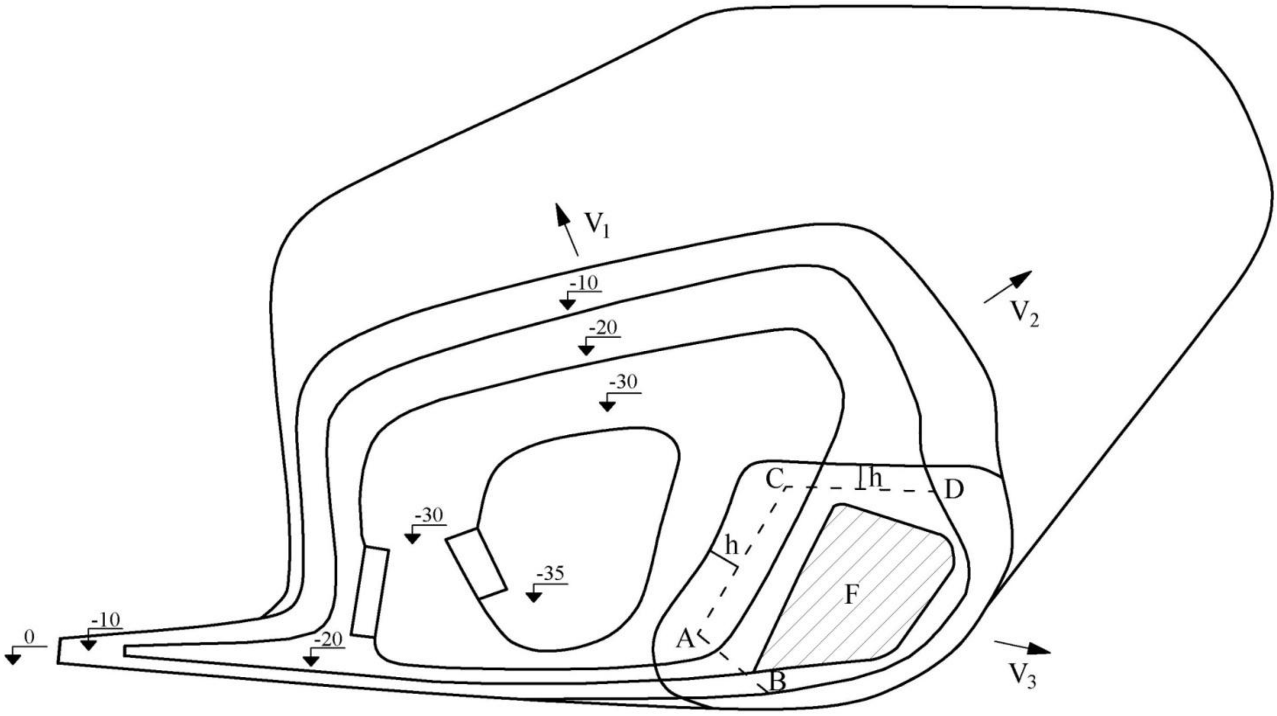

Fig. 6. Shielding pattern for the block stone extraction site from the working area of quarry.

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"Gornye nauki i tehnologii"/ "Mining science and technology", 2016, No. 2, pp. 3-10

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DOI:	**http://dx.doi.org/10.17073/2500-0632-2016-2-3-13**
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