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Technology of Blasting of Strong Valuable Ores with Ring Borehole Pattern

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The ores of non-ferrous and precious metals, represented by hard rocks, has a peculiar feature, that is the effect of segregation, that is the tendency of ore minerals to break down into small size classes, which in the underground mining method accumulate in significant quantities on uneven surface of bottom layers and subsequently are lost. When mining valuable non-metallic materials, there is an acute problem of overgrinding, when fines do not meet the requirements for the quality of the final product. It is well known that the granulometric composition of the ore depends mainly on the technology and parameters of drilling and blasting operations. In underground mining of ore deposits, the main method of drilling and blasting is the borehole blasting with continuous construction charges with the ring pattern. The main drawbacks of the method are: uneven distribution of the explosive along the plane of the broken layer and the expenditure of a significant part of the blast energy of the charges of the continuous structure on the blasting effect, necessarily associated with over-grinding the ore. To solve these problems, the authors proposed a blasting technology, the essence of which lies in the fact that the uniform distribution of the energy concentration of explosives in the broken layer is ensured by the dispersion of charges by air gaps and a certain order of their placement in the ring plane. For the practical implementation of the technology, a method has been developed to form dispersed charges in deep boreholes that do not require a significant increase in labor costs and additional special means. A special technique has been created that allows defining the dispersion parameters, ensuring the sustained specific consumption of explosives over the entire plane of the broken layer. Experimental studies of the proposed technology in the natural conditions of an underground mine for the extraction of valuable granulated quartz were carried out. As a result, the possibility of a significant reduction in the specific consumption of explosives (by 42 %) has been established. At the same time, the yield of the commercial product increased by 10.7 % in total, and the yield of the fraction most favorable for further processing increased by 33.7 %.

Key words: segregation; explosive blasting; crushing; dispersed charge; ring pattern; air gap; specific consumption of explosives

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Topicality and objectives of the research. The ores of non-ferrous and precious metals, represented by hard rocks, has a peculiar feature, that is the effect of segregation – the tendency of ore minerals to accumulate in small size classes during crushing [5]. In underground mining such as «enriched» ore fines accumulate in significant quantities on the uneven surface of the bottom layer. This type of loss of a valuable component can be reduced by cleaning-up of the bottom layer with hydraulic monitors, vacuum units, remotely controlled machines, etc. [6, 7]. However, with the unmanned development systems in the open stoping zone (chamber, a chamber with backfilling, with ore shrinkage), these methods of clearing are not effective and safe. For example, the tried and tested clearing methods using the water stream energy during the mining of inclined deposits of high-value ores (Mirgalimsai, Berezovsky, etc.) did not produce the expected effect, and in permafrost conditions, they are simply unacceptable. In systems with ore and host rocks caving, the loss of ore fines on the bottom layer becomes irretrievable. Also, when extracting valuable non-metallic materials, such as quartz [14, 17, 20], often there are quite strict requirements for the particle size distribution to limit the output of the fine fraction [19].

It is well known that the granulometric composition of the ore depends mainly on the technology and parameters of the drilling and blasting operations. In underground mining of ore deposits, the main method of drilling and blasting is the borehole blasting with continuous construction charges and ring pattern location.

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Thus, reducing the yield of small fractions of ore and non-metallic raw materials during its blasting, taking into account the ring arrangement of charges, is an urgent scientific and technical problem.

Previous studies. A characteristic feature of the ring pattern is the uneven distribution of the explosive along the plane of the ring [11]. To ensure the complete separation of the broken layer from the rock mass and to reduce the output of oversize, we calculate the borehole location parameters and explosive consumption in the end zones (bottoms) of the boreholes. In the rest of the ring, due to the spacing of boreholes from the bottom to the surface, the specific consumption of explosives turns out to be overestimated [3]. The main way to control the specific consumption of explosives in rings is various schemes of undercharging of boreholes.

At the same time, continuous borehole charges are not sufficiently effective from the beneficial use of the energy of an explosion [2, 18]. It is known that charge dispersion reduces the initial explosion pressure per unit surface of the borehole walls, extending the impact time of the explosion on the fractured rock, reduces the blasting effect of the explosion, causing overmixing of the material in the near zone, and contributes to the more uniform crushing of the rock. It is important to note that rational design is the charge, which is divided by the air gap, and not by the diving or any other inert material [16].

Therefore, it is possible to improve the quality of crushing when the boreholes are positioned by evenly distributing explosives along the plane of the broken layer and using a dispersed charge design.

In the practice of blasting, the formation of dispersed charges is carried out in various ways (filling the gaps with materials and objects of various shapes, densities and particle size distribution; placing explosives in separate containers separated by bulk materials, by hanging and special spacers; using the packaged explosives smaller than borehole diameter in flooded conditions, etc.) [1, 4, 10, 13, 15, 21], developed primarily for open-pit mining, packaged and emulsified explosives, manual loading or placement of explosives in the borehole under its own weight. In underground conditions, the possible area of their use is limited to loading downhole boreholes with increased diameter. With the most commonly used pattern of boreholes in the form of an ascending ring and their considerable length, these methods are inapplicable or difficult to implement.

Analysis of the theory and experience of the use of dispersed charges allowed us to establish the direction of research. The constraint in space and a certain limitation of the loading time, characteristic of the ring method of breaking, determined the need to develop such a design of explosive charges with air gaps, which does not require significant additional labor costs and special means. To determine the parameters of the dispersed charges, it is necessary to create a calculation method that takes into account the ring pattern.

Development of blasting method. The essence of the developed blasting method lies in the fact that with the ring pattern, the uniform distribution of the energy concentration of explosives in the broken layer is ensured due to the dispersion of charges by air gaps and a certain order of their placement in the plane of the boreholes. At the same time, the placement parameters and the specific consumption of explosives necessary for the complete separation of the rock from the mass and for obtaining the required quality of ore crushing are calculated for the bottom hole zone. As the boreholes thicken, the consumption of explosives decreases due to air inter-spaces, remaining approximately the same for different areas of the broken layer.

For the conditions of the Kyshtym underground mine, a method of forming an air gap in a borehole with mechanized loading was developed and practically tested. As a means of dispersal, it was proposed to use a traditional stemming material – clay or sand-clay mixture. Ammonite 6ZhV cartridge with a detonating cord was placed at the bottom of the borehole. The pneumatic charger supplied the first charge of granular explosives of the required length. The charging hose was removed from the borehole. With the same hose, a moist clay plug 25-40 cm long (depending on the

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diameter of the hole) was inserted into the borehole at a distance ensuring the formation of a given air gap (Fig.1, *a*). The control of the distance between the explosive charge and the plug was carried out by marking the charging hose. With light strokes of the hose, the plug was wedged and pressed in the borehole (Fig.1, *b*). Then the next portion of explosives was loaded (Fig.1, *c*). The loading experience showed that a clay plug pressed in this way withstands the pressure of the supplied explosive portion and reliably ensures the specified air gap. During the charging process, the grammonite charges are compacted and securely held in the borehole, without leaking in the downstream air gap and at the borehole. In general, this method of loading is simple (the complexity is comparable to the formation of a continuous charge in the borehole) and does not require additional special tools. This design has shown its reliability in boreholes with a diameter of 65 and 105 mm.

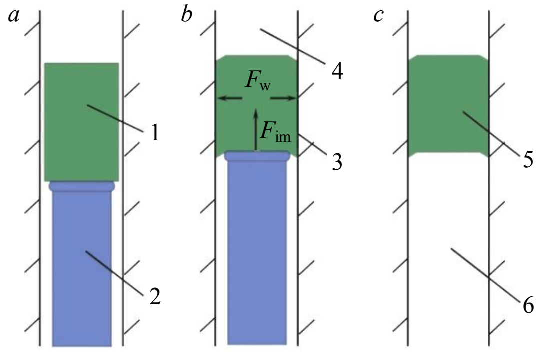

Fig.1. The process of forming the air gap in the borehole

1 – wet clay plug; 2 – charging hose; 3 – deformed clay plug; 4 – formed air gap; 5 – wedged clay plug; 6 – granulated explosive charge; F_{im}, F_w – forces of impact and wedge respectively

Method of calculating the parameters of dispersed charges. For calculating the parameters of dispersed charges, the borehole is presented in idealized form as a sector of a circle with a center in the drilling space (*O*) with a radius equal to the length of the boreholes (*L*) and a span angle (α) between the extreme boreholes of the ring. Such a scheme is valid in the case of approximately the same length of all boreholes. For rings, where the length of the holes varies considerably, the necessary number of groups of neighboring boreholes with similar lengths in the form of similar sectors should be distinguished. In general, the proposed calculation scheme is applicable both for the ring as a whole and for its sectors. The principal design diagram is shown in Fig.2.

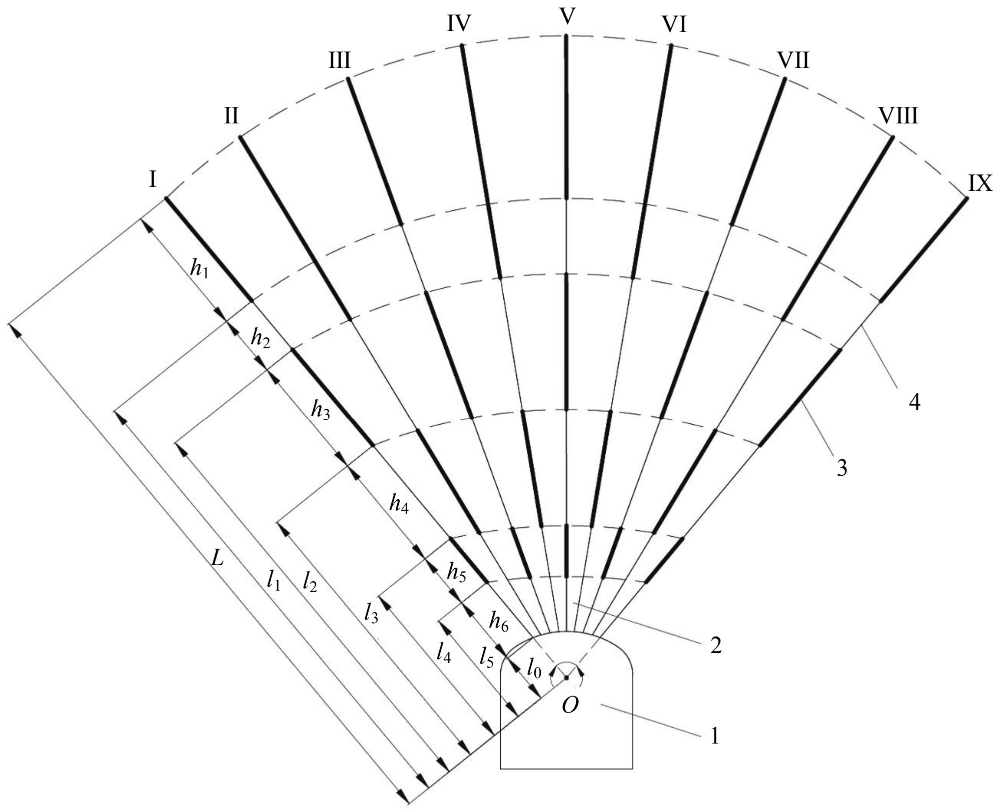

Fig.2. The principal design scheme of loading of the ascending ring of charges dispersed by air gaps

1 – drilling space; 2 – uncharged part of the ring; 3 – charge; 4 – air gap

The calculation method is based on the following principles. The plane of the ring is divided into arcuate zones – the explosive charges in the hole alternate with air gaps. In adjacent holes of the ring, the charges and intervals are staggered. The length of the charges and the gaps are taken to be equal to the height of the arcuate zone (h_i) in which they are located. An exception is made to the zone at the bottom of the holes, in which all holes are charged. The zone adjacent to the wellheads (the cover above the drilling output) is not charged. Thus, the task is reduced to determining the heights of the arcuate zones h_i depending on the parameters of drilling and blasting (burden of charge, burden-to-spacing ratio, specific consumption of explosives) calculated according to generally accepted methods or established during experimental explosions [12].

The height of the arcuate zones in generally is determined by the formula

$$h_i = l_{iu} - l_{il}\,, \tag{1}$$

where l_{iu} – length from the center of the ring to the upper border of the i-th arcuate zone, m; l_{il} – length from the ring center to the lower border of the i-th arcuate zone, m; i = 1...m – number of arcuate zones in a ring, items.

The height of the first arcuate zone (in meters) at the bottom of the holes, within which it is necessary to charge all the boreholes, is calculated as follows:

$$h_1 = L - l_1\,, \tag{2}$$

where L – length from the center of the ring (axis of the drilling rig) to the bottom of the borehole, m; l_1 – undercharging length in the formation of explosive charge of the first arcuate zone, m.

The length is determined by the formula

$$l_1 = \frac{90 n_{\text{bhl}} d^2 \rho_{\text{char}}}{W \alpha q_{\text{expl}}} - L\,, \tag{3}$$

where n_{bhl} – number of boreholes in a ring, items; d – borehole diameter, m; ρ_{char} – charging density, kg/m^3; W – burden, m; α – angle between the extreme boreholes of a ring fan, degree; q_{expl} – specific consumption of explosives for blasting, kg/m^3.

The height of the second from the bottom holes of the arcuate zone is calculated by the formula

$$h_2 = l_1 - l_2\,, \tag{4}$$

$$l_2 = \frac{90 n_{\text{bhl}}^{\text{evn}} d^2 \rho_{\text{char}}}{W \alpha q_{\text{expl}}} - l_1\,, \tag{5}$$

where $n_{\text{bhl}}^{\text{evn}}$ – the number of even boreholes in the ring, items.

In the general case, for subsequent even zones, calculations are made by analogy with (4) and (5). In this example, these are the values h_4 and l_4.

The height of the third zone is

$$h_3 = l_2 - l_3\,, \tag{6}$$

$$l_3 = \frac{90 n_{\text{bhl}}^{\text{unevn}} d^2 \rho_{\text{char}}}{W \alpha q_{\text{expl}}} - l_2\,, \tag{7}$$

where $n_{\text{bhl}}^{\text{unevn}}$ – the number of uneven boreholes in the ring, items.

By analogy with formulas (6) and (7), calculations are made for uneven zones, except for the last charged (h_5).

The heights of the last charged (h_5) and fully non-charging zone (h_6) are calculated in the same way. For the calculation, we assume that taking into account undercharging, the specific consumption of explosives is taken to the total volume of these two zones. Also here, the conditional interval of boreholes from the center of the ring to their surface openings is taken into account. The formulas will take the following form:

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$$h_5 = l_4 - l_5, \tag{8}$$

$$h_6 = l_5 - l_0, \tag{9}$$

$$l_5 = l_4 - \frac{W\alpha q_{\text{expl}}(l_4^2 - l_0^2)}{90 n_{\text{bhl}}^{\text{unevn}} d^2 \rho_{\text{char}}}, \tag{10}$$

where l_0 – the length of the conditional section from the center of the ring to the wellheads.

The number of arcuate zones depends on the variables included in the methodology, and can theoretically be large. However, the practice of blasting operations shows that it is enough to break explosive charges into intervals of 2-3 parts. During the experimental work at the Kyshtym underground mine, charges were formed with 2-3 air gaps in boreholes about 22 m long and 65-105 mm in diameter. Therefore, it is almost rational to divide the plane of the ring into 4-9 zones. The parameters determined according to the presented methodology should be corrected, taking into account the actual contour of the broken layer.

Results of experimental studies. The method was tested during mass breaking by ring patterns fans with a diameter of 65-105 mm at the Kyshtym underground mine (ore strength f = 12, density γ = 2.65 t/m^3) [8]. Grammonite 21 TMZ was used as explosives, charging was performed with a ZMK-1A charger, and Ammonite 6ZhV cartridges with DShE-9 were used as primers. The time spent on installing one plug, depending on the distance from the place of its wedging from the wellhead, was 2-4 minutes [9]. Evaluation of the effectiveness of the method was carried out according to the criteria of the maximum yield of a commercial piece (+20-700 mm) and the minimum yield of the oversized fraction (0-20 mm). For the conditions of the Kyshtym underground mine, the oversize output (+700 mm) is limited to 8-10 %.

In total, seven experimental explosions were carried out, and 6.7 thousand tons of ore mass was broken. As they were carried out, the specific consumption of explosives gradually decreased until the limit value for the output of the oversized fraction of +700 mm was reached.

To assess the results of the blasting by the proposed method, the first two explosions were carried out using continuous charges in rings with bore diameters of 65 and 105 mm, respectively. The specific consumption of explosives was 1.55 kg/m^3 for 65 mm, 1.7 kg/m^3 for 105 mm. Further experimental explosions were carried out according to the proposed technology with charge dispersion and a gradual decrease in the specific consumption of explosives. In the third explosion, the diameter of the boreholes was 105 mm, and the specific consumption of explosives was 1.37 kg/m^3. The fourth to seventh explosions were carried out with a hole diameter of 65 mm; the specific consumption decreased from 1.2 to 0.9 kg/m^3. According to the results of the experiments, the dependences of the particle size distribution on the specific consumption of explosives for blasting (Fig.3) were established.

Based on the obtained results of applying conventional blasting technology with a continuous charge design (highlighted in red) and the technology proposed by us with a dispersed charge design and uniform distribution of explosives along the plane of the broken layer (highlighted in blue), we can conclude that the output of crushed and fine ore directly proportional, and a commercial piece and oversize – inversely proportional to the specific consumption of explosives for blasting for the conditions of the Kyshtym mine.

At the same time, the results of the explosions show that the ratio of the fraction

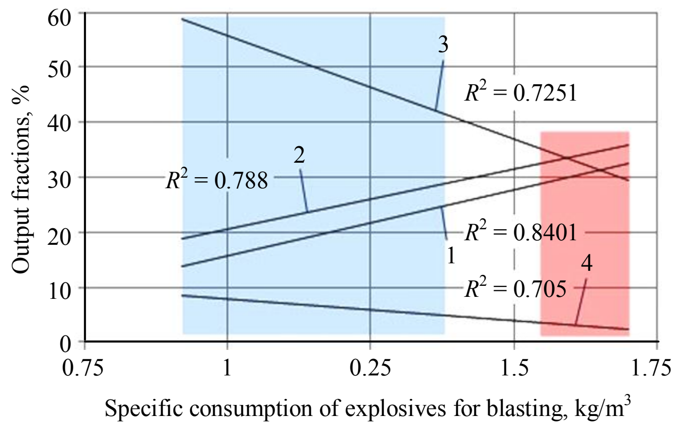

Fig.3. Linear dependences of the output of broken ore fractions on the specific consumption of explosives for blasting

1 – 0-20 mm; 2 – +20-65 mm; 3 – +65-700 mm; 4 – +700 mm.
Red – conventional blasting technology;
Blue – suggested blasting technology

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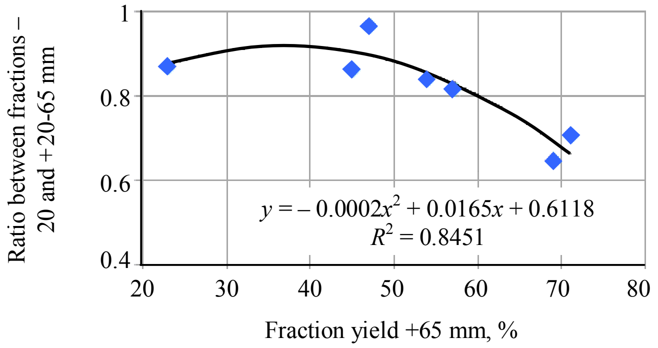

Fig.4. Dependence of the ratio between fractions 0-20 and + 20-65 mm from the fraction +65 mm

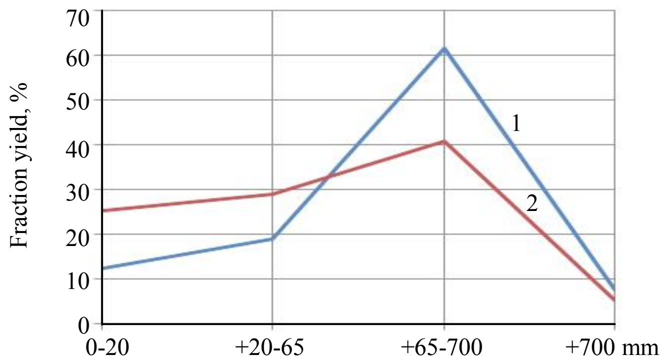

Fig.5. Comparison of explosion results with a dispersed and continuous charge design with borehole diameter 65 mm; q – specific consumption of explosives;
1 – dispersed charges, q = 0.9; 2 – continuous charges, q = 1.55

0-20 mm to +20-65 mm decreases with an improvement in the quality of crushing and can be approximated by a graph, with a determination coefficient sufficiently high for this kind of experiments (Fig.4).

As a result of testing the proposed drilling and blasting technology, the particle size indicators of the best quality ore mass were achieved with a borehole diameter of 65 mm and specific consumption of explosives for blasting of 0.9 kg/m^3. A visual comparison with standard blasting with a continuous design of charges of similar diameter is shown in Fig.5.

Conclusions. The developed method of blasting by dispersed charges does not require a significant increase in labor costs and additional special tools; it allows to significantly reduce the specific consumption of explosives and ensure a uniform distribution along the ring plane, thereby eliminating the main drawback of the ring pattern. (The authors have obtained a patent of the Russian Federation for invention N 2645048 for this method).

For the developed method of blasting, a method for calculating dispersed charges based on taking into account the optimal specific consumption of explosives, burden and burden-to-space ratio calculated or determined experimentally for conditions of a specific field has been proposed, which allows setting parameters that ensure uniform distribution of explosion energy in all areas of the rock mass ore without increased specific consumption of explosives with increasing distance from the bottom to the wellheads in the ring.

For conditions Kyshtym underground mine we set the following:

• the output of crushed and fine ore fractions is directly proportional, and the commercial lump is inversely proportional to the specific consumption of explosives for blasting;

• the ratio of the oversized fraction of 0-20 mm to + 20-65 mm decreases with the improvement of the quality of crushing;

• in comparison with conventional blasting technology, the output of a commercial lump (+20-700 mm) increases by 10.7%, and the share of the fraction that is most favorable for further processing (+65-700 mm) increases by 33.7%. At the same time, the specific consumption of explosives is reduced by 42%.

REFERENCES

1. Grishin A.N., Matrenin V.A., Muchnik S.V. The method of forming dispersed borehole charges. *Gornyi zhurnal.* 2007. N 4, p. 55-57 (in Russian).

2. Zharikov I.F. Energy-saving technologies for blasting in open pits. *Vzryvnoe delo.* 1998. N 91(48), p. 191-195 (in Russian).

3. Kutuzov B.N., Belin V.A. Design and organization of blasting operations. Moscow: Gornaya kniga, 2012, p. 416 (in Russian).

4. Leshchinskii A.V., Shevkun E.B. Dispersion of borehole charges. Khabarovsk: Izd-vo Tikhookean. gos. un-ta, 2009, p. 154 (in Russian).

5. Lomonosov G.G., Turtygina N.A. The phenomenon of segregation of the ore mass and its impact on the formation of the quality of mining products. *Gornyi informatsionno-analiticheskii byulleten'.* 2014. N 6, p. 37-40 (in Russian).

6. Test results of Canadian-made equipment at OJSC Mine Karalveem. *Gornaya promyshlennost'.* 2012. N 3 (103), p. 42-43 (in Russian).

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7. Sitnikov R.V. Hydromechanical cleaning of ore fines as an effective way to reduce ore losses. *Vestnik ChitGU*. 2010. N 2 (59), p. 18-22 (in Russian).
8. Smirnov A.A., Rozhkov A.A. Investigation of the action of the explosion of the ring borehole pattern. *Vzryvnoe delo*. 2018. N 119-76, p. 118-128 (in Russian).
9. Sokolov I.V., Smirnov A.A., Rozhkov A.A. Improving the efficiency of quartz mining using a flat system of dispersed charges. *Izvestiya vuzov. Gornyi zhurnal*. 2018. N 1, p. 56-65 (in Russian).
10. Shalaev M.S., Paramonov G.P. On the issue of increasing the stability of the pit walls during contour blasting due to the use of gel explosives. *Zapiski Gornogo instituta*. 2009. Vol. 180, p. 217-220 (in Russian).
11. *Bhandari S.* Engineering rock blasting operations. Rotterdam: Dalkema Publishers. 1997, p. 375.
12. Vokhmin S.A., Kurchin G.S., Kirsanov A.K., Shigin A.O., Shigina A.A. Destruction of rock upon blasting of explosive agent. *ARPN Journal of Engineering and Applied Sciences*. 2017. Vol. 12, p. 3978-3986.
13. Yue Z.W., Yang R.S., Chen G., Pan C.C., Meitan X. Dynamic test on siltcharge blasting of air-deck charge. *Journal of the China Coal Society*. 2011. Vol. 36(3), p. 398-402.
14. Götze J., Möckel R. Quartz: Deposits, Mineralogy and Analytics. Berlin, Heidelberg: Springer. 2012, p.360.
15. Jhanwar J.C. Theory and Practice of Air-Deck Blasting in Mines and Surface Excavations: A Review. Geotechnical and Geological Engineering. 2011. N 29, p. 651-663.
16. Melnikov N.V., Marchenko L.N. Effective methods of application of explosive energy in mining and construction. In Twelfth Symposium on Dynamic Rock Mechanics. New York: AIME, 1971, p. 350-378.
17. Müller A., Wanvik J.E., Ihlen P.M. Petrological and chemical characterization of high-purity quartz deposits with examples from Norway. In Quartz: Deposits, Mineralogy and Analytics. Berlin, Heidelberg: Springer. 2012, p. 71-118.
18. Onederra I.A., Furtney J.K., Sellers E., Iverson S. Modelling blast induced damage from a fully coupled explosive charge. *International Journal of Rock Mechanics and Mining Sciences*. 2013. Vol. 58, p. 73-84.
19. Sokolov I.V., Smirnov A.A., Antipin Yu.G., Baranovsky K.V., Rozhkov A.A. Optimal combination technology for high-grade quartz production based on modeling. *Journal of Mining Science*. 2016. Vol. 52. N 6, p. 1159-1167.
20. Götze J., Pan Y., Müller A., Kotova E.L., Cerin D. Trace Element Compositions and Defect Structures of High-Purity Quartz from the Southern Ural Region, Russia. *Minerals*. 2017. Vol. 7, p. 189.
21. Yang G.L., Yang R.S., Jiang L.L. Pressure distribution along borehole with axial air-deck charge blasting. *Explosion and Shock Waves*. 2012. N 32 (6), p. 653-657.

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