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MINE STABILITY WITH APPLICATION OF SUBLEVEL CAVING SCHEMES

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The paper expounds results gained in mathematical modeling of stress state of a rock mass under mining by sublevel caving with areal-frontal and frontal ore drawing schemes. Stability of underground excavations in the course of applying the compared methods is evaluated in terms of the Sheregesh deposit. The authors recommend on supporting the openings at the ore drawing-off level.

Technology, stress state, modeling, stability

INTRODUCTION

The feature of the current ore mining technologies is the maximally simplified mining methods and the philosophy of highly intensive mining with using mobile equipment unites and sets. For instance, equipage of underground mines in Canada, Sweden, Australia, USA includes more than 95 % of advanced mobile machinery both for primary and secondary mining operations [1].

Mining conditions at thick iron ore deposits (e.g., Sheregesh deposit) and at mid-grade ore deposits are most suitable for application of the method of sublevel caving with frontal ore drawing, the efficiency of which is proved world-wide [2]. This technology ensures qualitative and safe mining at any complex deposits; it is advantageous for high productivity and intensity of works, needlessness of ore chutes, pull holes, manholes, undercut levels, simplicity, flexibility and culture of the method. Though there are same drawbacks, too, e.g., high ore losses and dilution, mining in dead-ended stopes, which worsens working conditions and requires extra expenditures for ventilation. The presence of these disadvantages needs for new structural schemes to be developed for the method of sublevel caving.

METHOD OF SUBLEVEL CAVING WITH AREAL-FRONTAL ORE DRAWINGING

The researchers of the Institute of Mining SB RAS have developed a modification of the method of sublevel caving with areal-frontal ore drawing specially for thick and very thick steep pitching ore deposits with the aim of eliminating the above drawbacks of the frontal drawing but keeping the advantages of the sublevel caving (Fig. 1).

Th studies [3, 4] highlight in detail the features and efficiency of this innovative technology. The proposed modification, as compared with the "classical" frontal drawing, offers an additional driving of haulage inclines between haulage crosscuts in order to drawing ore over the whole area of a broken layer and ventilate stopes at the expense of all-mine airing [5, 6]. Hereby, it is possible to benefit from greater completeness, better quality and higher safety of ore mining.

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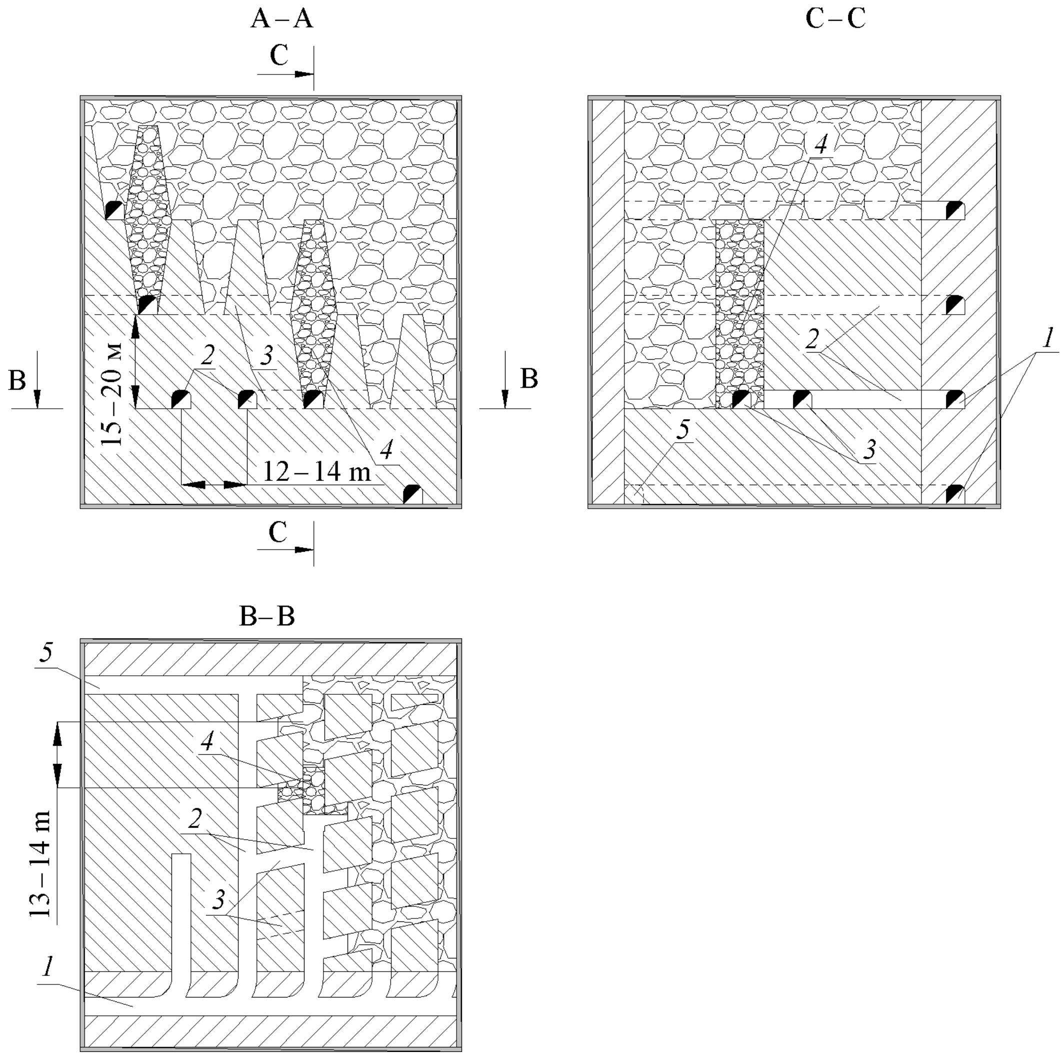

Fig. 1. Method of sublevel caving with areal-frontal ore drawing: *1* — haulage roadway; *2* — haulage crosscut; *3* — haulage inclines; *4* — broken ore layer; *5* — air drift

Based on the studies [3, 4], the technological parameters to gain the highest extraction indices were determined. Depending on a sublevel height of 15 m and 20 m, the distance between the haulage crosscuts is 12.0 m and 14.0 m, the haulage inclines (considering an ore layer for frontal drawing scheme) are spaced at 12.0 – 12.5 m and 13.5 – 14.5 m, respectively. The broken layer thickness is 0.45 – 0.50 of the sublevel height. It was found that the optimal regime of ore drawing is by batches from a haulage incline (over the broken layer area) and from a haulage crosscut at a ratio 2:1. Comparing the areal-frontal and frontal ore drawing schemes showed the better parameters of the first one: ore losses reduced by a factor of 1.4 – 1.5, ore dilution decreased by a factor of 1.5 – 1.7, while the quality of clean ore extracted before the dilution increased by a factor of 1.5 – 1.6.

Safety of the method of sublevel caving with areal-frontal ore drawing is determined by operational stability of underground opening for their whole service life. Worse stability of haulage crosscut, inclines and drifts confines the application field of the proposed method, yet not approved in the world mining practice. For that matter, it is necessary to evaluate from the view point of rock mechanics the determined technological parameters of the presented method and to develop measures for higher stability of underground openings.

PROBLEM STATEMENT

The study object is to develop a comparative rock mechanics evaluation of underground opening stability for the areal-frontal drawing scheme as against the frontal drawing. The stress-strain state of a rock mass is calculated by the finite element method for the conditions of the Sheregesh deposit located in Gornaya Shoria [7].

We used a 3D model of an isotropic linearly deformable homogeneous rock mass (Fig. 2). Mining depth H is 600 m. The calculation domain boundary conditions depended on stress state in the area of stoping, considering the overlying mined-out space. The calculation involved the following principal stresses: horizontal stresses across the orebody strike were $\sigma_z = 3.0\gamma g H$, horizontal stresses on the strike were $\sigma_x = 2.5\gamma g H$ and vertical stresses were $\sigma_y = \gamma g H$ [8, 9]. A volume force γg accounted for rock weight (γ was a density of rocks and g was free fall acceleration).

The calculation models involved sublevel haulage crosscuts, ventilation-haulage inclines and mined-out space (Figs. 2 and 3). The implementation parameters were identical for both models of the frontal ore drawing scheme and area-frontal drawing without haulage inclines.

The vertical stresses depend on the gravitation forces: $\sigma_y = \gamma g(H - h)$, where h is a distance between the upper model boundary and the level of 600 m, the horizontal stresses $\sigma_x = \lambda_1 \sigma_y$, $\sigma_z = \lambda_2 \sigma_y$, where λ_1, λ_2 are the lateral thrust coefficients.

The distance between the surface of boundary force assignment and the studied site openings is three times bigger than the maximum dimensions studied mining site. The assumed conditions are sufficient for the studied mining site to have no influence on the external model boundaries. The rocks in the calculations had the following properties: Young's modulus E = 50 GPa, Poisson's ratio $\mu = 0.26$, densities $\gamma = 2800$ kg/m^3 of rocks and $\gamma = 3000$ kg/m^3 of ores [8, 9].

The rock mass stress-strain state is analyzed in terms of principal stresses σ_1, σ_2 and τ_{max}, where the maximal stress was σ_1, the minimal stress was σ_2 and tension was of a "minus" sign.

The results comply with the rock mass stress-strain state data actual for the current mining situation. Note that modeling did not account for caved rocks which improve mined-out space stability in-situ at the expense of the lateral thrust. So, the calculation outcomes exhibit a certain reliability margin.

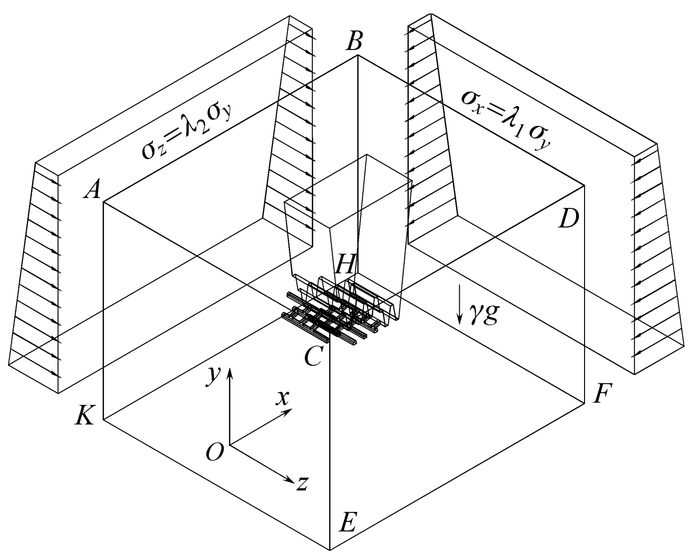

Fig. 2. Calculation of a rock mass stress-strain state for the areal-frontal ore drawing scheme

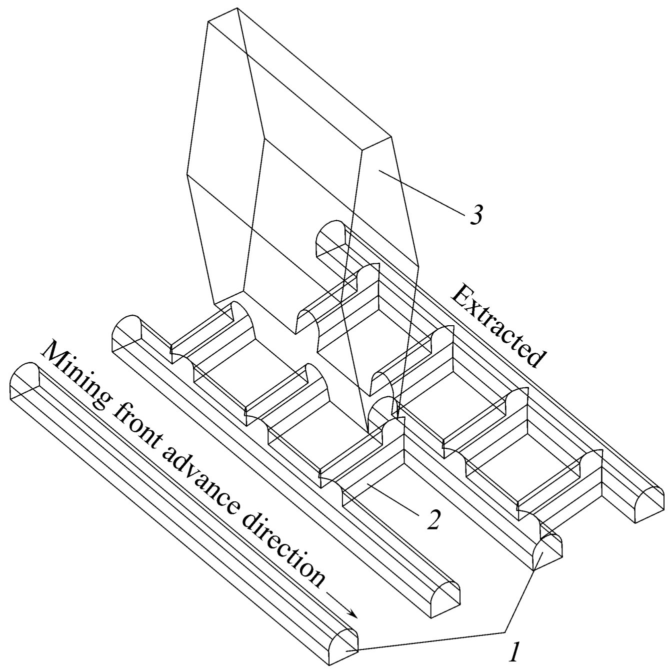

Fig. 3. A fragment of the areal-frontal ore drawing method in the area of stoping: *1* — haulage crosscuts; *2* — ventilation and haulage inclines; *3* — mined-out space

The stress-strain state of elements of the technology was evaluated for the following cross-sections in Fig. 2: across the strike (over the plane *Oyz*), along the strike (over the plane *Oxy*) in plan of the ore drawing and haulage level (over the plan *Oxz*).

RESEARCH FINDINGS

We have obtained the following results of modeling for the compared mining methods in the cross-section across the orebody strike (Figs. 4 and 5). The rock mechanics conditions are the most unfavorable for the areal-frontal ore drawing method as wall of sublevel crosscuts and haulage inclines undergo action of tensile stresses σ_2 ranging from 0 MPa to -10 MPa (Fig. 4). The orebody between the sublevels suffers stresses $\sigma_1 = 67-87$ MPa. The stress concentration σ_1 is maximal in roofs of the haulage inclines, where it exceeds 120 MPa. In rocks between the haulage inclines, the stress τ_{max} decreases along a vertical from 35 MPa to 20 MPa. The stresses for the frontal ore drawing method under the same conditions are lower by $10-15$ % (Fig. 5).

Figure 6 and 7 show the stress distributions across the orebody strike along a working panel. The areal-frontal drawing scheme is described by the tensile stresses σ_2 up to -5 MPa in the area of influence of the haulage incline; at that, σ_1 reaches 85 MPa, $\tau_{max} = 35-39$ MPa. In the center of the rhombic panel, σ_1 are $45-55$ MPa and σ_2 vary from -5 MPa to 5 MPa; in the conditions of the frontal ore drawing: $\sigma_1 = 65-70$ MPa, $\sigma_2 = 3-10$ MPa and $\tau_{max} = 23-26$ MPa in the walls of the underground openings, and τ_{max} in the roof changes between 26 MPa and 31 MPa.

The stress field distribution in plan of the ore drawing level is shown in Figs. 8 and 9. The estimate of the stress-strain state near the mined sublevel in the areal-frontal ore drawing scheme yields that the stresses in the area of the inclines change from the compression in the roof to the tension in the walls. In the walls of the haulage inclines, towards the haulage crosscut, the stresses σ_2 vary from 0 MPa to -5 MPa and reach -10 MPa in the center. In the roof of the inclines, σ_1 exceed 120 MPa. The situation is similarly unfavorable in the areas of intersection of the haulage crosscuts and haulage inclines when in the frontal ore drawing scheme is applied ($\sigma_2 = -5 \div -10$ MPa). Pressure of the sublevel crosscut roof is somewhat lower than in the haulage crosscut, and σ_1 range between 70 MPa and 90 MPa. On the floor of the underground openings, σ_1 changes from 65 MPa to 75 MPa, and $\tau_{\max} = 23-30$ MPa.

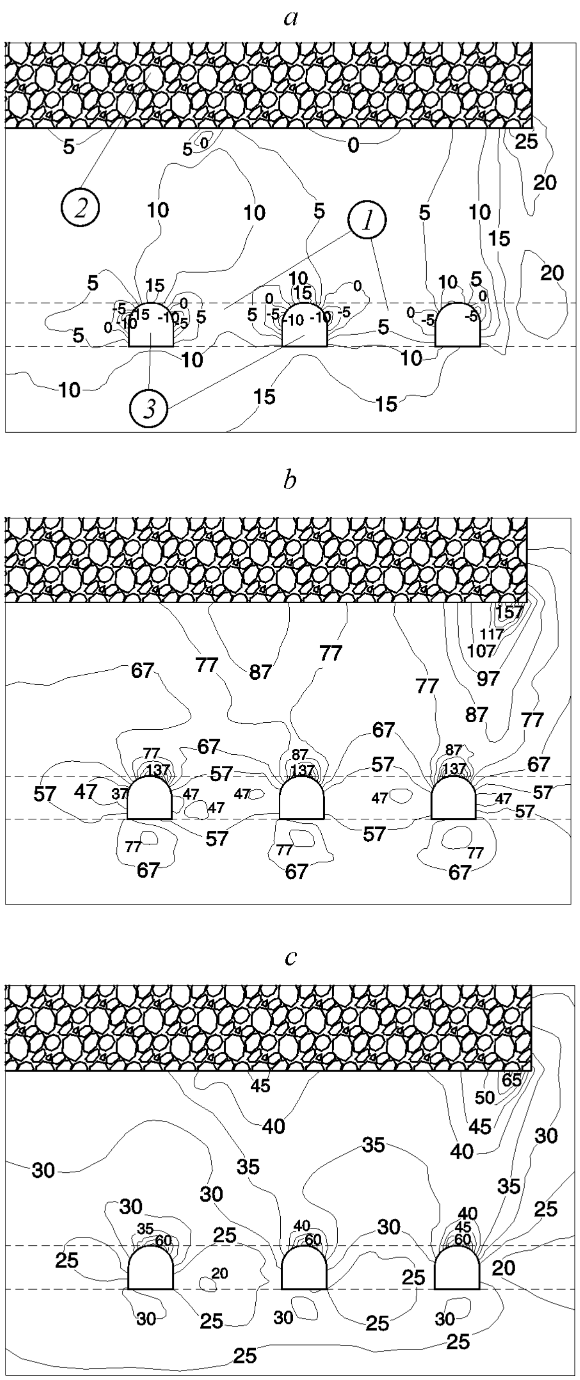

Fig. 4. Stress distribution (MPa) in rock mass for the areal-frontal ore drawing technology: *a*) σ_2; *b*) σ_1; *c*) $\tau_{\max}$ (*1* — haulage crosscut; *2* — mined-out space; *3* — haulage inclines)

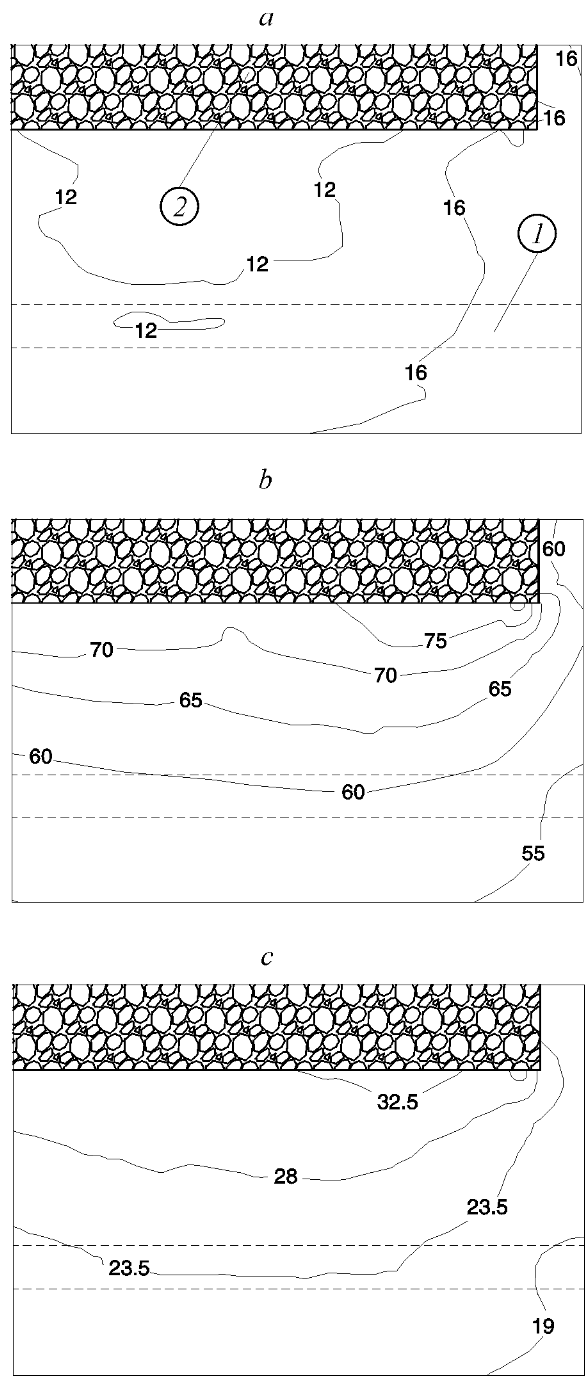

Fig. 5. Stress distribution (MPa) in rock mass for the frontal ore drawing technology: *a*) σ_2; *b*) σ_1; *c*) $\tau_{\max}$ (*1* — haulage crosscut; *2* — mined-out space)

Generalizing the calculation data for the stress-strain state on the mined level with the frontal ore drawing yields the following conclusions. There are almost no tension zones in the underground openings. Stresses in the roof are no higher than 70 MPa. The stresses τ_{max} between the crosscuts are $26-29$ MPa. The high stress concentration is in the area of the ore drawing ($\sigma_1 = 70$ MPa). The floor of the openings undergoes loading by τ_{max} to 25 MPa. The stresses σ_1 in the walls of the crosscuts are on the order of $53-68$ MPa.

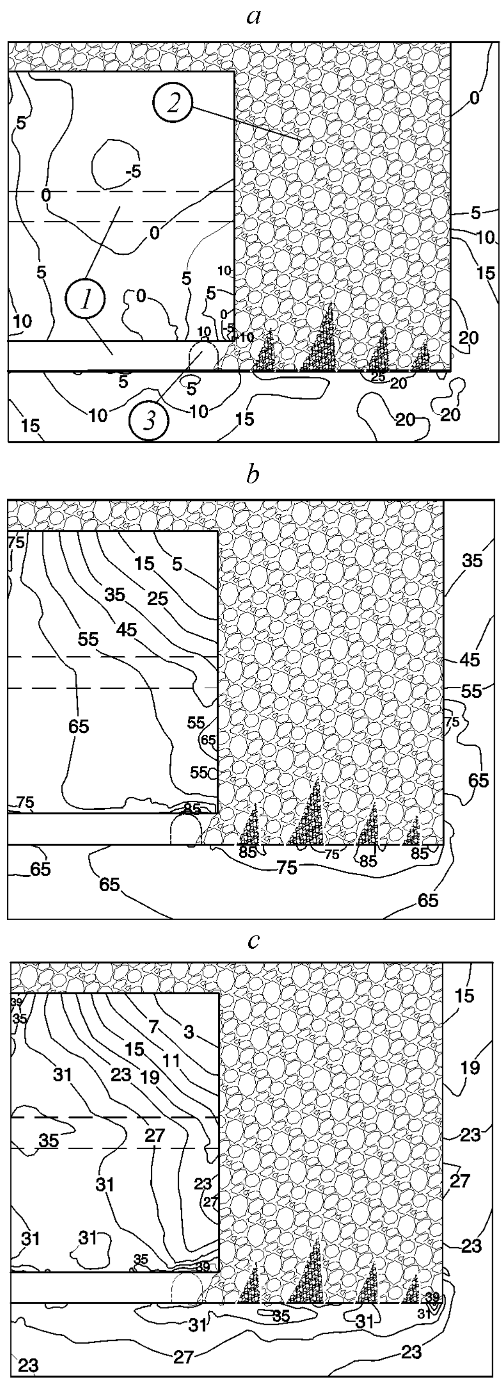

Fig. 6. Stress distribution (MPa) for the areal-frontal ore drawing methods: *a*) σ_2; *b*) σ_1; *c*) τ_{max} (*1* — haulage crosscut; *2* — mined-out space; *3* — haulage incline)

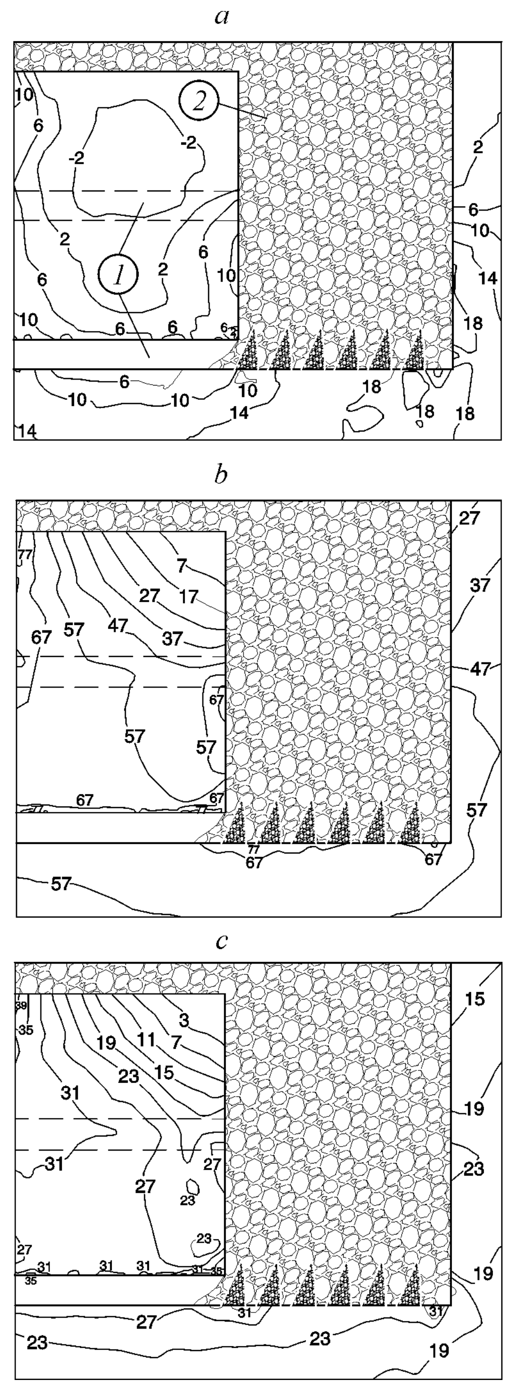

Fig. 7. Stress distribution (MPa) for the frontal ore drawing methods: *a*) σ_2; *b*) σ_1; *c*) τ_{max} (*1* — haulage crosscut; *2* — mined-out space)

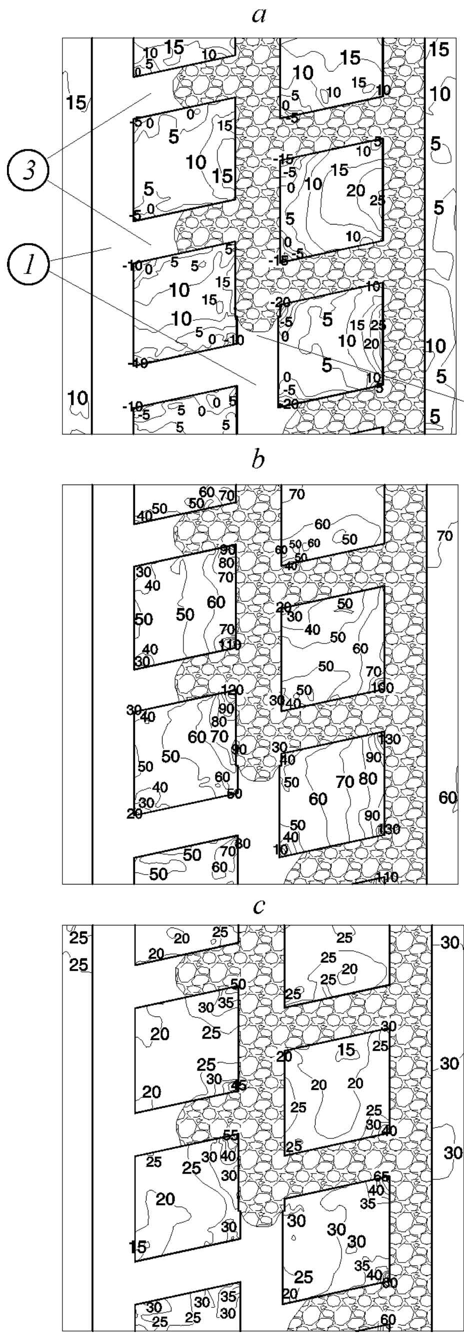

Fig. 8. Stress distribution (MPa) for the areal-frontal ore drawing methods: *a*) σ_2; *b*) σ_1; *c*) τ_{max} (*1* — haulage crosscut; *2* — ore drawing area; *3* — haulage incline)

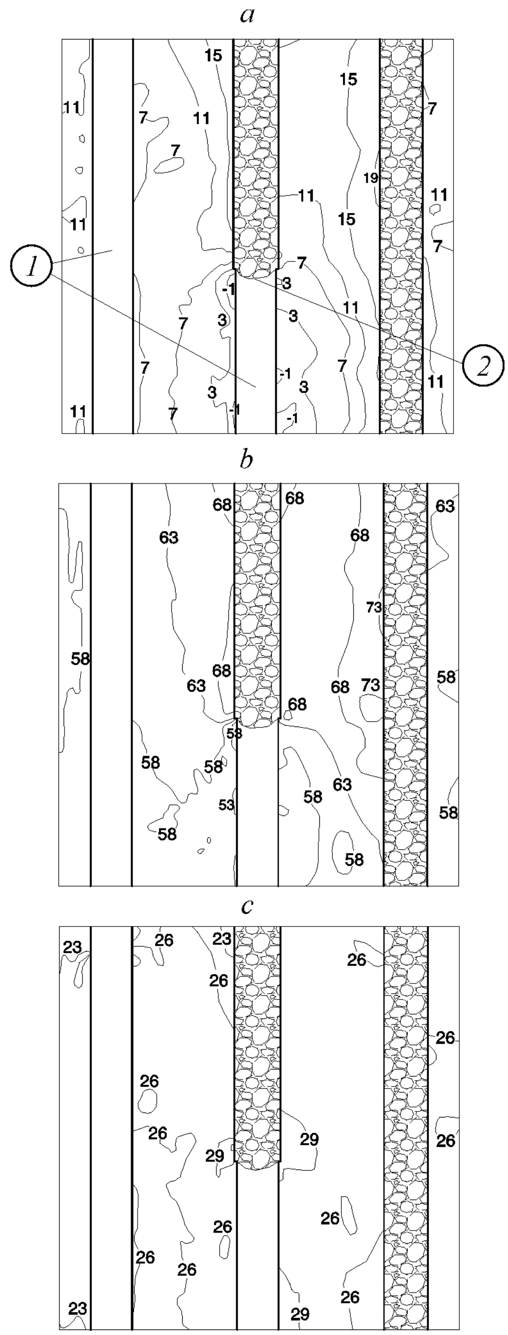

Fig. 9. Stress distribution (MPa) for the frontal ore drawing methods: *a*) σ_2; *b*) σ_1; *c*) τ_{max} (*1* — haulage crosscut; *2* — ore drawing area)

Now let us discuss the stress distribution along the orebody strike in the center of the studied domain (Figs. 10 and 11). For the areal-frontal ore drawing technology, it is typical that the stress σ_1 in rhombic panels changes along a vertical, from 80 MPa to 100 MPa in the upper part and to 70 MPa in the lower part. The maximal tensile stresses are observed in the upper portion of the panel, at the mined level

($\sigma_2 = 0 \div -4$ MPa), then, lowering to the central part, the stresses gradually change into the compressive ones. The situation is otherwise in the panels with inclines to be mined: $\sigma_2 = 1 \div 11$ MPa. In the roof of the haulage crosscuts, σ_1 and τ_{max} are, respectively, $70-90$ MPa and $26-31$ MPa, and towards the walls of the crosscuts, σ_1 decrease to $45-60$ MPa.

The stress distribution in a rhombic panel in the course of the front are drawing technology is the same as in the course of the areal-frontal ore drawing method. In the panels where stoping is going on, the stress σ_1 changes along a vertical, top to bottom, from 10 MPa to 60 MPa. No tensile zones are observed. Increased stresses ($\sigma_1 = 70-80$ MPa) develop in the panels prepared for stoping, where cutoffs are not driven.

Tensile stress zones arising in the course of the areal-frontal ore drawing mining (stresses up to -10 MPa) worsen stability of underground openings. The haulage inclines are in the most complicates conditions, especially in the areas of intersection with the haulage crosscuts, where fracturing, roof breaking and failure is probable.

In the frontal ore drawing scheme, there are almost no tensile stress zones in the sublevel openings.

The stress-strain state modeling to be summed up, it is worth-noting that stresses arising in the course of applying the frontal ore drawing scheme are lower than during the areal-frontal ore drawing method by $15-25$ % on average.

ESTIMATE OF STABILITY OF OUTCROPS

The most heavy duty element of a mining method is the ore drawing-off and hauling level. The stable state of a rock mass was determined with the Coulomb – Mohr criterion [10].

The rock mass stress state was estimated in terms of the Sheregesh deposit based on the stability factor K_y calculated by using the equation of a straight Mohr's envelope, considering characteristic structural weakening of the studied rock mass. When $K_y \leq 1$, it is a characteristic of probable rock failure zones when outcropped. The calculation results for the stability of rock mass elements with the areal-frontal and frontal technologies applied are given in Table 1.

Zone of the orebody between the haulage inclines and their roof are in the stable state. In places where the haulage inclines join the haulage crosscuts, the stability decreases and approaches critical values, which requires additional support for these sites.

The walls of the haulage crosscuts in the zone of stoping are to be supported, too. The roof of the openings is table. The strength of the rock mass between the neighboring crosscuts ensures their stability for their service life period. The stability of underground openings where the frontal ore drawing method is used apparent.

TABLE 1. Stability Factor K_y for Underground Openings

Element of an opening	Ore		Host rocks	
	Mining method			
	areal-frontal	frontal	areal-frontal	frontal
Incline and crosscut joint	0.8 – 0.9	—	0.9 – 1.1	—
Walls of inclines	1.0 – 1.1	—	1.1 – 1.2	—
Roof of inclines	1.1 – 1.2	—	1.2 – 1.3	—
Walls of haulage crosscuts	1.1 – 1.2	1.2 – 1.3	1.2 – 1.3	1.3 – 1.4
Roof of haulage crosscuts	1.1 – 1.3	1.3 – 1.5	1.2 – 1.4	1.4 – 1.6

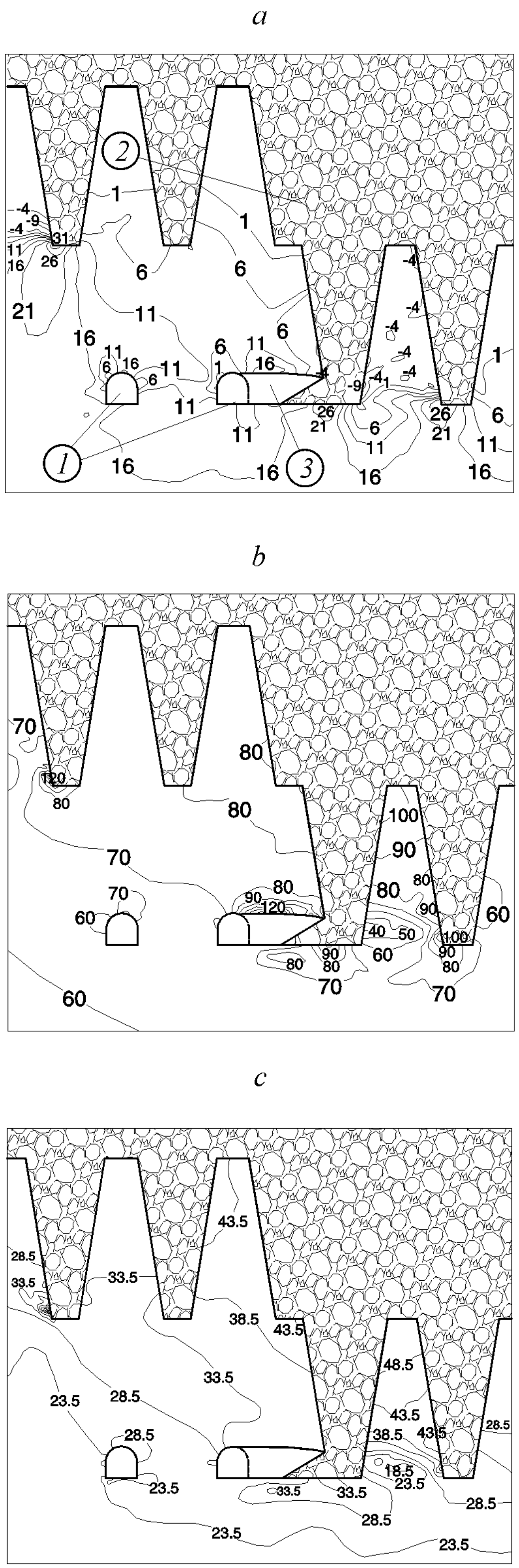

Fig. 10. Stress distribution (MPa) along the orebody strike for the areal-frontal ore drawing technology: *a*) σ_2; *b*) σ_1; *c*) τ_{max} (*1* — haulage crosscut; *2* — mined-out space; *3* — haulage incline)

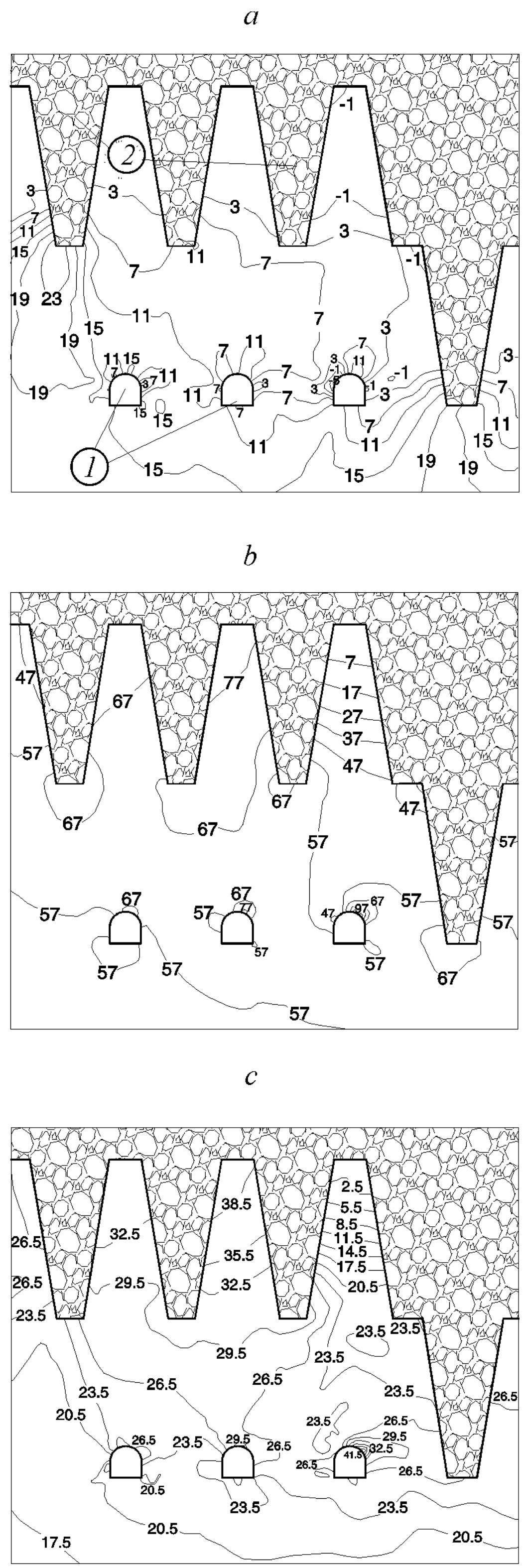

Fig. 11. Stress distribution (MPa) along the orebody strike for the frontal ore drawing technology: *a*) σ_2; *b*) σ_1; *c*) τ_{max} (*1* — haulage crosscut; *2* — mined-out space)

CONCLUSIONS

The calculations have showed that the method of sublevel caving with the areal-frontal or drawing scheme finds successful application in hard and stable rocks. For better stability of drawing-off workings, they are to be additionally supported. Driving of haulage inclines is carried out while ore layer breaking. In the course of mining, no more than 3 haulage inclines are to operate, one is for ore drawing-off, the other is for ventilation, and the third is under drivage. Service life of the haulage inclines is only 20 – 25 shifts, starting from the drivage onset, which requires no high expenditures for their maintenance and operation.

In a severely faulted rock mass, the areal-frontal drawing scheme can be readily transformed into the frontal ore drawing scheme, though completeness and quality of mineral extraction a bit worsen in this case.

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