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GEOMECHANICAL FEATURES OF UNDERGROUND MINING AT KOCHKAR DEPOSIT*

V. N. KALMYKOV[1],
Professor, Doctor
of Engineering Sciences

K. I. STRUKOV[2],
Founder and President ,
Candidate of Engineering
Sciences

R. V. KULSAITOV[3],
Engineer,
kulsaitov.ravil@gmail.com

E. N. ESINA[4],
Senior Researcher,
Candidate
of Engineering Sciences

[1]Nosov Magnitogorsk State Technical University, Magnitogorsk, Russia
[2]UGC Management Company, Chelyabinsk, Russia
[3]Uralenergoresurs Ltd, Magnitogorsk, Russia
[4]Institute of Integrated Mineral Resources Development — IPKON, Russian Academy of Sciences, Moscow, Russia

Transition to deeper level mining at Kochkar vein deposit is accompanied by the reduction in the valued component content of rock mass, complicated geomechanical situation with the increased frequency and intensity of dynamic events due to rock pressure and, consequently, by the higher cost of mining and haulage. The analysis of the raw materials base of the gold mine shows that large lower grade ore reserves remain in the subsoil after the primary extraction as their recovery was assumed unprofitable. One of the options of improving geomechanical situation is transition of mining to upper levels holding considerable reserves of lower grade ore. To this effect, the variants of mining low-grade ore reserves left in various purpose pillars and in pockets with low content of valued component under difficult ground conditions were studied. The geomechanical situation was assessed in intact and mining-altered areas in rock mass, and safe geomechanical parameters were substantiated. It is found that Kochkar deposit is composed of strong, rigid and brittle rocks characterized by high elasticity modulus and capable to accumulate and dynamically release elastic energy. With a view to enhancing geomechanical safety of mining, measures toward stress relaxation in rock mass are suggested. It is shown that movement of the mining works to an upper horizon, where density is 8–12 times less than lower horizons cut and fill methods of mining can be used.

Key words: *stress–strain state, stress distribution patterns, mining system, re-extraction, force field parameter, stress state components*

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Introduction

Many years-long high-rate mining of the South Ural's largest rockburst-hazardous gold field Kochkar [1] has resulted in complication of geotechnical condition and aggravation of geomechanical situation in the production-altered rock mass, especially in transition zone to deeper levels [2]. Under such conditions, re-extraction of mineral reserves in veins, mineralization zones altered in the course of primary extraction and left in various purpose pillars and in mineralized pockets of below-average gold grade is a challenge requiring detailed geomechanical research and geotechnical justification [3]. In the recent decade, UGC Gold Mining Company mines energetically develop combination geotechnologies aimed to the integrated treatment of the subsoil and mineral reserves using physico-technical (underground and surface) and physicochemical (leaching) methods of mining and processing. In use are various systems of mining: shrinkage stoping, sublevel stoping, cut-and-fill (cement and hydraulic backfill).

On the one hand, expansion of the range of mining systems allows development of very low-grade ore previously assumed noncommercial and occurring in complicated ground conditions. On the other hand, this imposes more stringent requirements on mining projects, for the first turn, connected with the safety of mining at abandoned levels under protected objects [4].

The efficiency of mining of earlier abandoned reserves is governed by: thickness of veins and mineralization zones, valued component content, stress–strain state of rock mass and condition of access openings, their location, remoteness from potentially mineable areas, etc. [5].

Development of mining-altered reserves is characterized by complex geomechanical situation due to disturbance of rock mass by drivage, absence of reliable geological and geotechnical documentation, which impedes decision making on validation of geomechanical parameters of process flow charts with respect to strata pressure and necessitates estimation and prediction of stress state of rocks and load on mine system elements.

Geomechanical peculiarities of rock mass

Analysis of the morphology, structure and strength and deformation characteristics of ore and enclosing rock mass around natural and altered ore-containing zones reveals mining difficulties conditioned by composite and close-spaced veins, extensive fracturing, faulting and rockburst

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hazard [5]. Operating practice at Kochkar deposit and the research findings on properties of ore and enclosing rocks show their brittle failure susceptibility under loading and capacity to accumulate potential elastic energy under deformation. The typical geomechanical features are: rockfalls in mined-out areas, which results in self-localization and filling of voids; required support installation even in narrow stopes; vigorous events due to strata pressure. Deeper level mining operations are carried out in complicated geomechanical and ground conditions of higher stresses and frequent dynamic events.

The estimate of state of underground openings and stoping zone reveals deformation of structural elements of mine systems with time. Despite the long life, the stoping zone and underground openings operated during the primary extraction period are in the satisfactory condition according to estimates. The underground excavations have clear cut walls, the cross dimensions conform with the mine project or have insignificant deviations. Intensity of jointing of adjacent rock mass is slightly changed with time due to high strength of ore and enclosing rocks, low exposure to weathering and absence of aggressive mine water. The stoping zone formed during the primary extraction has also well-defined boundaries and dimensions that are equal or close to the mine project.

The highest risk of instability of rocks is brought by parallel exposure surfaces and diagonal joints [6–8]. Mining of steeply dipping veins exposes such joints along the whole length of production heading. Footwall and hanging wall rocks are subjected to schistosity, the layers, under the own weight and rock pressure, are cut into blocks by joints that are parallel to the face, and rocks fall and cave into mined-out area along such joints.

The long-term high-rate mining in Kochkar field has resulted in the formation of many mined-out voids. The current geomechanical model of the deposit is represented by stopes cut along the veins and separated by ore and gangue pillars. Low-rate mining in the heavily dissected rock mass activates dynamic rock pressure events. Estimation of rockburst hazard based on various deformation and energy criteria proves that Kochkar rock mass is rockburst-hazardous and can accumulate elastic energy [2].

It is evident that reduction in hazardous rock pressure events (exfoliation of hanging wall rocks, failure of pillars, dynamic events) is possible through abridgement of block mining, refinement of mining system parameters and improvement of mine design [9]. It is obligatory to implement measures aimed at relaxation of deformation energy accumulated in rock mass.

To this effect, natural stresses have been assessed in various areas of Kochkar gold field, and mining-induced variation in the stress field is determined [2].

The in-site stresses in the intact rock mass were determined using the borehole slotter method at the depth of 150–700 m (**Fig. 1**) [10, 11].

According to the research results, Kochkar rock mass stress state is complex and nonuniform. This is explained by the effect of gravitational and tectonic forces, for the first turn. The in-situ experimentation data analysis shows that the horizontal stresses are unequal ($\sigma_x \neq \sigma_y$) and exceed the vertical stresses 1.1–1.6 times at upper levels and 2–2.6 times at deeper levels. The maximum compression stresses σ_x act mostly sub-meridionally, i.e. across the trend of geological structures. It is found that the measured vertical stresses are 30–70% higher than their calculated values with respect to the overlying strata weight γH, which is explained by the impact of stoping and development openings at the upper levels and heavy faulting of Kochkar rock mass.

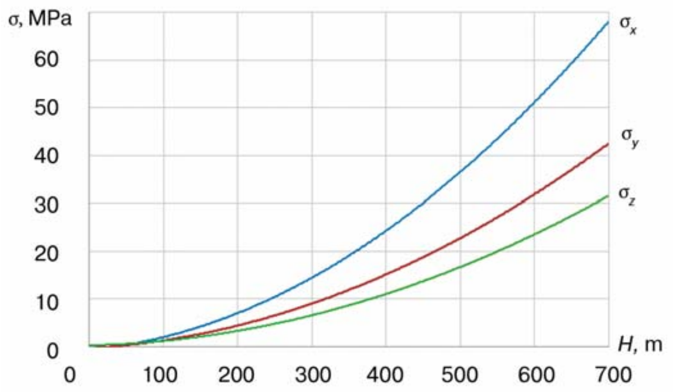

Fig. 1. Stress-depth curves:
σ_x, σ_y, σ_z — principal normal stresses in the intact rock mass, respectively, across and along the trends of geological structures, and vertical

The east–west strike and thickness of veins, as well as the accepted process flowsheets allow transverse arrangement of development openings. These details are taken into account in the design and justification of mining system parameters.

Transition to mining of mineralized pockets, introduction of stoping methods and re-extraction of ore reserves at upper levels enhances significance of geomechanical forecasts in the design of load-bearing elements of mine structure at deeper levels.

Aimed at prediction of stress–strain state of rock mass in the vicinity of stopes, re-extractions scenarios for upper and deeper levels are modeled (**Fig. 2**) [11–19].

Figure 3 shows the curve of normal stresses in the structural elements of mining system, height of stope, depth of mining and width of stope. It is seen that the normal stresses in the structural elements of stoping grow by 18–20% per each 10 m of increase in the height of stope (**Fig. 3**).

Analysis of operating practice in Kochkar Mine shows that rock pressure events in the form of spalling take place in case of a long extraction block (> 50–60 m) and long period of mining (more thane 12–14 months). The increase in stresses in the load-bearing elements in long block extraction is a consequence of relaxation of enclosing rock mass. High stress level in exposed surfaces of pillars and roof corresponds to elastic deformation stage that shows itself only in the early period of pillar formation. For this reason, it is highly probable that dynamic events due to rock pressure take place immediately after blasting operations that act as a triggering power factor.

In actual practice, the time variation in stress–strain state of pillars has the more complex behavior than results from the elastic medium modeling, owing to rheological processes accompanied by relaxation of stresses at the edges of pillars and by increase in the normal stresses in the middle

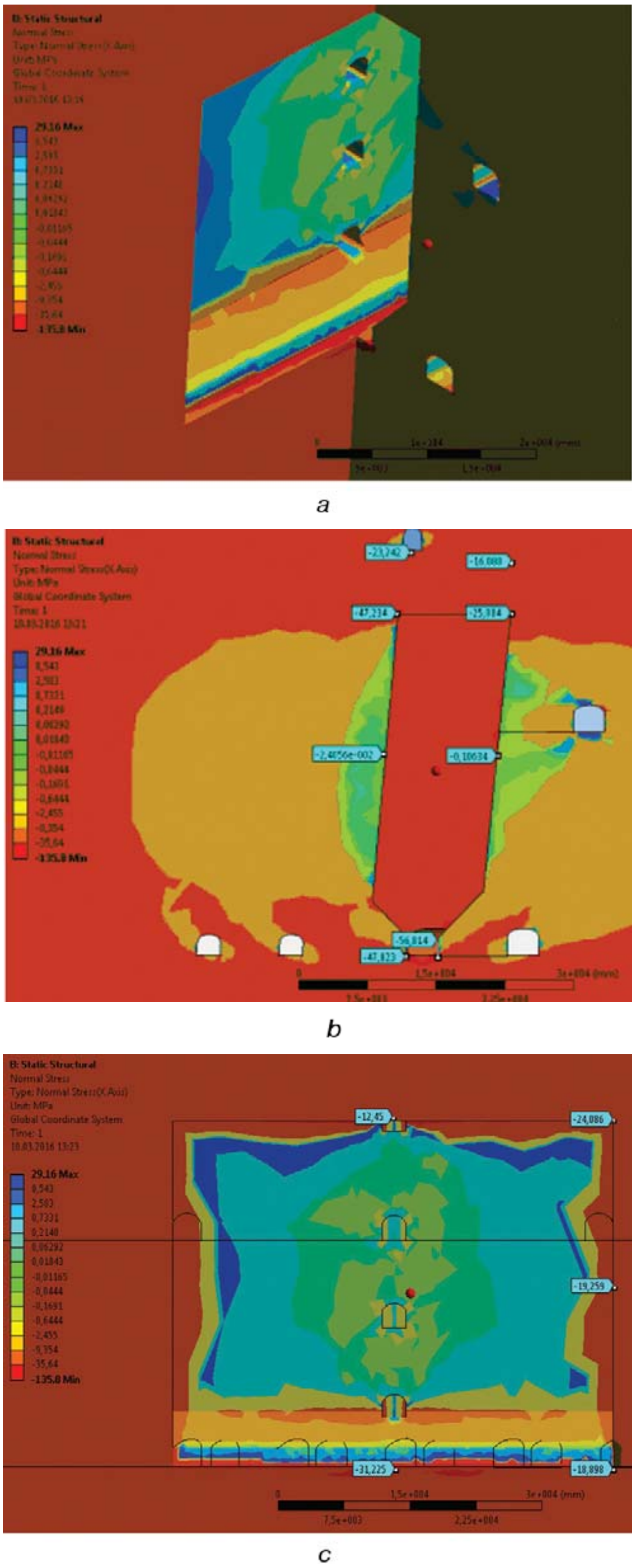

Fig. 2. Distribution of maximum normal stresses in rock mass around stoping zone during re-extraction operations:
a — general view; *b* — profile across the strike;
c — profile along the strike

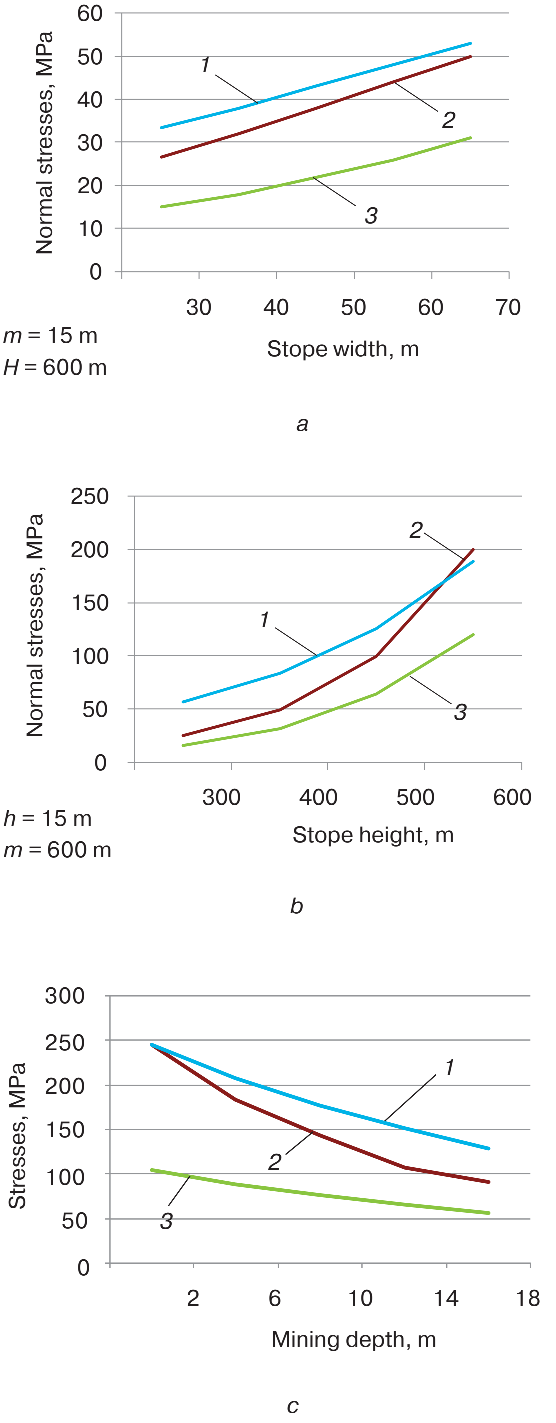

Fig. 3. Normal stresses in the load-bearing elements of mining system versus:
***a* — height of stope; *b* — depth of stoping; *c* — width of stope;**
***1* — upper part of crown pillar; *2* — bottom part of crown pillar; *3* — bottom;**
***m* — stope width, m; *h* — stope height, m; *H* — mining depth, m**

of the pillar. These processes run for a few months after rock mass exposure as the operating practice of Kochkar field mining shows. As a result, edges of pillars fail, and a core of triaxial compression forms in the pillars.

The deeper level mining induces increase of stresses in the structural elements of the mine. With an increase in the width of stopes, the normal stresses at the boundaries of the structural elements decrease due to redistribution of stresses in rocks mass and owing to the increased deformation of rocks toward the stoping zone. Evidently, re-extraction of mineralized zones with the enlarged span stopes will not aggravate the geomechanical situation as compared with the technology currently in use in the mine. Secondary extraction of mineral reserves is expedient to start from the upper levels under the stresses several times lower than at the deeper levels.

The studies into dynamics of deep rock mass stress state show that the stress distribution in the load-bearing elements of the mine system is the same as at the upper levels. The maximum compressive stresses are also recorded at the stope floor corners (152–236 MPa), in the roof (107–148 MPa) and in the crown pillar (66–90 MPa), and are comparable with the strength characteristics of rocks. In the footwall and hanging wall of the stope, stresses become tensile (0.1 MPa). Cemented backfill changes the distribution pattern of normal stresses around the stope insignificantly. The ore crown pillar is yet under loading. However, compressive stresses in the corners of the stope roof and floor reduce to 96–137 MPa and to 139–148 MPa, respectively.

Thus, transition to stoping with an enlarged span to 12–15 m will aggravate geomechanical situation as load-bearing elements of extraction blocks are subjected to higher stresses, which activates dynamic events due to rock pressure.

Conclusions

Mining practice at Kochkar deposit and the implemented research show that rocks are strong, rigid, brittle, are characterized by high elasticity modulus and can accumulate and dynamically release elastic energy. In deeper level mining, it is observed that geological and geotechnical conditions complicate: stress state of rocks increases, content of valued component drops, frequency and intensity of dynamic rock pressure events grow. According to the research findings, stress state of rock mass in Kochkar field is complex and nonuniform. Aimed at enhancement of mine safety from the viewpoint of geomechanics, measures are undertaken to decrease the current stress state of rocks and to transfer mining operations to zones of lower stresses. The former implies relaxation of rock mass by drilling, confined blasting, advanced blasting in local areas, orientation of stopes along the lines of principal stresses and by specific shaping of stopes. The latter suggests transition of mining to upper levels where stresses are 8–12 times lower than at the deeper levels and it is possible to enlarge the stoping span.

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