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EVALUATION OF THE STRESS-STRAIN STATE OF THE KOCHBULAK AND KYZYLALMA DEPOSITS WITH TECTONIC STRESSES INCLUDED WITH THE FINITE ELEMENT METHOD

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Abstract: *In the world, the modern development of the mining industry is directly related to the development of complex structural mineral deposits at great depths under conditions of geodynamic and geomechanical risk. Especially when mining mineral deposits underground at great depths, rock pressure is manifested in a dynamic form and there is a danger of rock bursts. The practice of mining in rock burst conditions and the fight against rock bursts have more than 100 years of history. However, many important issues are currently far from being resolved, which is due to the complex nature of the stress-strain state of the developed deposits of mineral deposits, the formation of which involves numerous natural and man-made factors that are difficult to take into account. In this regard, rock pressure management with the use of methods and tools for assessing and monitoring the geomechanical state of a rock mass, fully taking into account the features of geodynamics and mining conditions within specific ore fields, is an* *important scientific and technical task. The article presents the results of an assessment of ways to eliminate the negative consequences of geomechanical processes occurring in the rock mass of the Kochbulak and Kizilalmasai deposits based on geodynamic modeling of a natural stress field.*

Keywords: *forecast, geomechanical state, rock mass, rock impact, stability, deformation, stress-strain state, collapse, rock pressure, fracture, geomechanics, geodynamics, mine workings, impact hazard, rock structures, geodynamic hazard, stress field.*

INTRODUCTION. To date, a lot of experience has been accumulated in the creation and application of methods and tools for assessing the stress-strain state of rock masses. Deformation methods have been developed for measuring the full values of stresses acting in a rock mass (methods of unloading and hydraulic fracturing), based on the registration of mechanical displacements and deformations in the process of mechanical disturbance of the stress state of the rock mass [1, 2, 3].

These instrumental methods, having a number of advantages, have a number of disadvantages, which are their laboriousness, the need to determine the elastic characteristics of rocks at the measurement site, as well as the difficulty of extrapolating the results of point measurements to large volumes of rocks. In addition to unloading methods, instrumental methods for measuring stresses and strains are used, which include methods of downhole deformometers, hydraulic inclusions, photoelastic sensors, coatings, depth and contour benchmarks, etc. [2, 4, 5, 6].

To assess the geomechanical state and rockburst hazard of the massif, a number of methods based on the study of the behavior of rocks during well drilling and workings have been developed and are being applied. Of these, the core disking method is recommended as the basic one [7]. The Mining Institute of the Kola Scientific Center (KSC) of the Russian Academy of Sciences (RAS) has developed the workover method, which is based on the effect of destruction of borehole walls in zones of high stress concentration [8]. When assessing the impact hazard, methods are also used based on the indentation of a punch into the walls or bottom of the well and implemented using MHS (multi-point hydraulic sensor) and BP-18 hydraulic devices [7, 2]. The degree of shock hazard in all methods is established by special nomograms, built on the basis of the results of experimental studies.

An increase in the efficiency and reliability of the forecast of both the rockburst hazard of deposits and the regional forecast in the process of their development is provided by knowledge of the block structure of the rock mass in the area of the deposit and the interaction of blocks and, as a result, the stress state of the untouched massif in each block.

The results of a comprehensive study of the stress-strain state of rock masses, which showed the comparability of the measured stresses with the stresses determined using tectonophysical methods [9, 10], indicate that geological structures, including tectonic faults, contain information about modern stress fields in the earth's crust. An analysis of the conditions and factors of dynamic manifestations of rock pressure in mines shows that the signs of burst hazard and more prone dynamic processes mainly occur after blasting and, as a rule, are confined to areas of the massif with hard rocks. The experimental studies of the effect of blasting on the seismoacoustic activity of rocks showed that the seismic effect of blasting during breaking has a significant effect on the manifestation of rock pressure in a dynamic form.

MATERIAL AND METHODS. Analytical, engineering and experimental methods for determining the stress-strain state of the massif are widely used in assessing the state of mine workings at rockburst-prone deposits. Studies of the stress-strain state of a rock mass were carried out using the slot unloading method [1, 11]. The use of the slot unloading method makes it possible to obtain information about the stress in a section of about 1 m. To obtain this information over a larger area, especially when the rock mass has a large fracturing and heterogeneity, it is necessary to increase the number of slot unloading measurements.

The essence of the slot unloading method is the formation of a slot (Fig. 1, 2) with a radius of 0.3 m and measuring the deformation of its walls by the slot. The influence of such a zone of unloading of the rock mass in this method reaches three slot sizes. In this case, the influence of the multi-modulus nature of the rocks included in this zone, the interaction of structural blocks and their residual stresses is significantly reduced.

Fig.1. Horizontal discharge slot

Fig. 2. Vertical discharge slot

According to the method described above, field measurements were carried out at the Kochbulak deposit in the crosscut and the second northern drift at the height of 1030 m (14 measurements), at the adit 44 and the field drift of the ore body 238 (15 measurements), at the crosscut No. 1 of the mountains. 1080 m, on Crossroad No. 1, roadway 1sev, and on field roadway 216/9 mountains. 930m. and at the Kyzylalma deposit - in adit No. 15 mountains. 1165 m, crosscut, mountain drift 806 m, crosscut-2 and drift 10B mountains. 865 m. The total number of unloading slots was 29. Based on the results of these measurements, the stresses of the rock mass were determined, acting vertically ($\sigma_{в}$), along the strike of ore bodies (longitudinal $\sigma_{пр}$), across the strike of deposits (transverse$\sigma_{п}$). A total of 267 stress values were determined. Statistical processing of calculation materials was done according to a well-known method [15, 18].

The confidence interval for determining the average stress values is 12.7-40.3% of their absolute values, which corresponds to the accuracy limit of rock stress measurements using modern methods. Therefore, the measured values of the initial stresses can be used to assess the impact hazard of deposits and determine the parameters of structural elements of underground structures.

An analysis of the results of determining the initial stresses of the rock mass allows us to note the following: - at the measuring sites, a spread of measurement data was obtained, and, consequently, of the calculated stresses of the rock mass; - the uneven distribution of stresses in the massif causes a complex tectonic structure, in particular, blocky rocks, limited by systems of cracks and disturbances, as well as mountainous terrain; - the actual vertical stresses of the rock mass are practically equal to the gravitational stresses due to the weight of the overlying rocks, equal to γH according to Heim, where γ - is the volumetric weight of the rocks, MN/m^3, H - is the mining depth; - horizontal stresses directed along the strike of ore bodies are 1.3-1.5 times less than vertical stresses; - the maximum values are stresses acting across the strike of ore deposits. They are 1.4 times higher than the vertical stresses.

RESULTS AND DISCUSSION. The excess of horizontal stresses $\sigma_{п}$ over vertical ones can be explained by the presence in the massif, along with gravitational stresses, of significant stresses of tectonic origin, supported by modern neotectonic movements of the earth's crust. Summarizing the given data on the geological and tectonic structure and on the geomechanical state of the rock massifs of the Kochbulak and Kyzylalma deposits, we note the following features:

1. Unequal component stress fields operate in the deposit arrays, in which horizontal

compressive stresses predominate, the largest of which are oriented in the sublatitudinal direction. They are 1.1-1.4 times higher than the gravitational component of the weight of the overlying rock strata, thus indicating the determining influence of tectonic forces in the formation of a natural stress state.

2. The heterogeneity of natural stress fields is replaced by the complexity and features of the tectonic structure of deposits, which is further enhanced by the technogenic impact on the rock mass as a result of mining operations.

In recent years, numerical methods have been increasingly used to study rock bumps and theoretically solve various geomechanical problems, among which the finite element method (FEM) and the boundary element method (BEM) should be singled out. These methods are especially widely used in modeling technogenic stress fields caused by the influence of mining operations, as well as in calculating the stability of various elements of development systems and mine workings [12, 13, 14].

Summarizing the above, the following can be noted:

- to date, a large number of methods and tools for field studies of the geomechanical state of the massif have been developed, the area of effective application of which is determined by the specific geomechanical and mining-technical situation;
- reliable prediction of hazardous dynamic manifestations of rock pressure requires the use of a set of regional and local methods of geomechanical monitoring and rock burst hazard control in combination with methods for modeling conditions and processes that cause rock bumps;
- full-scale and theoretical methods should be maximally adapted to the mining-geological and mining-technical conditions of the development of a particular deposit and ensure continuous monitoring of the geomechanical and geodynamic processes occurring in the rock mass.

The purpose of this study is a numerical study by the finite element method (FEM) of the stress-strain state (SSS) of the host rock massif of the Kyzylalmasai deposit (hereinafter referred to as the “massif”) in the vicinity of a single mine working with a tent section and comparison of the SSS of the massif with the results obtained experimentally in two mine workings: crosscut No. 2 and drift 10*b*. These experiments show that horizontal stresses acting in the array exceed vertical ones. Consequently, tectonic stresses act in the massif. Comparison of experimental studies with numerical ones made it possible to establish the direction of the main vector of tectonic stresses in the massif.

The work [16] presents a number of experimental measurements of horizontal stresses in workings remote from the main mining operations with axes directed mainly across the strike of the ore body. In the future, it is planned to supplement these data with experiments in workings with axes of other directions. To date, there is no assessment of the stress-strain state of rocks for multi-storey and multi-block excavation spaces, which comprehensively takes into account the variable depth of development and tectonic loads. In this paper, we have developed a method for restoring a constant in depth tectonic stress field using the above measurements and performed a 3-dimensional finite element modeling of the stress-strain state of the zone of the final state of the treatment works, performed by three floors and three chambers, at different depths of the zone loaded with its own weight, weight of overlying rocks and tectonic stresses. The following analytical formulas for horizontal stresses in an intact massif were obtained [16]:

$$\sigma_x = \sigma_T + \chi \cdot \sigma_y,$$
$$\sigma_z = \nu \cdot \sigma_T + \chi \cdot \sigma_y. \quad 1$$

and in workings remote from the main excavation works, directed along their axes *v*

$$\sigma_{xv} = \sigma_{tv} + \nu\sigma_y . \quad 2$$

In addition, the following formulas were obtained for calculating the main values of tectonic stress from the maximum value (excavation axis n) of the tectonic component in two intersecting excavations (axis *m, n*) (Fig. 3).

$$\sigma_t = \frac{2\sigma_{tn}}{1+\nu+(1-\nu)\cos 2\theta} . \quad 3$$

$$\delta = \sigma_{tm} / \sigma_{tn}, \quad 4$$

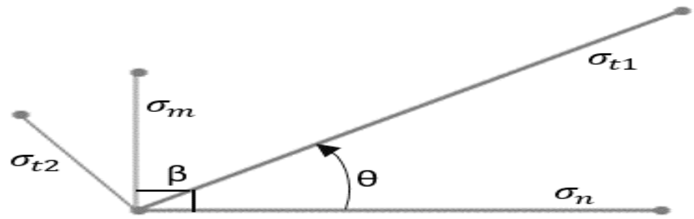

Fig. 3. Scheme for calculating tectonics stresses.

The quantity vector (3) makes an angle ϑ with the direction of the n axis. To calculate ϑ, formulas are obtained:

$$A = \frac{1-\nu}{1+\nu}\sqrt{1-2\delta\cdot\cos 2\beta+\delta^2},$$
$$\varphi = \arccos\frac{\sin 2\beta}{\sqrt{1-2\delta\cdot\cos 2\beta+\delta^2}},$$
$$\theta = \frac{1}{2}(\varphi - \arcsin\frac{1-\delta}{A}). \quad 5$$

According to (2), correctly measured stresses in the workings should include, in addition to the tectonic component, a part of the vertical stress, which depends on the depth of the working. Taking this into account allows us to formulate two criteria for incorrect voltage measurements:

- coinciding stresses of the same direction, related to different depths.
- stresses exceeding the stresses of the same direction of deeper horizons.

The application of these criteria makes it possible to exclude measurements at horizons 1080 and 930 from consideration (Table 1).

Table 1

Selection of measured horizontal stresses

Depth	Along strike	Across	Mining/Horizon	Not correct
120	4.8	6.5	Crosscut 1. 1080	Stretch
170	4.8	8.4	Drift 2. 1030	
270	7. 2	12.53	Crosscut 1. 930	Cross and stretch
320	7. 2	10.5	880	

Further, we consider stress values only at horizons 1030 and 880. In addition, the considered depths should have a single tectonic stress field. Therefore, by equating the values of relations (4) for two depths, we obtain considering that according to (2) *σt* = *σ*г - *νσH*:

$$\frac{\sigma_{\text{гm}1}-\nu\sigma_{\text{H}1}}{\sigma_{\text{гn}1}-\nu\sigma_{\text{H}1}}=\frac{\sigma_{\text{гm}2}-\nu\sigma_{\text{H}2}}{\sigma_{\text{гn}2}-\nu\sigma_{\text{H}2}} \quad 6$$

A simple solution takes place when the numerators and denominators are equal, respectively:

$$\sigma_{\text{гm}1} - \nu\sigma_{\text{H}1} = \sigma_{\text{гm}2} - \nu\sigma_{\text{H}2} \quad 7$$

$$\sigma_{\text{гn}1} - \nu\sigma_{\text{H}1} = \sigma_{\text{гn}2} - \nu\sigma_{\text{H}2} \quad 8$$

Then, separating the measured and weight components, we obtain:

$$\sigma_{\text{гm}2} - \sigma_{\text{гm}1} = \nu(\sigma_{\text{H}2} - \sigma_{\text{H}1}) \quad 9$$

$$\sigma_{\text{гn}2} - \sigma_{\text{гn}1} = \nu(\sigma_{\text{H}2} - \sigma_{\text{H}1}) \quad 10$$

Two expressions (6) represent two independent values of horizontal stresses from the four stresses included in these expressions, since the right parts of these expressions are the same value: $\Delta = \nu(\sigma_{\text{H}2} - \sigma_{\text{H}1})$. Leaving the stresses at a depth of H_2 = 320 m unchanged, we will correct the measurement values at a depth of 170 m (Table 2) [17].

Table 2

Correction (σg), (5) for H= 320 m, ν=0.23.

H, м	Measurements, MPa		Correction, MPa				
	σгn	σгm	σH =PgH	νσH	Δ	σгn	σгm
170	8,4	4,8	4,553	1,047		8,4	4,8
320	10,5	7,2	8,57	1,971	0,924	9,324	5,724

In table. 3 obtained the same values of the tectonics components in pairs of workings located in their vertical planes.

Table 3

Isolation of the tectonic component in the working, MPa

Horizon	H, m	Weight, MPa			Correction, MPa		σt=σг - νσH, MPa		δ (4)
		σH =PgH	ν	νσH	σгn	σгm	σtn	σtm	
1030	170	4,553	0,23	1,047	8,4	4,8	7,353	3,753	0,51
880	320	8,57	0,23	1,971	9,324	5,724	7,353	3,753	0,51

According to formulas (3) , (4) and (1) - (lower formula at σ_y = 0) the main components of tectonic stresses are restored (Table 4).

Table 4

The main stresses of the tectonic field

σtn	σtm	δ	β˚	ν	A	φ ˚	θ ˚	σt1, MPa	σt2, MPa
7,353	3,753	0.51	90	0,23	0,946	90	29,408	9,029	2.077

CONCLUSION. A detailed analysis of the results of modeling tectonic stresses in the structures of the Kochbulak ore field showed that the areas of conjugation and intersection of faults are zones of concentration of tectonic stresses, the value of which sometimes reaches 22 g/cm^2. But this does not always happen. In some areas, the reverse process is observed - the unloading of tectonic stresses.

Complete stress relief is usually noted along faults, where zones in the form of elongated lenses meet, and also in the inner parts of blocks - in the form of a ball. The axes of almost all lenticular unloading zones are oriented to the northwest at some angle to the direction of horizontal displacement along the faults along which they formed. A similar picture was observed in the experiment when modeling tectonic stresses in the structures of the Kochbulak-Kairagach ore fields, where neutral zones of the northwestern direction are marked. The formation of tectonically weakened zones between large fault structures can only be associated with shear displacements along these faults during tectonic compression.

Analysis of the experimental results allowed us to draw the following conclusions:

- introduction of additional structures into the model, imitating ore-controlling and ore-bearing faults, to a large extent changes the nature of the distribution of tectonic stresses both in the Kochbulak ore field as a whole and in its individual blocks;

- there is a significant concentration of tectonic stresses in the southern block of the ore field with a wide range of their variation (from = 0 to = 20 g/cm^2);

- a technique for restoring a constant depth tectonic stress field based on measurements of horizontal stresses in a pair of workings with intersecting axes has been developed;

- formulas for correcting the results of stress measurement were obtained;

- the main tectonic stresses for object *K* were restored, exceeding the vertical stress at depths of 170-320 m, respectively, by 1.98-1.05 times.

In general, the developed technique can be fully used to solve similar problems at other facilities.

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MAPPING OF MINERALS BY THE METHOD OF GEOLOGICAL INDICES FROM ASTER SPACE IMAGES

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Abstract: *The study of the spectral properties of minerals and rocks by remote sensing methods are based on mineralogical and petrographic studies. The article presents the results of calculation of mineral indices using ASTER (Advanced Space Thermal Emission and Reflection Radiometer) satellite images of the central part of the North Nurata Mountains. Pre-processing of the space image, including geometric and radiometric correction was carried out with the ENVI 5.3 program. Mineral indicators of ore minerals, such as iron oxides, carbonate, silicate and siliceous minerals were identified based on mathematical operations of ASTER space imagery channels. The mineral index results provided accurate spectral information on mineral indicator minerals and lithologic mapping while showing the spatial distribution of these materials. The areoles of the identified mineral groups mostly coincide with mineralized zones on the various ore minerals. The results can be used to create and update mineral distribution maps to predict new areas of mineral accumulations.*

Keywords: *ultispectral images, ASTER, indicator minerals, combination of channels, interpretation, mineral indices, hydrothermal alteration of rocks, gold mineralization.*