E3S Web of Conferences **56**, 02025 (2018) https://doi.org/10.1051/e3sconf/20185602025
VII International Scientific Conference "Problems of Complex Development of Georesources"

THE GEOMECHANICAL STATE OF THE MINE «MNOGOVERSHINNOE» LOWER LEVELS MONITORING

Arkady Avdeev[1*], *Elena* Sosnovskaya[2] and *Roman* Krinitsyn[1]

[1]Institute of mining- the Ural branch of the Russian Academy of Sciences, Ekaterinburg, Russia
[2]Irkutsk National Research Technical University, Irkutsk, Russia

Annotation. In the low level mining of the Mnogovrshonniy mine, there was a harmful rock stress manifestation in the form of displacement and collapse of rock blocks, which adversely affected the safety of mining operations and reduced the mining efficiency. There was an urgent need to conduct special studies of the geomechanical execution process at the mine. In the process of research the basic physical and mechanical rock characteristics were determined, the initial natural ground stress, man-made stress in mines and pillars was measured, the stability degree of underground cavities was determined. Based on the current geological and surveying documentation analysis and visual observations, the areas of mine workings that are dangerous because of the rock stress and displacement manifestations were established. For the identified areas, projects to set the observation stations to monitor the parameters of the geomechanical state of excavations that affect the safety of mining operations have been developed. The most optimal methods and observing techniques for specific conditions of the mine were chosen. Based on the developed projects, a complex of observation stations on the low mine level was set. Several series of observations were made. The research helped to identify the factors that had the most influence on the mine stability. The assessment of the underground cavities stability degree was carried out, measures to ensure the safety of mining operations were proposed, and the directions for the further research on the creation and improvement of the rock stress observation stations system at the mine were proposed.

1 Introduction.

The Mnogovershinnoe deposit has a complex geological structure and faulting. There are several ore bodies: Glubokoye, Promezhutochnoye, Severnoye, which are being mined simultaniously and often combined. The underground working of ore bodies Tihoye and Olenye has started. Severnoyer and Verhneye ore bodies mining is complicated because of a significant amount of unextinguished underground cavities and closely spaced quarry

*Corresponding author: avd8691@yandex.ru

workings. The day surface is substantially damaged by underground operations, especially in the area of Glubokoyer and Severnoye ore bodies.The depth of mining operations at the mine currently reaches 400 meters and more.

The low level Mining of the Mnogovershinniy ore showed harmful rock pressure manifestations - the displacement and collapse of rock blocks, which adversely affects the safety of mining operations and reduces the efficiency of the field mining. For example, in 2012 there was a collapse of the entry site to the underground cavity of the underlying Promezhutochnoye ore body-producing block. In 2014, the balmstone appearance was observed at the lower level on the roof and the sides of the vehicle and ventilation entry 380-1, waste roadway, 327, orts 327-1-2, 327-1-1 and near the block rising 352-327. Intensive water inflow in the form of the water drip was noted [1].

There was an urgent need to conduct special studies of the development of geomechanical processes at the mine to improve the safety and efficiency of mining operations.

The IRGTU (Irkutsk national research technical University) and the Institute of mining, Ural branch of Russian Academy of Sciences conducted a comprehensive research of geomechanical condition of the structural elements of mining systems in 2012-2017 In the course of studies in accordance with current instructions of the Federal Budgetary Institution Scientific and Engineering center "Power Safety" there was an urgent need to build complex rock stress observing stations for the operative monitoring of the current manifestations of rock displacement and rock stress processes.

2 Methods of research

In 2012 on the basis of normative documents of the Irkutsk Research Institute of precious and rare metals and diamonds, Research Institute of mining geomechanics and mine surveying — intersectoral scientific center "VNIMI" and Unipromed institutions, and many years of practical experience in the study of rock stress at the gold-mines, experts of the institutes of the Irkutsk National Research Technical University and Institute of mining, Ural branch of Russian Academy of Sciences developed a package of normative-technical documentation for the mine, including:
guidelines for determining the design parameters of mining systems; instructions for the protection of structures, natural objects and mining from the harmful effects of underground mining; instructions for safe mining; instructions for the organization of comprehensive monitoring of geomechanical condition; conclusion about the potential rock-bump hazard of the mine. In the developed documents for the specific conditions of the mine, the main objects of protection were selected and the basic methods and techniques for monitoring the parameters of geomechanical and geophysical condition of areas potentially dangerous for the manifestations of displacement and rock stress, and protected mine workings were set.

Dangerous and protected areas are:

- Mining, disturbed by steeply dipping tectonic faults, which possibly contain water, causing the collapse processes.
- II category of protection mining (ventilation and transport entries, etc.), in the security pillars which had suffered partial dredging of the mineral
- Mining sites of the III category of protection, which are located in the zone of influence of the stopes and after the expiration of the pillars expected service life and the roof exposures of the underlying operational blocks chambers.
- Mining sites, where the processes of displacement and collapse of individual blocks of rocks by visual and instrumental surveying observations were identified.

During the stoping the protected objects are: temporary over- and under-track pillars, inter-chamber pillars, and the exposure of the walls and roof of the chambers. Long-term effect monitoring stations (slice discharge, pairs of landmarks, the profile lines landmarks) setting is expected to be conducted using transport and ventilation entries, as the main protected workings of the II category [4]. The III category protection excavations (block rising, a subsidiary crosscuts and entries, haulage orts, etc.) are recommended to be performed using the following methods: sound-ranging control, analysis of fracture by core exploration wells, visual observations. In areas potentially dangerous for the manifestations of displacement and rock stress, surveying measurements of deformation and convergence of the working walls were proposed, along with the visual observation and slice discharge. To forecast the category of rock-bump hazard of potentially dangerous areas of the low mine level, the core disking is used as the basic method.

The category of protection of mine workings and their separate sites, dangerous with the displacement and rock stress manifestations are set based on the current geological and surveying documentation analysis and visual observations. The relevant projects of monitoring stations settings to track the geomechanical condition of mine workings that affect the safety of operations were developed later. The type of stations, their spatial position and methods of observations were specified for specific geological and technical conditions of mining.

3 Research result

The main geomechanical factors that complicate the field mining were identified. The physical and mechanical characteristics of rocks and ores were determined, the regularities of the tectonic structures formation were revealed, and the initial stresses of the rock mass were determined by the natural measurements [1].

It was found that rocks and ores of the Mnogovershinniy Deposit have high elastic characteristics and are capable of brittle destruction under load. Prone to brittle destruction are andesites, diorites-porphyry, siltstones, sandstones, ore metasomatites, unconventional – basalts and tuffs.The initial stress of the rock mass was measured using the slice discharge according to the Mining Institute, Ural branch of RAS method (table.1) [2].

The measurements were carried out in August 2012 in Glubokoe ore body in the runaway 253/183 and in the block rising pass 183/2511-2. The depth of mining operations at the site of measurement was 284 m. The stress was measured in slots. In October of the same year, measurements were carried out in the transport and ventilation entry 245/254 and access crosscut № 1 at the depth of 380 m in 21 slots. In may 2017, held in the transport and ventilation entry 395 m (runaway 1 410/395) and in the cutting №30. The depth of mining operations at the site of measurement was 350 m. the Total number of slice discharges - 12

Analysis of the measurements results of natural stresses allows us to note the following.

The values of natural stresses in the rock mass on average are approximated by formulas

$$\sigma_v=-\gamma H \qquad \sigma_L= \sigma_t= - K\gamma H = -1.23..1.24\, \gamma H \qquad (1)$$

With σ_v, σ_L, σ_t - natural vertical, horizontal longitudinal and horizontal transverse stresses of the rock mass, MPa

γ - the density of rocks and ores, MN/m3; H - The depth of mining operations, m; K - The horizontal stress coefficient.

It is obvious that the magnitude of the horizontal stresses measured are close to the values of the stresses according to the hypothesis of gravitational tectonic stress (hypothesis E. I. Shemyakin, M. V. Curleni, N. P.Vloh, etc.) [2,3,5,6].

The spread of this coefficient is explained by the uneven distribution of natural stresses in the rock mass. Taking into account the fact that the difference between the depths of all three stations does not exceed 100m, it is advisable to average the coefficient by the results of all three measurements to predict the natural stress state of the field as a whole. The resulting the horizontal stress coefficient will be 1.23..1.24.

It seems appropriate to carry out in the process of further research the clarification of the stress state of the massif with the reduction of mining operations and the mining of the other ore bodies in the Deposit.

Table 1. Results of field measurements of natural stresses

Orientation of stresses relative to the ore body stretch	Mining depth m	Results of field measurements	
		The number of individual stress measurements	Stress value, MPa
Runaway 253/183 and block rising access 183/2511-2			
Vertical σ_v	284	42	-7.7±1.0
Longitudinal σ_L	284	18	-11.8±2.7
Transverse σ_t	284	18	-11.1±1.2
The transport and ventilation entry 245/254 and access No. 1			
Vertical σ_v	380	54	-10.3±0.7
Longitudinal σ_L	380	24	-10.6±0.8
Transverse σ_t	380	24	-11.3±1.3
The transport and ventilation entry 395 and the cutting №30			
Vertical σ_v	350	16	-9.7±2.3
Longitudinal σ_L	350	16	-11.2±2.7
Transverse σ_t	350	16	-11.1±1.9

In addition to the measurements of natural stresses, long-term rock stress monitoring stations in the form of slots in the pillars and walls of excavations were set in the mine using the method of slice discharge. It should be noted that the service life of such stations mainly depends on the degree of safety of mine workings.

Rock stress measurement station set in 2012 in the transport and ventilation entry 245/254 and access No. 1, in the runaway 253/183 and block rising access 183/2511-2 were destroyed in the mining process (flooding of mine workings). An effective method of observation of processes of rock pressure is the deformations of paired landmarks mine monitoring. It is obvious that the use of this technique is convenient for extended workings of II and III categories of protection [4]. In November 2014 in the area of the stope 380-5 in the transport and ventilation entry 380-1 was studied. The depth of mining operations on the site of measurement was 180-200 m. pair landmarks were laid in the amount of 8 pieces, i.e. 4 pairs landmarks. Landmarks were laid on expanding anchors with the depth of 12-15 cm, with a diameter of 12 mm. Two series of observations were made - in 2014 and 2017. It was found that the total deformation between the pairs of landmarks were 1-14 mm over a three-year period of measurement, i.e. there was a slight compression of the walls of the workings. Given the error of surveying measurements, it can be concluded that the deformation is small and does not exceed the permissible, equal to 100 mm for displacements in the workings of II category protection. Walls of transport-ventilating entry 380-1 are sustainable. It is recommended to continue the measurements at the station.

To control the mine working and pillars walls stability the station was set in 2014 in the form of a number of relieve slots in block C320-15, on the field entry 327-1 and entry orts (Fig.1). The destruction of certain pillars and the reinforced water flow were found on the site. Three series of surveying instrumental observations were made: in November and December 2014, and in May 2017.

The results of the observations allow us to note the following: the nature of the stresses in the slope is compressive, in the field entry - compressive too. The resulting stresses in them are in the horizontal plane (vertical slots) – minus 13.4 MPa, in the vertical plane (horizontal slots) – minus 13.9 MPa on average.

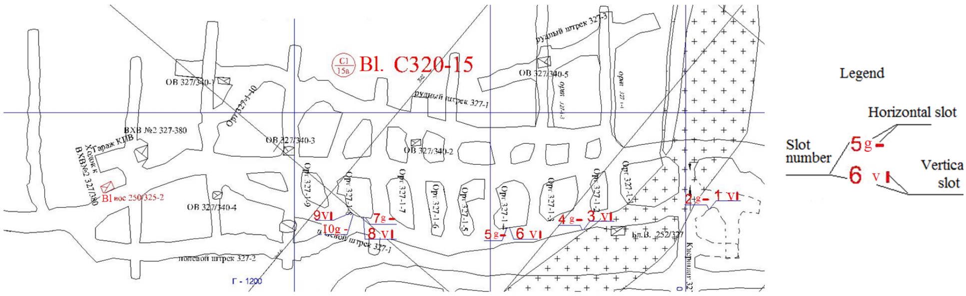

Fig 1. Observation station plan to control of geomechanical state of the mine workings by the relieve slots (327 m level)

The strength limits of rocks in dry and water-saturated state, respectively, equal to 103 and 66 MPa were determined from the samples taken on the studied level. The allowable compression stress is not less than 0.7 compression strength limit. Consequently, the allowable stress in dry workings will be minus 72 MPa, in watered-minus 46 MPa (minus means compression of rocks). It is obvious that the actual stress in mining is much less than acceptable at any degree of water cut. The crosscut 327 m level and the slope junction, the southern wall of the field entry 327-1 are sustainable.

The pillar No.1 (slots 5 horizontal, 6 vertical), there is a stable lateral extension with a small vertical compressive stresses. Apparently, this is due to the gradual destruction of the pillar or the possible opening of the fracture in the area of the slot No. 6. The pillar No. 2 (slots 8,9) has a small tension in the horizontal plane that marks a gradual unloading of the pillar. The resulting horizontal stresses in the pillar are close to the transition from compressive to tensile and are +0.3....-1.7 MPa. With this dynamics, the pillar number 2 will also gradually collapse.

It is recommended to continue to make regular visual observations and to assess the stability of the other pillars in a timely manner. It is necessary to provide the possibility of the collapsing pillars extraction. In May 2017 activities on the development of a rock stress monitoring stations network continued. Observation stations were set in the transport and ventilation entry 395 m (runaway 1 410/395) and ore body Glubokoye cutting №30 .Depth of mining works at the site of -350 m. Relieve slots in the amount of 12 pieces. The results of stress measurements at the station on the mining level of 395 m allow us to note the following. The nature of the stresses in the cutting number 30 and transport and ventilation entry 395 m (runaway 1 410/395) - compressive.

The stress level in the cutting No. 30 averages: in the horizontal plane (vertical slots) or minus 9.4 MPa, in a vertical plane (for horizontal slots) – - 12.5 MPa, in the transport and ventilation entry 395 m stresses in the horizontal plane will be -9.5 MPa, in a vertical -12.3 MPa, in the runaway 1 410/395 -8.7 MPa to 15.6 MPa, respectively.

Allowable stress in compression in the area of observation stations in the dry state of the mine workings is equal to minus 60 MPa, due to flooding minus 52 MPa. It is obvious that the actual stress in the mine workings, constituting minus 9.4 ÷ minus 15.6 MPa is significantly less than acceptable at any degree of water cut. Currently, cutting No. 30, transport and ventilation entry 395 m and the runaway 1 410/395 are sustainable.

The core material of the drilling camera exploration wells № 3 cutting № 30 was selected on the same site to assess the degree of danger of rocks by the method of core disking. The analysis of core material of the disking zone on did not reveal small discs with a thickness of 1-5 mm, the danger of the rock-bumps in the Glubokoye ore body lower level does not exist. It should be noted that the calculated critical depth of rock-bumps is 300-440 m (in the mathematical modeling of the stress-strain state of mine workings, conducted in the zone of stopes bearing pressure) [1]. Therefore, in addition, in order to confirm the rock-bump resistance of the rock mass, during the excavation of new workings, experimental field observations were carried out by the acoustic emission device SB32 №002 [7-10]. Measurements were made on the mining level of 305 m in the area of the Glubokoye ore body after rock blasting.

The results of the measurements showed that the total number of pulses measured during 40 minutes is 39. The average activity of acoustic emission is 0.97, i.e. approximately 1 signal per minute. This distribution of sound pulses corresponds to the steady state of the rock mass. The results of emission measurements confirm the hazard category "not dangerous" at the current depth of mining operations in the development of the Glubokoye ore body.

It should be noted that at the mine by the staff of The Mining Institute, Ural branch, Russian Academy of Sciences (senior researcher Liping J. N., senior researcher, V. V. Bodin) were also carried out geophysical researches of the degree of rock works stability in the the rock stress station setting area in 2012 in the runaway 253/183 and block rising pass 183/2511-2. As experimental methods, seismic transmission of the massif with the construction of tomographic scheme of the site (elastic wave velocities trend) and seismic profiling of the massif on mine workings were used.

The tectonic structure of the rock mass was estimated based on the results of seismic transmission at the station location. Two zones of tectonic disturbance were discovered: one perpendicular to the field entry 250-1 and the junction of the field entry and the orts 250-1-4250-1-6. It is suggested that the position of mineralization zones can also be predicted using the seismic transmission method at the mine. According to the results of seismic profiling of the massif, a correlation between the magnitude of the horizontal natural stresses σ_h and the velocity of the longitudinal seismic wave V was established

$$\sigma_h = -18.87 + 0.00507 \cdot V \text{, m/s} \quad (2)$$

Unfortunately, both methods have not been further applied at the mine due to the high complexity and cost of work.

4 Summary

Mnogovershinnoye Deposit stand the gravitational tectonic stress. On the upper levels, the rock mass is characterized mainly by a stable state. The earth's surface, minings and stopes in the area of mining Olenye, Glubokoye, Tihoye ore bodies are currently stable. Geoinformation researches of the tectonic structures formation regularities, evaluation of exploration wells core disking, measurements of stress did not show the areas of the rock massif with the rockburst hazard [1].

The factors reducing the stability of mine workings at the Mnogovershinniy Deposit are established: steep tectonic disturbances, water saturation of rocks, working off of contiguous ore bodies, the depth of mining operations of 300 m or more, a high degree of earth's surface damage, the influence of nearby open-pittings.

Thus, the mining of ore bodies Severnoye and Verhneye is complicated by a high degree of the earth's surface damage and quarry workings. Mining of the Promezhutochnaya ore body is complicated by the high damage, steeply dipping tectonic faults, water-bearing rocks. It is necessary to make provisions for the setting of the long-term observation stations in the form of profile landmarks on the earth's surface over these ore bodies and paired, profile landmarks or slice discharges - on the lower levels. The calculated critical depth of the rock pressure manifestations in dynamic forms during the stoping is 300-440 m

[1]. At these depths, the mine workings carried out in the zone of bearing pressure of the stopes have the calculated stresses above the critical rock bumps.

At present, the maximum depth of mining operations has not yet reached the deadline. However, preparatory mining works at depths of 300-350 m are carried out (Glubokoye ore body). On the lower levels, according to the results of observations for the period 2014-2017, partial destruction of the pillars was established, especially in the flooded areas. Therefore, it is necessary to continue periodic instrumental and analytical studies of natural and man-made stresses of rock mass on the lower levels of the mine. With the external signs of rock and ore rock-bump hazard appearance, it will be necessary to implement the appropriate measures to forecast and prevent of rock bumps.

The mine is encouraged to continue work on the observations on the old and setting the new observation stations for monitoring of geomechanical condition parameters of the mine workings along with the further accumulation of subsurface voids at the existing levels and the depth of mining operations increase. Methodological guidance on the rock stress assessment and its harmful manifestations should be undertaken by specialized agencies (Institute of mining Ural Branch of RAS, Institute of mining Far Eastern branch of RAS, Irkutsk Research Institute of precious and rare metals and diamonds, etc.)

References

1. The study of geomechanical conditions Mnogovershinnoe gold deposits for the purpose of predicting its potential rockburst hazard. Sosnovskaya E. L. Bulletin of ISTU. 4. 82-88 p. (2015).
2. Geomechanics and Geotechnology. Zubkov A. V., Ekaterinburg: Uro RAS. 335 p. (2001).
3. Technology of the gold deposits mining. Neganov, V. P., Kovalenko V. I., Zaitsev, B. M., Sosnowski, L.I. Under the editorship of V. P. Neganov. M. Nedra. 336 p. (1995).
4. Temporary rules of structures, natural objects and mining protection from the harmful effects of the underground mining on gold deposits- Irkutsk: Irgiredmet. 76 p. (1994).
5. Strength and deformation of rock massives. Shuplecov U.P, Yekaterinburg: Uro RAS. 195 p. (2003).
6. Vloh N.P. Management of rock massifs strains in underground mines. Nedra. 208 p. (1994).
7. Barbezat M., Brunner A.J., Flueler P., Huber C., Kornmann X. Acoustic emission sensor properties of active fibre composite elements compared with commercial acoustic emission sensors. Sensor and Actuators A. Physical. **1**. pp.13-20. (2004).
8. Zandt G., Leidig M., Chmielowski J., Baumont D., Yuan X. Seismic detection and characterization of the altiplano-puna magma body, central Andes. Pure and Applied Geophysics. **3-4.** pp. 789-807. (2003).
9. Zang L., Ma S., Ren M., Jiang S., Wang Z., Wang J. Acoustic emission frequency and b value characteristics in rock failure process under various confining pressures" Yanshilixue Yu Gongcheng Xuebao **10** pp. 2057-2063. (2015).
10. Reuber G., Kaus B.J.P., White R.W., Schmalholz S.M. "Non lithostatic pressure during subduction and collision and the formation of (ultra) high-pressure rocks" Geology. **5**. pp. 343-346. (2016).