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Assessment of Rock-Burst Hazard in Deep Layer Mining at Nikolayevskoye Field

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The paper presents results of conducted research using regional and local methods of forecast and control over geomechanical state of the rock mass at burst-hazardous Nikolayevskoye field, located in a geodynamically active region. The study subject is the ore mass of Nikolayevskoye field, characterized by man-induced and tectonic disturbances and high geodynamic activity. The aim of research was practical implementation of methods and instruments of forecast and control over geomechanical state of the burst-hazardous rock mass and safety improvement of mining operations. Exploitation practice of burst-hazardous fields demonstrates that forecast accuracy of hazardous rock pressure demands cutting-edge multi-level systems, where local methods and tools complement regional ones. A regional forecast of rock-burst hazard at Nikolayevskoye field was performed by means of seismoacoustic method using automated control system for rock pressure (ACSRP) «Prognoz-ADS». Local forecast was carried out using «Prognoz-L» device, geophysical (sample disking) method and visual observations of dynamic pressure manifestations in the mining tunnels. Quality assessment of stress-strain and burst state of the rock mass was performed using specialized software «PRESS 3D URAL». Integration of engineering and geomechanical data in the process of conducting research guarantees a relevant assessment of rock-burst hazard in various areas of the field at various stages of its development. Practical verification of the system, where local methods and tools complement regional ones, demonstrated satisfactory results at Nikolayevskoye mining plant, which makes it recommendable for other mining facilities extracting ore at great depths under similar conditions of active geodynamic processes.

***Key words*:** tectonics; rock mass; stress-strain state; mathematical modeling; mining engineering system; geodynamic processes; rock pressure; rock-burst hazard

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Introduction. In the Far Eastern region of Russia, as in many other mining regions, field development occurs under complicated mining, geological and geomechanical conditions. A serious problem for underground mining is caused by dynamic manifestations of rock pressure and its most hazardous form – destructive rock bursts and man-induced earthquakes that can have devastating effects [1, 4, 5, 15]. As the Far East lies in the zone of enhanced geodynamic activity, the fields are characterized by intensive manifestations of rock pressure: i.e. they are accompanied by a powerful seismic effect, pressure bumps, structural recomposition of rock mass blocks with possible movement along tectonic boundaries. As the mining operations go deeper and the area of mined-out space increases, geodynamic processes get activated and it adds up to the probability of rock bursts [2, 3, 7, 12, 14].

The unsolved status of the problem associated with rock bursts and man-induced earthquakes can be explained by complex nature of the stress-strain state of exploited rock mass, as well as difficulties in considering a wide range of natural and anthropogenic factors that shape these catastrophic events. Hence, in order to reduce the risk of geodynamic activities, potentially hazardous areas in the mine field must be identified in advance, and effective recommendations must be formulated on how to manage rock pressure and to increase safety of mining operations using a combination of regional and local methods of assessment and control over geodynamic state of the rock mass.

Problem statement. Among the actively developed fields of Fear Eastern region subject to rock bursts, the most difficult conditions have been found at Nikolayevskoye polymetallic ore field, exploited by AO «GMK «Dalpolymetall». This field is located within the boundaries of tectonically active Amur plate, characterized by high structural heterogeneity, tectonic compartmentalization and presence of increased stress areas [6, 8].

In recent years Nikolayevskoye field is being developed primarily from the southern and northern sides of the ore zone «Vostok-1» (blocks Sever-3; Sever-8 and Sever flank), as well as in the ore zone «Kharkovskoya». Since 2014-2015 geomechanical conditions started to decline and the process continues up to this day. Analysis of spatial distribution of geodynamic centers, registered in the period from 5th till 8th October 2015, and a series of powerful shocks in the deep layers of Nikolayevskoye field demonstrated that they have been initiated by the activation of geodynamic processes along the boundaries of an underworked triangular tectonic block, the volume of which exceeded 5 million m^3 (Fig.1).

Earlier, in 2012 and 2008, in the area of actively developed blocks Sever-8 and Sever flank there were detected powerful dynamic manifestations of rock pressure, accompanied by rock shattering, dusting and seismic oscillations. Measurements performed with «Prognoz-L» – a device of local forecast and control over rock-burst hazard - in the period from 5th till 7th October 2015, were most informative, as they were carried out in the mine workings before and after geodynamic events, when the processes of gradual strain loading and relaxation of the rock mass took place, accompanied by acoustic emission impulses of varying intensity.

From the middle of 2015 the frequency of geodynamic events at Nikolayevskoye field visibly increased, so did seismic effects and disruption of mining tunnels. Growing intensity of hazardous dynamic manifestations of rock pressure at Nikolayevskoye field is caused by mining operations upsetting the balance between natural and man-made systems, where the defining role belongs to the central block of asthenolith, along the boundaries of which take place movements and displacements, accompanied by man-induced seismicity [8]. Only in the 4th quarter of 2015, 25 dynamic manifestations of rock pressure have been registered, including a series of devastating shocks in the period from 5th till 7th October 2015. The latter were mainly confined to active faults, areas composed of high-strength and fragile rocks disrupted by mining operations, boundaries of tectonic blocks and elements of geologic structure (dykes, contacts of lithological varieties etc.).

In 2016 geomechanical situation continued to decline. The effects of a strong geodynamic activity, registered on 25th March 2016 in the proximity of an ore body Vostok-1, included support destruction and interruption of mining tunnel outlines at depths of –375, –390, –406, –420 m, as well as formation of open faults and fractures in the rock mass (Fig.2), tens of meters in length. Along the fault boundaries there were surface lifts 10-12 cm high, whereas the faults themselves coincided in space with the elements of field's tectonic structure. The volume of disrupted rock mass exceeded 400 m^3 [1].

As the mining operations go deeper under such difficult geomechanical conditions, field development requires a complex assessment of stress-strain dynamics of the rock mass in certain areas of the ore field, characterized by enhanced seismic activity.

Methodology. In order to assess and control rock-burst hazard at Nikolayevskoye field, seismoacoustic monitoring has been performed with an automated control system for rock pressure (ACSRP) «Prognoz-ADS», used at the mining plant since 2011. To obtain more precise information on geomechanical state of the rock mass in certain areas of the ore field, data from regional seismoacoustic monitoring was combined with modeling results and data obtained with «Prognoz-L» – a device for local rock-burst hazard control – as well as visual observations on the dynamics of rock pressure manifestations in the mining tunnels. A portable device for local rock-burst hazard control, «Prognoz-L» allows to register impulses of elastic oscilla-

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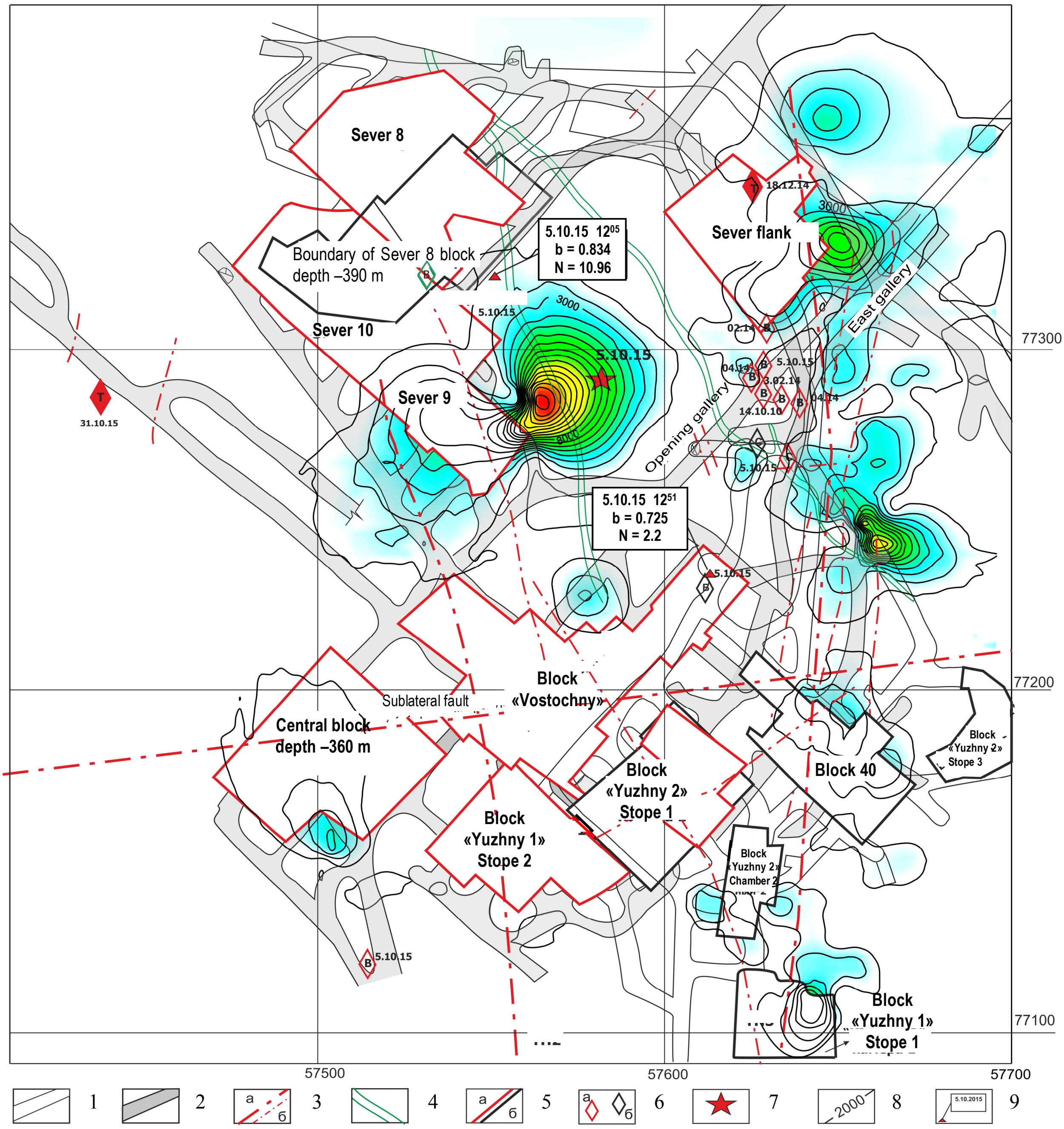

Fig.1. Seismoacoustic activity of the rock mass at Nikolayevskoye field in the area of geodynamic activity registered on 05.10.2015

1 – mining tunnels at depth –390 m; 2 – mining tunnels at depth –360 m; 3 – tectonic faults of: a – 1st order; b – 2nd order; 4 – intermediate and mafic dykes; 5 – mined-out areas: a – at depth –360 m, b – at depth –390 m; 6 – dynamic manifestations: a – at depth –360 m, b – at depth –390 m; 7 – man-induced earthquake; 8 – cumulative energy isolines of AE activities; 9 –points where AE parameters are measured with «Prognoz L» device

tions, occurring in the process of irreversible rock mass deformation (process of natural acoustic emission), and to display registered results of acoustic emission (AE) impulses on an LCD with automatic calculation of parameters and criteria of rock-burst hazard. Obtained criteria can be used to estimate potential threat of a rock burst in the specific area of the measurement [9].

The methods, used to assess the state of rock mass using «Prognoz-L» device, are based on such criteria as AE intensity with no visible impact of industrial processes N_{AE} and indicator of amplitude distribution b. Intensity indicator N_{AE} allows to detect when working load is reached

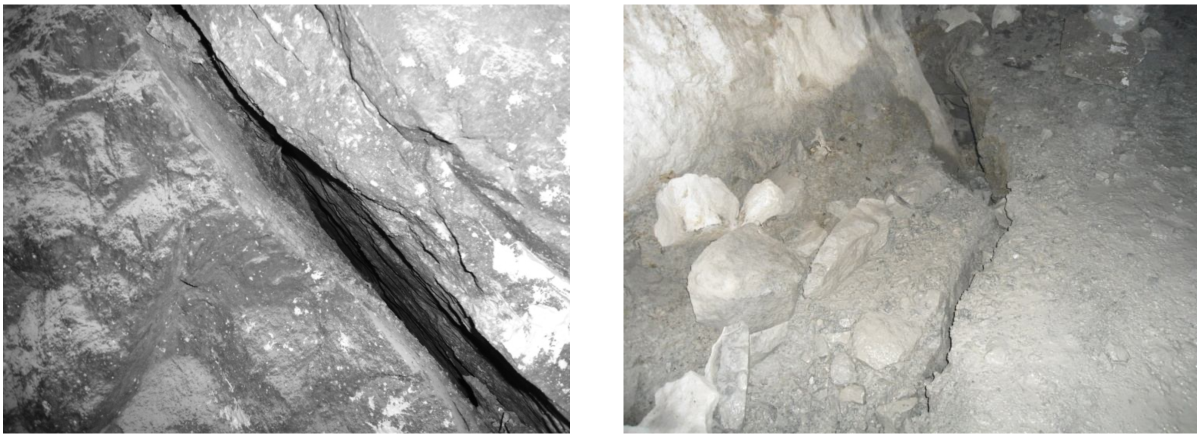

Fig.2. Bursting disruptions in the body of the rock mass at Nikolayevskoye Field caused by geodynamic activity on March 25, 2016

at the boundary areas of the rock mass. Amplitude distribution indicator characterizes variability of the deformation process, building-up of high energy impulses and can be calculated using formula [16]:

$$b = \lg \frac{N_{\text{AE}}^{1}}{N_{\text{AE}}^{2}} / \lg \frac{A_2}{A_1},$$

where b –ratio of acoustic impulses of varying amplitude (energy); A_1 and A_2 – thresholds (device sensitivity levels); N_{AE}^{1} and N_{AE}^{2} – AE intensity at varying thresholds.

According to the requirements [10], rock mass areas, categorized as «hazardous», must be brought into non-hazardous condition using additional precaution measures, which guarantee the safety of miners. Bringing the areas into non-hazardous condition occurs by means of performing preventive activities aimed at stress reduction in the adjacent rock mass (e.g., caving of the underworked rock mass or reduction of boundary outcrop capacity to store potential energy of elastic compression and to fail by fracture as a result of modified physical and mechanical properties). Bringing the areas, categorized as «hazardous», into safe condition is performed by constructing a protective belt no less than 2 m wide in the boundary outcrops of the rock mass. A protective belt is created by blasting inducer charges, formation of relief slots, drilling of relief wells or combination of these methods.

Selection of relief measures is based on quantitative assessment of stress-strain state of heavily loaded areas. According to regulations [10], numerical assessment methods may be used in mathematical modeling of stress-strain state parameters to estimate stress state in mining areas. To identify specific distribution characteristics of natural and man-induced stress fields, three-dimensional geodynamic models of stress-strain rock mass have been proposed and realized using specialized software «PRESS 3D URAL», based on a 3D positioning of boundary element analysis [7, 13]. 3D geodynamic modeling of ore fields amounts to stepwise accumulation of data on structure, properties and geodynamic state of the rock mass. Information about stress-strain state of the block mass and field structure allows to analyze past, present and future geodynamic processes at the field, whereas additional geological, geophysical and engineering data serves to specify position and structure of geodynamically active zones considering applied mining technologies.

Research results. Regional forecast of seismoacoustic activity of the rock mass at Nikolayevskoye field has been performed using automated control system for rock pressure (ACSRP) «Prognoz-ADS», and potentially hazardous zones with anomalous concentration exceeding threshold values have been mapped (see Fig.1).

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To improve information from the regional forecast of rock-burst hazard in mining tunnels located within the boundaries of potentially dangerous zones, a local instrumental forecast has been carried out using a geophysical device «Prognoz-L» to estimate acoustic emission in the marginal rock mass area. Basing on the data of local instrumental forecast (see Table), a section of the transport gallery N 8 at depth –406 m has been categorized as rock-burst hazardous.

Results of AE parameter measurement in the rock mass at Nikolayevskoye field using «Prognoz L» device

Date, time	Mining tunnel	t, min	Threshold, dB		No of impulses along channels		Average activity N_{15}	Rock-burst category
			1	2	N_1	N_2		
05.10.15 12:05	Transport gallery No. 8 at depth –406 m	10	10	19	362	203	10,96	HAZARDOUS

Computer modeling has been carried out using primary documentation: geologic sections along the lines from II-II till XVIII-XVIII; mining and geologic sections along the lines from 30-30 till 50-50; exploration plans for the depths –120 m, –220 m, –320 m, –420 m; mine layouts for depths from –323 till –420 m. According to the concept of geodynamic zonation, block (geologic-structural) and geodynamic models of the mine take at Nokolayevskoye ore field have been developed. Fig.3 demonstrates results of the block (geologic-structural) model of the ore body, which consisted in elemental processing of mining constructions and tunnels within the scope of a mine layout, including fault planes of tectonic disruptions N 1-10 (the software divided tectonic fault planes into computative elements), and accumulation of a 3D model database in «PRESS 3D URAL» software with an AutoCad visualization.

Fig.4 demonstrates a horizontal section of a geodynamic mining model with a distribution of normal pressure tensions under the impact of tectonic faults. Assessment of rock mass stability has been carried out using a widely-recognized criterion of brittle failure, defined as the excess of maximum pressure tension over compression strength of the rocks adjusted for their structural weakening (disruption). Maximum pressure (60 MPa and higher) has been observed in boundary areas of the rock mass along the mined-out stopes, as well as in safety pillars left between development tunnels. As adjacent rocks of the modeled area are limestones and sinters of quartz porphyry with compression strength of 99 and 99.6 MPa (taking into account structural weakening – 67 and 70 MPa) respectively, stress rates in the rock mass along the mined-out stopes and in the safety pil-

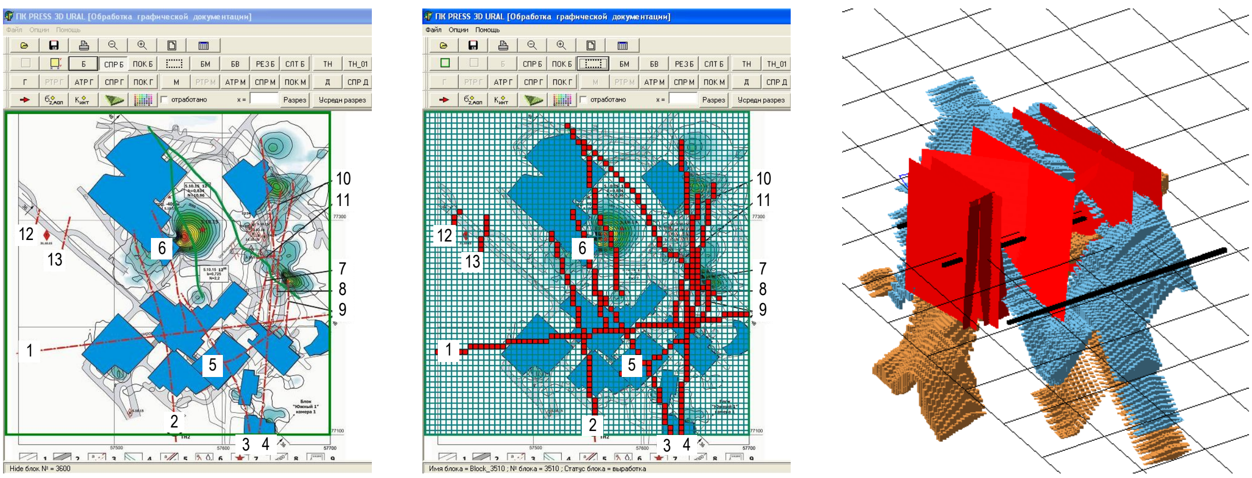

Fig.3. Construction of a block (geologic-structural) model of the rock mass area
1-13 – tectonic faults

lars left between development tunnels approach their threshold values, which indicates enhanced level of geodynamic hazard in the areas and the need for preventive measures.

Hence, numerical modeling of stress-strain state of the rock mass near the focus of the strongest geodynamic activity, registered in the period from 5th till 8th October 2015, allowed to estimate the level of active pressures in a potentially hazardous zone and to implement required measures to prevent dangerous manifestations of rock pressure. One of the preventive measures, allowing to reduce the tension hazard, is drilling relief wells, which implies utilization of rock pressure energy.

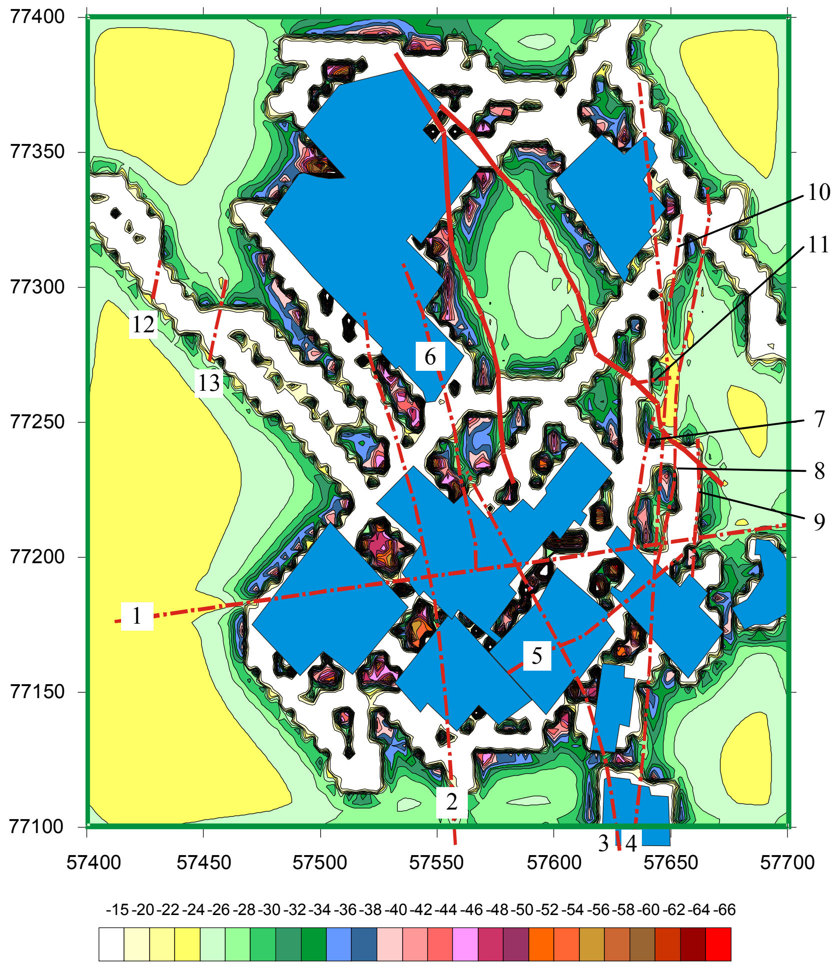

Fig.4. Normal stress (MPa) distribution in ore and rock elements during production operation at depth–390 m (tectonic faults taken into account)

1-13 – tectonic faults

Efficiency of this measure greatly depends on the drilling pattern and parameters of relief wells (their depth, diameter and direction regarding maximum tensions) and need to be separately specified for each potentially hazardous area [10, 11]

Conclusion. Obtained data demonstrated a satisfactory correlation of seismoacoustic forecast of rock-burst hazard, completed using regional system «Prognoz-ADS» and local device «Prognoz-L», with the results of numerical modeling of the stress-strain state, performed in «PRESS 3D URAL» software. Thus, suggested forecast method of rock-burst hazard in mine take areas with a complicated geological structure at great depths under active geodynamic processes allows to increase reliability of parameter estimation for potentially hazardous rock-burst zones at the initial stages of their formation and to perform required measures to prevent dangerous manifestations of rock pressure.

REFERENCES

1. Rasskazov I.Yu., Saksin B.G., Usikov V.I., Potapchuk M.I. Geodynamic State of the Rock Mass at Nikolayevskoye Polymetallic Field and Specifics of Rock-Burst Hazard Manifestations in the Process of Its Development. *Gornyi zhurnal*. 2016. N 12, p. 13-19 (in Russian).

2. Eremenko V.A., Eremenko A.A., Filippov V.N. et al. Management of Geomechanical State of Geologic Environment in the Process of Sheregesh Field Development. *Gornyi informatsionno-analiticheskii byulleten'*. 2007. N 2, p. 155-169 (in Russian).

3. Eremenko A.A., Eremenko V.A., Matveev I.F. et al. Tectonic Block Development in the Zones of Large Tectonic Faults at Rock-Burst Hazardous Iron Ore Field. *Gornyi zhurnal*. 2007. N 11, p. 34-36 (in Russian).

4. Rasskazov I.Yu., Kursakin G.A., Potapchuk M.I. Geomechanical Assessment of Deep-Layer Development Conditions at Yuzhnoye Polymetallic Field. *Fiziko-tekhnicheskie problemy razrabotki poleznykh iskopaemykh*. 2012. N 5, p. 125-134 (in Russian).

5. Rasskazov I.Yu. Supervision and Management of Rock Pressure in the Far Eastern Mining Plants. Moscow: Izd-vo «Gornaya kniga», 2008, p. 329 (in Russian).

6. Saksin B.G., Rasskazov I.Yu., Shevchenko B.F. The Principles of Complex Study on Modern Stress-Strain State of Upper Crustal Layers of Amur Lithospheric Plate. *Fiziko-tekhnicheskie problemy razrabotki poleznykh iskopaemykh*. 2015. N 2, p. 53-65 (in Russian).

7. Sidorov D.V., Potapchuk M.I., Sidlyar A.V. Forecast of Rock-Burst Hazard of the Tectonically Disrupted Ore Mass in the Deep Layers of Nikolayevskoye Polymetallic Field. *Zapiski Gornogo instituta*. 2018. Vol. 234, p. 604-611. DOI: 10.31897/PMI.2018.6.604 (in Russian).

8. Rasskazov I.Yu., Saksin B.G., Petrov V.A., Shevchenko B.F. et al. Modern Stress-Strain State of Upper Crustal Layers of Amur Lithospheric Plate. *Fizika Zemli*. 2014. N 3, p. 144-153 (in Russian).

9. Tereshkin A.A., Rasskazov M.I., Tsoi D.I. Assessment of the Rock Mass Burst Hazard by Means of Local Geoacoustic Method. Problemy i perspektivy kompleksnogo osvoeniya i sokhraneniya zemnykh nedr: Sb. dokladov 3-i Mezhdunarodnoi nauchnoi konferentsii. IPKON RAN. Moscow, 2018, p. 132-136 (in Russian).

10. Rasskazov Yu., Kursakin G.A., Osadchii S.P., Popov V.V. et al. Guidelines on Safety of Mining Operations at Rock-Burst Hazardous Fields Nikolayevskoye and Yuzhnoye (AO «GMK «Dalpolymetall»). IGD DVO RAN. Khabarovsk, 2018, p. 72 (in Russian).

11. Federal Standards and Rules on Industrial Safety «Regulations on the Safety of Mining Operations at Rock-Burst Hazardous Fields» N 576 from 02.12.2013. Moscow, 2013, p. 41. URL: https://normative.kotur.ru/document (in Russian).

12. Kosukhin N.I., Sidorov D.V., Beloglazov I.I., Timofeev V.Yu. Assessment of stress-strain and shock bump hazard of rock mass in the zones of high-amplitude tectonic dislocations. IOP Conf. Series: Earth and Environmental Science. 2019. Vol. 224, p. 1-5. DOI: 10.1088/1755-1315/224/1/012014

13. Sidorov D.V., Ponomarenko T.V. The development of a software suite for predicting rock bursts within the framework of a system for ensuring geodinamic safety of mining operations. 17th International Multidiscip-linary Scientific GeoConference SGEM 2017, 29 June – 5 July, 2017. Vol. 17. Iss. 22, p. 633-638. DOI: 10.5593/sgem2017/22/S09.079

14. Galchenko Yu.P., Eremenko V.A., Myaskov A.V., Kosyreva M.A. Solution of geoecological problems in underground mining of deep iron ore deposits. *Eurasian Mining*. 2018. N 1, p. 35-40.

15. Zhang Z., Shimada H., Sasaoka T., Kai W. Study on the overlying strata movements and stability control of the retained goaf-side gateroad. *Memoirs of the Faculty of Engineering, Kyushu University*. 2016. Vol. 76. Iss. 2, p. 1-17.

16. Tereshkin A.A., Rasskazov M.I. Assessment of burst-hazard rock massif by geoacoustic method. Eurock 2018. Geomechanics and Geodynamics of Rock Masses (set of 2 volumes) proceedings of the 2018 European rock mechanics symposium. Saint-Petersburg Mining University. St. Petersburg, 2018, p. 1627-1632.

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