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METHODOLOGY OF REDUCING ROCK BUMP HAZARD DURING ROOM AND RILLAR MINING OF NORTH URAL DEEP BAUXITE DEPOSITS

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The article describes practical experience of using room and pillar mining (RAPM) under conditions of deep horizons and dynamic overburden pressure. It was identified that methods of rock pressure control efficient at high horizons do not meet safety requirements when working at existing depths, that is explained by changes in geodynamic processes during mining. With deeper depth, the geodynamic processes become more intensive and number of pillar and roof failures increase. When working at 800 m the breakage of mine structures became massive and unpredictable, which paused a question of development and implementation of tools for compliance assessment of used elements of RAPM and mining, geological, technical and geodynamic conditions of North Ural bauxite deposits and further development of guidelines for safe mining under conditions of deep horizons and dynamic rock pressure.

It describes reasons of mine structure failures in workings depending on natural and man-caused factors, determines possible hazards and objects of geomechanic support. It also includes compliance assessment of tools used for calculations of RAPM structures, forecast and measures for rock tectonic bursts at mines of OAO "Sevuralboksitruda" (SUBR). It describes modernization and development of new geomechanic support of RAPM considering natural and technogenic hazards. The article presents results of experimental testing of new parameters of RAPM construction elements of SUBR mines. It has data on industrial implementation of developed regulatory and guideline documents at these mines for identification of valid parameters of RAPM elements at deep depths.

***Key words*:** methodology, methodological support, software support, forecasting, room and pillar mining, North Ural bauxite deposits, stress and deformed state, rock burst hazard, deep depth

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Introduction. The unified state policy was implemented for provision of stable geopolitical and economic safety of Russia (strategy for development of metallurgical industry of Russia up to 2020, approved by Russian Ministry of Industry and Trade d.a. March, 18, 2009. N 150), in particular, for promoting dynamic development of mining and metallurgical industry with key focus on resource portfolio development.

Conceptual and methodological approaches to finding strategic tools for solving similar issues in the past were developed by leading academic and industrial research institutes under the supervision of famous scientists: K.N.Trubetskoy, N.N.Melnikov, D.R.Kaplunov, V.N.Oparin, A.G.Protosenya, A.A.Eremenko, B.A.Kartoziya, I.M.Petukhov, Y.P.Galchenko, M.A.Iofis et al., they confirmed the necessity to carry out complex researches for developing methods of increasing industrial safety and economic feasibility of mining due to worsening of mining and geological, geomechanic and geodynamic conditions at deep horizons.

Regional issues and prospectives of mining development were covered in many works under supervision of famous scientists of Northwest region: N.N.Melnikov, A.A.Kozyrev et al., Ural region: D.R.Kaplunov, A.D.Sashurin et al., Siberia region: M.V.Kurleny, V.N.Oparin, A.A.Eremenko, B.V.Shrepp, P.V.Egorov, A.M.Freidin, V.A.Eremenko et al., Far Eastern region: I.Y.Rasskazov et al., showing the results of multiannual researches in mines developing rock burst hazardous deposits in different mining and geological, mining-technical and geomechanic conditions.

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The overview of these articles showed that irrespective of significant differences in mining methods in order to provide geodynamic safety, the common set of forecasting and preventing activities were used as a rule [3]. With that because of specificity of mining conditions the criteria of rock-bump hazard for every deposit (group of deposits) were set separately [3]. The authors focused on a need of developing methods for forecast and control of stress and deformed state and rock bump hazards in rock mass, as well as calculation methods for identifying safe parameters of structural units of mining of friable rock bump hazardous ores under conditions of high concentration of natural and technogenic stress fields due to deep depth, goaf sizes and faulting of deposits.

This issue became very important at mines of SUBR [3], where they develop North Ural bauxite deposits liable to rock bumps using room and pillar mining, which is one of the most efficient methods of underground mining of flat deposits and used in 90 % cases on SUBR mines. The main feature of RAPM is pillars supporting chamber roof from falling. The safety of operations is provided by stability of roof exposure and inter-chamber pillars, which depends on correct identification of their parameters (deck passages, pillar sizes).

The parameters of RAPM become very significant in case of forever abandoned inter-chamber pillars. This is due to the fact that when leaving pillars of bigger sizes (more than it is required), we have additional losses of minerals. If the sizes are too small to support the roof and overburden, then failures lead to accidents or catastrophes when chambers or their elements are destroyed and people are hurt and this causes serious social-economic problems.

Usage of RAPM in rock bump hazardous regions requires additional attention to specific conditions of these areas like overburden pressure in its dynamic version (rock bursts). The examination of practical experience of RAMP at SUBR mines showed that at deep depths sometimes accompanied by dynamic overburden pressure the methods used to control it at upper levels do not match the safety requirements of deep depths because of changes in geodynamic processes of mining. With greater depths, we can observe increase of intensity of geodynamic processes and cases of pillar and roof failures. When reaching depth of 650-700 m, the intensity of rock bumps greatly increased [4, 5], and structure elements failures became massive, random and unpredictable, which led to development and implementation of multiyear program of research and development activities for assessment of structural elements parameters during RAPM used under mining-geological, mining-technical and geodynamic conditions of North Ural bauxite deposits, and further development of guidelines for safe usage of RAPM in rock burst hazardous conditions of deep depths.

In order to develop these guidelines for SUBR mines there have been worked out a concept of elaborating geomechanic support of RAPM (Fig.1).

Implementation of stage I. North Ural bauxite deposits fall into a category of complex geological structure deposit (Classification of deposits reserves and forecast of solid deposits d.a. 11.12.2006. N 278), which is characterized by large tectonically disturbed karst-bedding plane deposits with leveled roof and uneven floor and variable thickness.

The ore horizon is divided in two levels: lower – red easily soiled, not easily soiled and jasperlike bauxites and upper – variegated pyritized bauxites. More common are red easily and not easily soiled bauxites (about 80 %). Jasperlike bauxites are separated by cleats into plates of different sizes. The bauxite compression strength varies in a wide range: bauxite red easily soiled (BRES) – a type of soft bauxite ore with compression strength of 20 MPa; bauxite red

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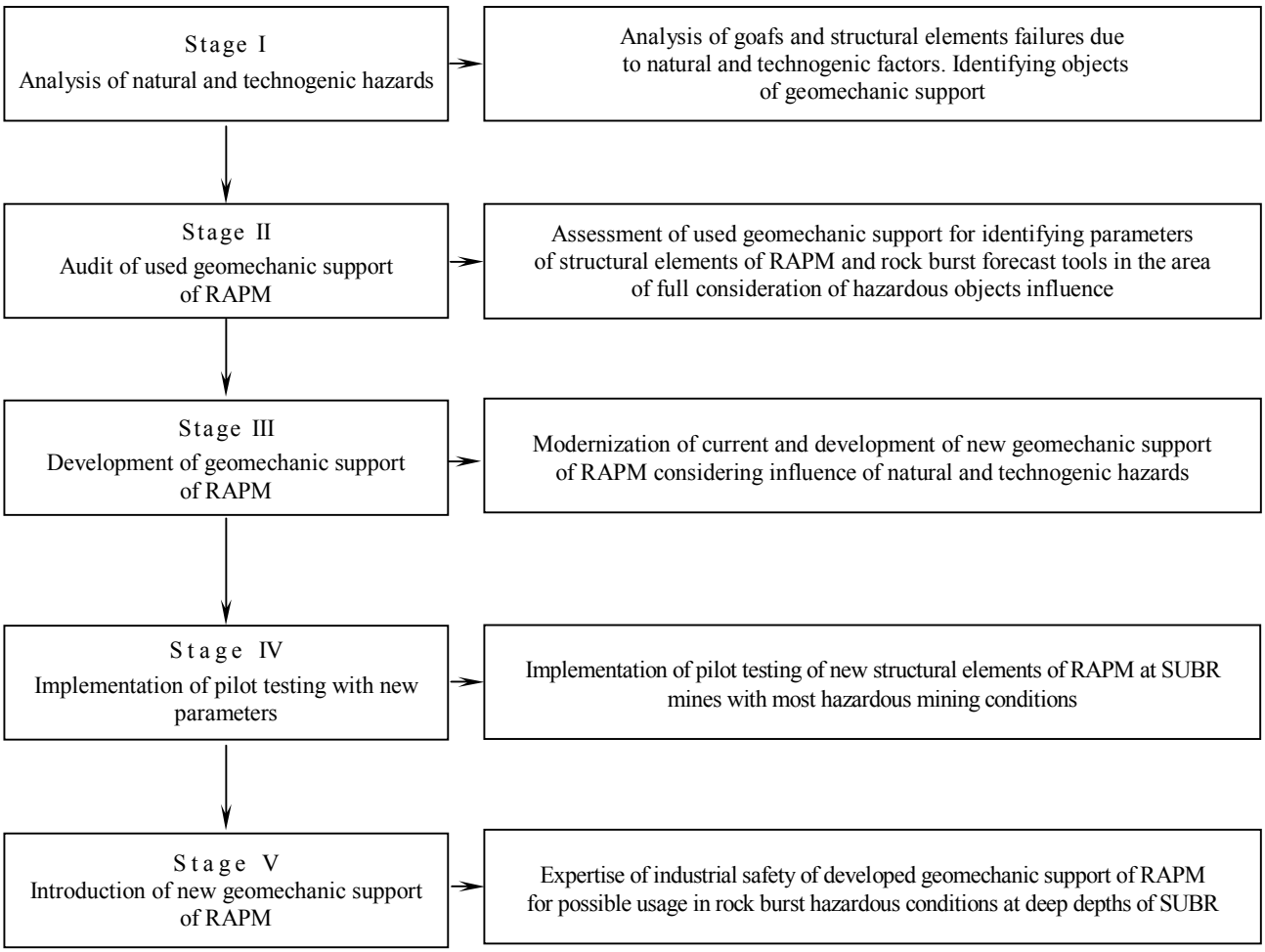


Fig.1. A concept of reducing rock burst hazards when using RAPM at deep depths

not easily spoiled (BRNES) – a type of medium strength bauxite ore with compression strength of 40 MPa; bauxite variegated (BV) – a type of bauxite ore with compression strength of 80 MPa. The thickness of deposit varies from several cm up to 20 m and more. The tectonics of North Ural bauxite deposits differs by a great number of faults of different age and multiple forms of their occurrence. The block structure of North Ural bauxite deposits determines the uneven distribution of original field stress, which in general has the following correlation of main stresses 1:0.6:0.5. At the same time the correlation of normal main stresses of mining pattern slightly varies and have the following parameters: Krasnaya Shapochka (Eastern deposit) – 1:0.6:0.5; Kalinskoe – 1:0.7:0.5; Novo-Kalinskoe – 1:0.8:0.6; Cheremukhovskoe – 1:0.7:0.6.

The problem of rock bursts become very important when using room and pillar mining assuming creation of a great number of different sized pillars becoming stress-concentrators. In accordance with [3] North Ural bauxite deposits from depths of 250 m are considered to be liable to rock bursts and most hazardous among all known global deposits [8]. As of 2014 SUBR mines using RAPM had 216 investigated rock bursts with destruction of goafs and structural elements.

Seismic station «Severouralsk» annually registers about 1000 seismic events including rock and rock-tectonic bursts of different power (10^2-10^{10} J). With depth the strong rock-tectonic bursts happened with power of 10^8-10^{10} J, registered within the radius of more than 500 km by state seismic network [8].

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The assessment of rock burst hazards at North Ural bauxite deposits based on rock bursts data showed that they greatly vary in their hazard level. The most hazardous are deposits «Krasnaya Shapochka» within the field of mine N 14-14 bis and South Kalinsky area of «Kalinskoe» deposit within the field of mine «Kalinskaya», and the least hazardous deposits are «Cheremukhovskoe» and southern part of «Krasnaya Shapochka» deposit, within the field of mine N 16-16 bis.

The rock burst hazardous mass and ore types are those subjected to saving potential energy and liable to fracture failure: porphyrite, breccia, tuff breccia, tuff sandstones, underlying and overlying limestone, and rocks of different lithological composition. The rock burst hazardous ores are the following types of bauxite: red not easily soiled, jasperlike, variegated, colorless, and transitional types of red not easily and easily soiled bauxites.

The assessment of rock bursts frequency in simple and complex mining-geological conditions shows that the majority of them happen during mining in complex mining-geological conditions. One of the factors leading to rock bursts is inhomogeneous lithological composition of ore deposit (geological profile and mineralization area). One of the contributing factors leading to formation of inhomogeneous stress field and different conditions of loading the side parts of rock mass and hence appearance of rock pressure in its dynamic form is inconstant thickness of beds. The analysis of rock bursts cases in complex mining-geological conditions with sections of uneven distribution of thickness (sharp reduction) shows that 10 out of 36 registered cases happened in homogeneous beds, the majority of rock bursts (26) happened in sections with inhomogeneous lithological composition. The most dangerous ones are sections with barren rock, sharp changes of thickness, reduction of ore bed thickness up to 4,0 м, zones of tectonic disturbances influence, contact areas of changes of lithological differences of ores and rocks [6, 7].

The rock bursts are significantly influenced by tectonic disturbances of ore body, characterized by a wide range of parameters (parameters of rock joints, stratigraphic throw, angle of fault plane thrust, etc.), which lead to creation of isolated sections of ore with concentrators of higher and stressed zones liable to rock bursts.

The analysis of rock bursts at sections with tectonic disturbances shows that deeper depths lead to significant increase of number of rock bursts at sections with high amplitude of tectonic disturbances (HATD) – 28 rock bursts in comparison to low amplitude of tectonic disturbances (LATD) – 14 rock bursts. This could be explained by creation of conditions for loading fault LATD planes, forming areas of rock bed movements along developed planes of faulted HATD planes (slip deformations), promoting liberation of large amount of saved strain seismic energy. The reduction of rock bursts at LATD areas with deep depths are mainly connected with slower destruction of undeveloped fault LATD planes in the zones of stress-deformed state of ore bed edges as a result of redistribution of bearing pressure. The assessment results of rock bursts at LATD and HATD zones at deep depths enable improving the conclusions of All-Union Research and Development Surveying Institute scientists and SUBR specialists, who noted that absolute number of dynamic activities happened in low-amplitude tectonic disturbances zones with fault plane shift up to 5 m.

The rock bursts due to drilling of blasting holes are, as a rule, connected to presence of hard types of bauxite ore with maximum stress at the edges of ore body and unloading with insignificant mechanical load of drilling equipment or to absence of proper time for relaxation of stress between drilling cycles and blasts. Rock bursts as a result of lashing or during weekends,

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as a rule, are connected to distribution of loads after blasting to areas with harder types of bauxite ore and their complex failure with time.

Besides the abovementioned reasons of rock bursts at current depths of mining there is an obvious mining-technical factor – goaf sizes and correlation of pillars and roof exposure areas within the zone of a single mining block. The SUBR specialists found out that the increase of rock burst danger is directly connected to increase of roof exposure area. The support pillars left in the chamber were overloaded when the roof exposure was increasing and started to deteriorate statically and dynamically. A part of the load from undermined overburden rock previously supported by pillars was shifted to edges of ore body within the mining area. It was accompanied by uncontrolled roof deformations, ore bed pinches and slides. Frequently they were in a form of roof shocks, which led to failure of single or grouped pillars. At depths of 1000-1200 m the values for safe passages to the dip were 55-75 m [14].

The sharp increase of rock burst hazard at depths of 650-700 m led to development of new solutions aimed at increase of RAPM safety. The essence of these solutions was to reduce the sizes of chambers by moving natural support (sterile grounds), barrier and support pillars. Within the framework of pilot testing of SUBR, AURDSI and Uniprommed at the most hazardous areas of mines 14-14 bis and Kalinskaya, which mining was done with traditional patterns and tools of RAPM developed in accordance with Technical project «Room and Pillar Mining for SUBR mines » (1977) and happened to become extremely difficult, there have been carried out the following mining RAPM variants: with leaving ore barrier pillars with their extraction by unmanned equipment and methods; with forming chain support pillars placing their major axis along to the rise; with forming chain pillars without their following cutting; with increasing sizes of ore support pillars in comparison to their calculated sizes; with reduction of chamber passages.

Proceeding form the above, the key factors leading to rock bursts during RAPM at SUBR are: block structure of rock mass related to tectonic disturbances with different loads of fault planes; presence of sterile grounds and zones of non-commercial mineralization (fixed support) of different sizes and shapes and random placement pattern in the chambers; sharp changes (irregularity) in ore bed thickness to the dip as well as to the strike; presence and random pattern of ores having different physical-mechanic and deformation parameters.

The main technogenic factors leading to rock bursts during RAPM are mainly: huge areas of goafs and uncaved rock; uneven reduction (advancing) of mining; unevenness of ore mass because of advanced mined out areas; location of goafs and their roadheads within the areas of mining and natural stress concentrates.

As a result of detailed analysis of natural and technogenic hazards there have been identified objects of geomechanic support of RAPM, influencing mining safety in the given conditions and requiring geomechanic justification: goafs with regard to acceptable passages taking into account rock burst hazard of ore body and weakening of inter-chamber pillars in goafs; stopes with regard to identifying acceptable passages between edges of inter-chamber pillars taking into account simultaneous deformation or roof and weakened inter-chamber pillars; barrier pillars with regard to identifying acceptable width taking into account their rock burst hazard and weakening of inter-chamber pillars in goafs; inter-chamber pillars with regard to their acceptable width taking into account their weakening and additional dynamic load and possible differentiation of the following additional conditions: horizon depth, hardness and elasticity properties of or and wall rock, thickness and seam angle, tectonic features.

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Implementation of stage II. Before introducing the guidelines, the selection of RAPM parameters is done on the basis of Guidelines for selection structural parameters of room and pillar mining at mines of OAO «Sevuralboksitruda» (Ekaterinburg – Severouralsk, 1997). When analyzing methods for calculating inter-chamber pillars parameters, the physical contradictions were discovered, such that, the dome of natural equilibrium theory in SUBR mines developing brittle hard bauxites not inclined to significant plastic deformations, is applicable when inter-chamber pillar fail or have artificial yielding property. The Guidelines didn't take into account these deformational process and inter-chamber pillars were considered to be elastic bearing objects, characterized by true ore compressive strength with additional introduction of load factor. Despite certain contradictions at low horizons the methodology was working fine and gave good results due to significant strength of pillars. However, the artificial limitation of actual overburden weight load on inter-chamber pillars reached their bearing capacity and pillars started to fail by fracturing. The analysis of methods for defining parameters of barrier pillars at SUBR mines showed that despite using efficient theory of limit analysis they didn't consider the rock burst hazard factor.

The analysis of Russian practices of calculating pillar parameters presented in articles of L.D.Shevyakov, V.D.Slesarev, G.E.Gulevich, S.G.Avershin, Y.M.Liberman, N.A.Davydova, V.R.Rakhimov, Ts.Gomes, K.V.Ruppeneit, V.D.Paliy, S.V.Vetrov, Y.A.Modestov, V.V.Sokolovsky, V.F.Trumbachev, E.A.Melnikov, F.P.Bublik, G.L.Fisenko, Zh.S.Erzhanov, A.K.Chernikov, V.I.Borsch-Konponiets, A.B.Makarov, showed that their researches were mainly focused on finding ways to provide long-term stability of pillars, needed for stable roof and permanent mine opening support. Several authors think that working at deep horizons and increase of mined-out space volumes are accompanied by activation of geodynamic processes and lead to more powerful geodynamic activities – mining-tectonic disturbances and technogenic earthquakes.

The detailed overview of foreign methods for defining pillar parameters is done in summarizing articles of M.Tavakoli [26] and W.G.Maybee [21]. The analysis of their papers proves that the main criterion for selecting pillar parameters is safety factor, describing correlation between experimental stress defined with empirical tools and calculated stress. The Hoek-Brown criterion is used for calculation of strength [19]. The pillar parameters are safe when the safety factor is above 1. The foreign mining industry uses empirical methods based on re-analysis of stress state and stability of pillars assessment results, and identify parameters for certain mining-geological and mining-technical conditions (limit of ore cube strength, pillar width and height, correcting pillar width and height, constants), included into empirical formula for defining stress state of pillars [15, 17]. The results of researching different mechanic conditions of pillars are given in several papers [20, 22]. The Turner method is mainly used for calculation of assessment of stress in pillars located in even pattern, it helps to determine evenly distributed load on pillars from whole overburden rock pressure [16, 18].

The development of efficient calculation methods (boundary element, finite element, and finite difference) and computer technology enabled wide use of computational modelling for estimating stress and parameters of elastic pillars for more complicated cases (uneven pattern of pillar placement, variable capacity and stability of pillars and other factors). The most commonly used methods for calculation of stress-deformed condition of rock mass are method of finite elements (FEM) and method of boundary elements (BEM). The FEM has the following

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advantages: low sensitivity to complex geometry and mechanic properties of rock. Though it is very common and universal, its application for tasks with areas of sharp changes of stress and shifts, for example, at edges of ore body and pillars, has doubtful accuracy. The advantages of BEM are reduction of problem scale and amount of initial data, and high accuracy in the areas with high stress gradients.

The article [1] showed advantages of using different variants of BEM for solving issues of geomechanics in coal deposits and presented results of stress state modelling for series of strata and single coal seams with infinite stiffness and using software developed in AURDSI – SHWARTZ, SUIT2D, SUIT3D, LAY3D, based on different modifications of LIE. The constant complex research and analysis of theory and practice of geodynamic events enabled development of computational method based on a special form of hypersingular integral equations and FAULT3D software [2] for calculating natural field of stress in block rock mass. When calculating contacts between blocks they preset a condition of complete seizing except for areas with instrumentally confirmed shifting faults, i.e. matching the mode of complete sliding. A special type of LIE software PRESS3D was developed to assess stress-deformed state of ore body and pillars taking into account random pattern of spatial configuration of ore body edges, natural (inhomogeneous lithological structure and complex deposit morphology) and technogenic (parameters of bore unloading) yield of a deposit and pillars [10].

Since underground mining of SUBR deposits is characterized by complex spatial geometry of front, during assessment of possibility to implement the existing software for forecasting rock bursts and parameters of preventive measures in SUBR mines we examined geomechanic software packages for solving tri-dimensional tasks of elasticity theory. Among foreign software using FEM we could single out the following ones: ABAQUS, ADINA, ANSYS3D, BEFE, DIANA, ELFEN, FLAC3D, MIDASGTS3D, PENTAGON3D, PLAXIS3D, SIGMA3D, SIGMA/W, SVSLOPE, TOCHNOG, and from Russian ones: NEDRA3D (Saint-Petersburg Mining University), SIGMAGT (Mining Institute of KSC RAS). The foreign package using LIE is EXAMINE3D, and Russian one is FAULT3D, PRESS3D (Saint-Petersburg Mining University).

The main problem of efficient geomechanic computational software packages is a complexity of creating the initial informational geological structural model of ore body [23]. It is mainly connected to necessity for differential consideration of the following geoinformation data: spatial deposit and ore body position, as well as a wide range of properties of calculated elements including geometric dimensions (width, height and length), physical-mechanic ore (rock) properties, parameters of tectonic disturbances and preventive measures. Hence, the number of input data is usually limited, there is a necessity to interpolate their values.

The most common methods for solving these tasks in global practices are IDW and TIN methods used by known and popular geoinformation systems: ArcGIS by «ESRI, GeoMedia» corporation «Intergraph», MapInfo Professional by «Pitney Bowes MapInfo» et al, for building different surfaces using sets of data points. The quality of the results of IDW method largely depend on evenness of initial points data distribution and, consequently, will produce significant error while solving SUBR cases, because their initial data is uneven. The Delaunay interpolation method is used to create an uneven surface using triangulation irregular net (TIN). The usage of TIN method will help to reduce errors when modelling complex bauxite North Ural deposits with their sharp gradients of initial data for geological profiles and deposit area.

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The assessment of efficiency and sufficiency of methods used for forecasting mining and mining-tectonic disturbances showed that local and regional forecasts of rock burst hazards of ore and rock masses at SUBR mines are used in compliance with all requirements [3].

The analysis of regulatory and methodic documentation showed that local forecasting methods are designed for identification of hazard category of goafs or certain parts of rock mass (ore). The local forecast was done by teams of FPRB (forecasting and prevention of rock bursts) using one of the geomechanic or geophysical methods or, in some cases, a set of methods. Geomechanic methods of local forecasting currently used at SUBR mines are: method of core disking during well development and method of inserting punches in borehole (well) walls with MGD equipment; geophysical is a method based on registration of acoustic emission (AE) with equipment like SB-32.

We need to realize the purpose of local methods, when assessing their efficiency, i.e. identification of rock burst hazardous areas formed as a result of higher stresses concentration in edges of stopes, developing entries and permanent mining openings. The scope of these methods is within sections near goafs within the zone of rock pressure. In accordance with scope of these methods the assessment is done to depths of where it is possible to estimate level of stress in edge areas to its maximum, i.e. about 3-4 m. According to present assessment results the geophysical forecasting methods used at SUBR mines are based on probing the edge areas to a depth of 5 m.

The regional forecasting is done with the help of seismic control net helping to forecast stress within the areas of fracture nucleus, identification of shearing deformation presence and type of shifts in rock mass. The main advantages of this method are: continuous monitoring, possibility to identify deformation appearance zones and control their changes in time, receiving information at rock mass points; the disadvantages are: absence of current assessment of critical condition of a given section using equipment data and low efficiency for forecasting high power seismic activity, which are specific for mining-tectonic disturbances. In general, the results of regional forecasts help to monitor tendencies in development of hazardous situation at mines and single out potentially unsafe areas including places of mining-tectonic disturbances. However, the qualitative criteria for rock burst risk assessment using this method are absent (as well as for any other existing methods).

The prevention of mining and mining-tectonic deformations at SUBR mines is based on complex actions for unloading rock mass in accordance with requirements [3] and enables efficiently influence edge areas of goafs and release hazardous stress in them and wallrock. Usage of regional unloading methods (areal rock mass unloading, unloading of seams of active tectonic faults) enable temporary unloading of some areas of tectonic disturbances when they are within the zones of current mining. Blasting operations may have the following disadvantages: if a shock wave does not damage the keystone and cause tectonic unloading, the situation can become worse because of re-distribution of stress and additional loading of peripheral sections of the loaded area. There is a flagrant necessity to continue development of preventive measures and their efficiency assessment tools for blocks with active tectonic activity. Currently there is no reasonably sufficient calculation methods for estimating stress-deformed condition and rock burst hazards of rock mass in the areas of tectonic disturbances influence, which will enable making efficient technical solutions for operational planning, selection of development method parameters and preventive measures taking into account the tectonic disturbances of rooms at different stages of mining, sliding conditions of faulting planes and expected energy increase due to block movements.

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Proceeding from the above, the existing regulation and methodology documents describing RAPM at SUBR mines miss the regulations on the following: permissible dimension of goafs; width of barrier pillars taking into account rock burst hazards; width of inter-chamber pillars taking into account their weakening process; absence of procedures and software support for forehand forecasting of rock bursts in ore body and pillars and identification of optimal parameters of preventive measures.

Implementation of stage III. To fill the gap in geomechanic support of RAPM for deep depths of SUBR mines there have been developed:

• method for calculating parameters of inter-chamber columned and rib pillars, having differences form existing solutions because they were designed with regard to depth of mining; size of goafs (distance between fixed support); distances between edges of inter-chamber pillars (passages of rooms); thickness of ore body; modulus of elasticity of wallrock, stress-strain modulus and limit of residual ore strength (changes in mechanic state of pillars because of failure); specific gravity of wallrock, angles of complete sliding of undermined rock with regard to presence of inter-chamber pillars in mined-out space and tectonic element of natural stress field [12];

• method for calculating permissible sizes of goafs different from existing solutions because they were designed with regard to depth of mining; distance between foxed support (ore body edges, barrier pillars, ore-free zones); ore body thickness; seam angle; specific gravity of wallrock, modulus of elasticity of wallrock and ore (if ore body roof is weakened with plastic shist of variable strength, the combined modulus of elasticity was taken as a parameter describing ore elasticity modulus), ore strength profile, ore uniaxial compression strength limit; tectonic element of natural stress field; technogenic gap width [9];

• method for calculation of permissible roof passages under conditions of out-of-limit deformation of inter-chamber pillars, different from existing solutions with regard to coefficients of structural weakening for different subclasses and classes of roof rock type using similarity of geomechanic conditions of loading sublevels and just levels without sublevels [25];

• method for calculation of barrier pillars parameters, different from existing solutions with regard to deep depths; sizes of goafs adjoining to pillars; size of goaf along major axis of barrier pillar; ore body thickness; seam angle; specific gravity of wallrock; ore strength profile, ore uniaxial compression strength limit; values of tectonic element and safety coefficient of barrier pillar providing its required bearing capacity with regard to rock burst hazards [11];

• guidelines and software PRESS 3D URAL [13, 24] for making forecasts of geodynamic state of ore body and beforehand planning of rock burst preventive measures when designing and developing areas with rock burst hazard, different from existing solutions with regard to deep depths, spatial configuration of stopes, pillars and goafs, natural and technogenic yield of ore and pillars, parameters of tectonic disturbances, conditions and sizes of sliding zones along fault planes and possibility of software automatic creation of initial geological-structural and geomechanic model.

Implementation of stage IV. The justification of using the abovementioned methods for identifying permissible parameters of goafs and different pillars was proved by significant research of goafs and mine structures in the most rock burst hazardous areas in mine «Kalinskaya»: in blocks 10e, 13'°, 9u, 9-10u, 10u hor. –680 m, and mine N 14-14$^{tm\circ}$: in blocks 2-5" hor. – 620 m, 2-5 *L* hor. –570 m, 22-23s hor. –740 m, 1-2°, 2sbis and 17-18e hor. – 680 m.

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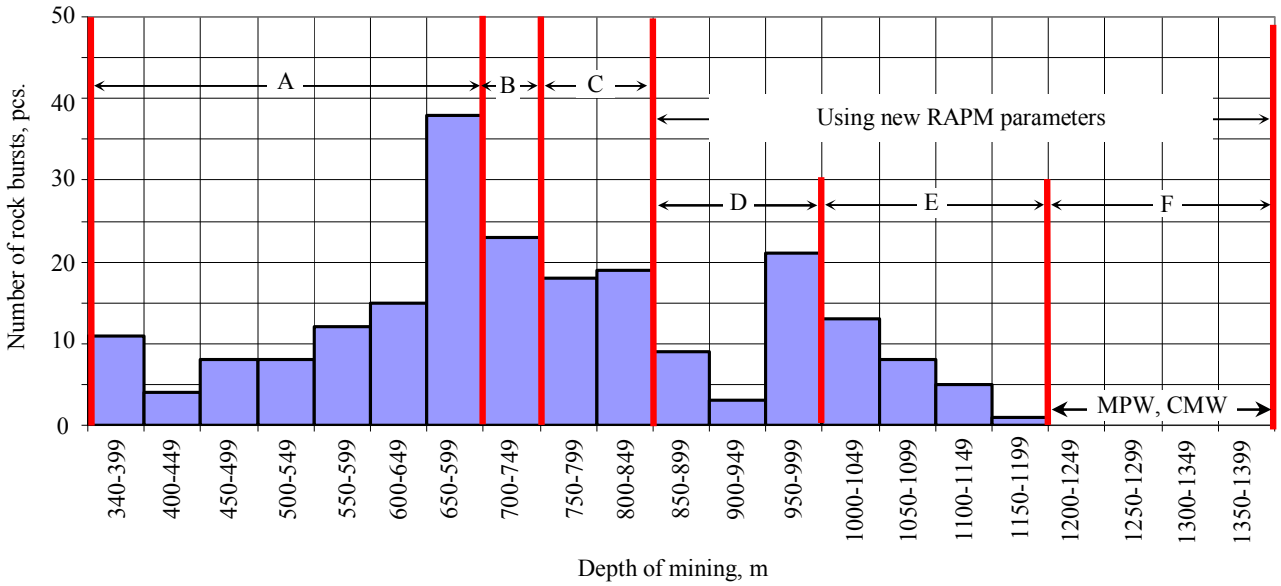


Fig.2. Intensity of rock bursts at SUBR mines along all development period
(A-E – stages of using different regulatory guidelines for RAPM)

Assessment of RAPM guidelines implementation efficiency

Type of conditions	Number of rock bursts investigated when using RAPM, pcs.							Guidelines efficiency, %
	Before implementing the stage guidelines				After implementing stage guidelines			
	A	B	C	Σ_1	D	E	Σ_2	
Mining-geological conditions								
Simple MGC: PHO + NDT	4	0	2	6	1	2	3	+50.0
Complex MGC: PIO + NDT	9	3	1	13	2	1	3	+76.9
Complex MGC: PHO + DTR	6	1	0	7	0	3	3	+57.1
Complex MGC: PIO + DTR	12	2	7	21	4	1	5	+76.2
Complex MGC: PHO + NDT + LATD	15	2	6	23	0	1	1	+95.7
Complex MGC: PIO + NDT + LATD	16	5	2	23	8	2	10	+56.5
Complex MGC: PHO + DTR + LATD	7	1	0	8	0	0	0	+100.0
Complex MGC: PIO + DTR + LATD	11	2	5	18	2	1	3	+83.3
Complex MGC: PHO + NDT + HATD	2	3	6	11	4	6	10	+9.1
Complex MGC: PIO + NDT + HATD	10	2	5	17	10	5	15	+11.8
Complex MGC: PHO + DTR + HATD	2	1	2	5	1	3	4	+20.0
Complex MGC: PIO + DTR + HATD	2	1	1	4	2	1	3	+25.0
Mining-technological conditions								
Bore hole drilling	11	4	4	19	5	0	5	+73.7
Blasting	50	12	22	84	19	15	34	+59.9
Mucking	14	4	6	24	5	5	10	+58.3
Barring	4	0	0	4	1	1	2	+50.0
Hole unloading	0	0	3	3	0	0	0	+100.0
Weekends	17	3	2	22	3	5	8	+63.6
Mining-technical conditions								
Panel entries	9	2	3	14	1	6	7	+50.0
Holing-through	4	1	4	9	1	1	2	+77.8
Panel pillars	37	3	8	48	4	4	8	+83.3
Inter-chamber pillars	21	4	1	26	1	3	4	+84.6
Ore body edges	5	5	13	23	10	5	15	+34.8
Ore-free zones	7	3	2	12	4	1	5	+58.3
Areas with tectonic disturbances	13	5	6	24	12	7	19	+20.8

Notes: «+» means positive effect; PHO – part of the deposit with homogeneous ore; PIO – part of the deposit with inhomogeneous ore; NDT – normal deposit thickness; DTR – deposit thickness reduction; LATD – low amplitude of tectonic disturbances; HATD – high amplitude of tectonic disturbances.

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The accepted parameters of goafs and pillars enabled safe mining operations in rock burst hazardous conditions (uneven ore body thickness, uneven mineralization: ore-free zones and areas of non-commercial mineralization, difference in physical-mechanical ore and wallrock properties, tectonic disturbances, complex mutual influence of stoping, the sequence of mining operations, using development methods with pillar leaving, large areas of roof exposure, high irregularity of ore mass). The consistency of developed software package PRESS 3D URAL is approved by similarity of the modelled geomechanic processes to real ones, identified during pilot testing at mines of OAO «Sevuralboksitruda» (mine «Kalinskaya», hor. – 680 m, bl. 7u-9u).

The validation of RAPM with new parameters is given in the graph (Fig.2), built on factual data of rock bursts during all period of SUBR mines development and showing changes of rock burst intensity at different depths and data (see Table) on rock bursts in different mining-geological, mining-technical and mining-technological conditions.

Implementation of stage V. The developed guidelines for determining safe parameters of structural elements of room and pillar mining were included into the following procedures and technical documentation: 1) Guidelines for selection of structural parameters of room and mining development at mines of OAO «Sevuralboksitruda», mining deposits at depths of 1000 m and more; 2) Guide supplement for selection of structural parameters of room and mining development at mines of OAO «Sevuralboksitruda», mining deposits at depths of 1000 m and more for depths less than 1000 m; 3) Project «Room and pillar mining of bauxite deposits at depths of 1000 m and more» at mines of OAO «Sevuralboksitruda»; Supplement to project «Room and pillar mining of bauxite deposits at depths of 1000 m and more» at mines of OAO «Sevuralboksitruda» was implemented in all SUBR mines by the directive of Rostekhnadzor of Sverdlovsk region.

The developed software package «PRESS 3D URAL» for current and predictive evaluation of stress and rock burst conditions of ore body edges and pillars in complex mining-geological, mining-technical and geodynamic conditions is used to monitor safety of mining by a team of forecasting and prevention of rock bursts.

Conclusion. As a result of research, we have developed methodology for geomechanic support of RAPM with regard to changes of natural and technogenic factors and their influence on goafs and mine structures. The staged implementation of these methods enables significant reduction of rock bursts when mining at deep depths. We also have proved the prospective viability of using the developed geomechanic support for RAPM in conditions of rock bursts in deposits of North Ural bauxite basin at deep depths.

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