Geodynamic risks of developing rockburst-hazardous deposits in the Far Eastern region

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Abstract. Geodynamic activity of the Earth's crust depends on the parameters of the movement of lithospheric plates and stress fields, both inherited in aseismic areas and modified in seismic active ones. Geomechanical processes occur in rock mass under the influence of various natural (endogenous and exogenous) and man-made (anthropogenic) factors. The degree of influence of these factors on the change in the energy saturation of blocks of various ranks will depend on various factors. In the geological environment of natural and man-made systems, there are dynamic phenomena of various energy levels from acoustic noise (microseismic) to rockburst and mining-induced earthquakes, that is, there is always a geodynamic risk in the geological environment of natural and man-made systems, especially in mining ones. The conditions of the geodynamic risks occurrence at specific deposits are considered on the example of rockburst hazardous deposits in the Far Eastern region of the Russian Federation. The influence of natural seismic activity on the realization of mining-induced seismicity is shown.

1. Introduction

Geodynamic activity of the Earth's crust depends on the parameters of the movement of lithospheric plates and stress fields, both inherited in aseismic areas and modified in seismically active areas. For rock masses represented by the most solid strong and brittle rocks capable of accumulating significant stresses and unloading in a dynamic form, the problem of technogenic seismicity in the development of deposits is the most acute and relevant not only for a number of regions of Russia, but also for many mining provinces of the world. Especially in seismically active regions [1–3].

Geomechanical processes occur in rock mass under the influence of various natural (endogenous and exogenous) and man-made (anthropogenic) factors. From the point of view of the development of ideas of the change mechanisms in the energy saturation of blocks of various ranks, the process of cracking in a hierarchical block rock mass and its reflection in stress and strain fields during large-scale mining operations is of the greatest interest for research. As can be seen, various factors can be the trigger of the processes of deformations and displacements in a hierarchical block rock – natural, man-made, and most often, their various aggregates. The degree of influence of these factors on the change in the energy saturation of blocks of various ranks will depend on various factors [1–8].

Let's consider schematically the influencing factors, and how they affect the change in the process of cracking in the rock mass. The relationship diagram (figure 1) represents the main factors and causes affecting this process.
Figure 1. Factors affecting the processes of fracturing in rock massifs of mined deposits.

Since the process of cracking is the result of the factors manifestation reflection (or their combination) in the rock mass, the degree of qualitative (strong, medium, weak) influence of individual factors is determined depending on the analyzed scale level.

A large-scale impact of mining operations, anthropogenic factors influence the processes of cracking to a greater extent, although the role of others is no less significant under certain conditions. This is due to the fact that the natural and technical system is a complex hierarchical block environment, and its destruction is realized in the weakest zones (discontinuous disturbances filled with permeable and water-absorbing rocks and being the boundaries between the blocks). In the zone of the mining operations impact, where significant volumes of rock mass are extracted and moved and significant developed spaces are formed, firstly, the rate of the rocks deformation increases compared to natural, and secondly, the influence of dynamic effect from mass explosions is imposed on the stability of the mined deposits various sections. With the participation of natural (in addition to anthropogenic) factors in the process of cracking, there is an ambiguous reaction of the rock mass to their impact (either an increase or a decrease in cracking) [2].

In the geological environment of natural and man-made systems, there are dynamic phenomena of various energy levels from acoustic noise (microseisims) to rockbursts and earthquakes caused by mining operations, that is, there is always a geodynamic risk in the geological environment of natural and man-made systems, especially in mining ones [1–8].

Geodynamic risks in mining operations are determined by the level of two main factors: natural and man-made seismicity of massifs (the number of recorded rockbursts and mining-induced earthquakes) within the mine fields of the mined deposits.
2. Results and discussions

In the Far Eastern region, a number of ore deposits are being developed, prone and dangerous for rockbursts (figure 2). The most difficult conditions are characterized by the Antey deposit (Zabaikalsky Krai), which is being worked out by the Priargunsky Production Mining and Chemical Association (PJSC PPMCA), the Yuzhnoye and Nikolaevskoye deposits developed by MMC Dalpolymetal (Primorsky Krai). According to the results of studies carried out in previous years, it was found that the deposits of the Far Eastern region, prone and dangerous for mountain impacts, are located within the tectonically active Amur Plate, characterized by high structural heterogeneity, tectonic fragmentation and the presence of areas of increased stress [9].

![Figure 2](image)

**Figure 2.** Geodynamic position of rockburst hazardous deposits in modern structures of the Amur geoblock.

The Amur lithospheric plate (or geoblock) is a tectonic element of the Central Asian Orogenic Belt, which is sandwiched between the North Asian and Sino-Korean craton [10]. According to the interpretation of seismic materials, the modern horizontal movement of the Amur Plate occurs under external force from the North Asian Craton (Siberian Platform). On the other hand, it is obvious that the stress-strain state of the eastern part of the Amur Plate is influenced by geodynamic conditions associated with the subduction of the Pacific Plate under the continent, and from the northwest – by the zone of active formation of the Baikal rift system [11]. It should be noted that most of the deposits developed within the Amur Plate are characterized by a complex mining and geological structure, which is due to their frequent localization near the interface of different structural floors of the geological section. At these sites, there is an increased tectonic disturbance of mine fields, which is combined with heterogeneity in the physical and mechanical properties of the host medium, as well as the complex morphology of ore bodies and ore-modified rocks. All deposits are post-magmatic and are divided into vein, stockwork and scarn.

In addition, it should be borne in mind that according to previously obtained results [10], in historical time intervals (months, years, decades, etc.) within the Amur craton, selective geodynamic activation of faults or their parts was observed, which is associated with the time sequence and direction of a certain seismic process. In this regard, block-forming faults are activated in recent times not along their entire length, but in separate sections. Based on the results of field measurements at
specific deposits, the spread of the expected values of the modern compression of the upper part of the Earth's crust of the Amur Plate can range from 20 to 100 MPa and maybe more. Moreover, the position of the known impact-prone deposits of the Amur Plate, both in relation to its boundaries and in relation to the distinguished neotectonic elements, differs significantly and this circumstance cannot be ignored in their structurally scalable geomechanical assessment [10, 11].

The current natural stress-strain state of the subsurface in the inner regions of the Amur Plate is determined by geodynamic events occurring on its borders. Currently, the main compression forces come from the North Asian Craton and from the subduction zone of the Pacific Plate under the Asian continent. This is expressed by the presence of highly active seismic belts: from the north and northwest – Baikal-Stanovoy, from the east – Sakhalin. The inner region of the Amur Plate is characterized by relatively low seismicity [10].

The spatial distribution of earthquakes registered by the network of stations of the Federal Research Center “Unified Geophysical Survey of the Russian Academy of Sciences” (FRC GS RAS) from January 2019 to May 2021 with a magnitude greater than 4 [13] and the geodynamic position of rockburst hazardous deposits in the modern structures of the Amur geoblock are shown in figure 2. As can be seen from the data in the figure, in recent years, geodynamic processes have continued to intensify within the northernmost boundary of the Amur Plate near Lake Baikal and the northeastern one near Sakhalin Island and the eastern one in the Sea of Japan in the area of influence of the Pacific subduction zone. At the same time, the activation of the northern boundary of the plate has intensified in the area of influence of the Baikal continental rift zone, which is actively developing at the present time, as well as in the area of the Border fault passing almost along the center of the plate. The results of geomechanical studies at such deposits as Antey (Zabaikalsky Krai), Nikolaevskoye, Yuzhnoye (Primorsky Krai) and a number of others indicate that their impact hazard is largely determined by the high level of tectonic stresses acting in the massifs [11, 12, 14, 15].

The excess of horizontal compressive stresses over vertical ones is determined by their geodynamic position within the tectonically active Amur Plate, characterized by high structural heterogeneity, tectonic fragmentation and the presence of the increased stress areas [16, 17].

An earlier analysis of the rockburst hazard at the underground mines of the Eastern Primorye and Transbaikalia revealed a complication of the mining situation and an increase in the geodynamic risk during mining operations due to the growth of the developed spaces and the depth of development. There is an activation of geodynamic processes occurring in the form of restructuring and self-organization of a block rock mass in a natural and man-made stress field. These processes are accompanied by displacements and movements along tectonic disturbances of various scale levels, the release of significant elastic energy and the manifestation of mining-induced seismicity [10–12, 14, 15].

It should be noted that the probability of a rockburst or a mining-induced earthquake is due not only to the geodynamic situation of the deposit areas shown in figure 2. Firstly, the carried out studies of the physical and mechanical properties of the exploration wells core from these fields have shown the presence of strong and brittle rocks capable of collapsing in a dynamic form. Secondly, visual inspections of underground workings showed the presence of peeling, shooting and dynamic formation of rock blocks. Thirdly, seismic events of various energies (up to 10E6 J) were registered by monitoring systems at these deposits. At the same time, the depth at which the probability of the implementation of rockbursts and mining-induced earthquakes is very high at different deposits is individual. This circumstance is due not only to the depth, but also to the technology used for developing a particular deposit.

From the point of view of geodynamic risks at the studied objects, the probability of the implementation of rockbursts and mining-induced earthquakes is currently possible at ore deposits: Irokindinskoye, Antey, Perevalnoye, Yuzhnoye, Nikolaevskoye and Partizanskoye.

Previously performed geodetic studies have established the specifics of fluctuations of different-scale blocks of rocks under the influence of natural and mining-induced seismicity, and the analysis of seismoacoustic data has shown the nature of the development of cracking in certain
areas, preceding the destruction of the massif sections in dynamic form [10–12]. In the course of
the studies carried out on rockburst hazardous deposits, areas with varying degrees of probability
of mining-induced earthquakes during seismic activity of the blocks containing these deposits
were identified [14]. The influence of natural seismic activity on the realization of man-made
seismicity is estimated [15].

During the development of deposits, such dangerous geodynamic phenomena as slabbing, shooting,
rockburst, mining-induced earthquake are recorded. It should be noted that the geodynamic
phenomenon may not lead to the destruction of mine workings, but the presence of such events clearly
indicates the danger to mining operations. But, from the above list, the latter phenomenon is a
powerful dynamic event with catastrophic consequences for the mines.

It is quite obvious that the consequences of the geodynamic phenomenon for the mine will be
determined not only by the energy of the event, but also by the location of the source. If the source is
sufficiently remote from mining operations, there will be push, sound and shaking by which the
energy of event will be identified; if the source is located near mining operations, a mining-induced
earthquake in its generally accepted formulation will take place. That is, there is an influence of
various factors that need to be taken into account when assessing risk:

- The further away the zone of geodynamic activity is from the zone of influence of the
  cleaning front, the less likely the destruction of the workings.
- The further away the zone of geodynamic activity is from the zone of influence of a
discontinuous disturbance, the less likely the destruction of the workings located in this zone.
- The further away the mining contour is from the zone of geodynamic activity, the less likely
  its destruction in the case of dynamic manifestations of rock pressure.

At the same time, preventive measures are being carried out at the enterprises developing the
deposits under study to bring the workings into a state that ensures a reduction in stresses in the rock
mass and the safety of mining operations. From this point of view, the probability of catastrophic
dynamic phenomena in certain areas of the developed deposits is very low.

In the future, developing the direction of work on the assessment of geodynamic risk, neural networks
are supposed to be used to make decisions on managing the state of the deposit being worked out. This is
due not only to the variety (qualitative and quantitative) of the analyzed parameters used in the
assessment of geodynamic risk, but also to the differing degree of their influence on the development of
the geodynamic situation both individually and with various combinations of the parameters under
consideration.

3. Conclusion
The conditions of geodynamic risks occurrence at specific deposits are considered on the example of
high-impact deposits in the Far Eastern region of the Russian Federation. It is shown that dynamic
phenomena of various energy levels from acoustic noise (microseisms) to rockburst and man-made
earthquakes always take place in the geological environment of natural and man-made systems, that is,
geodynamic risk is always present in the geological environment of natural and man-made systems,
especially mining. The analysis of geomechanical processes at rockburst-hazardous deposits in the Far
Eastern region of the Russian Federation showed a high degree of risk of the rock mass sections
destruction in dynamic form for the Yuzhnoye and Nikolaevskoye deposits.

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