Re-Using of Data on Rockbursts for Up-to-Date Research of the Geodynamic Safety Problem

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Abstract. Nowadays, anthropogenic seismicity during mining operations is actual in many countries around the world. Strong rockbursts and anthropogenic earthquakes cause not only large material damage but also social and environmental impact. At that, the major geodynamic events and sudden seismic activity remain statistically rare events that makes it difficult to study these phenomena and to find out regularities. Uniqueness of their occurrence conditions and, often, inaccessibility of information contribute to such state of affairs. At that, rockbursts were known since the 19th century and information on conditions of their occurrence is available in published papers and special catalogues. It seems that use in summarizing and analysis of the data on strong rockbursts occurred in the past at the deposits worldwide could contribute to a better understanding of a nature and mechanisms of anthropogenic earthquakes which take place today. In this connection, a problem on the rockbursts data re-using for search of the anthropogenic seismicity regularities has been arisen. In paper, structure and content of the published in the Soviet Union and Russia special catalogs and international bibliography indexes on rockbursts are analyzed. The data available in the catalogs and publications can be used for studying and confirming of some studying regularities related to the reactivation of tectonic faults, presence of tectonically strained zones, occurrence of geodynamic hazard far from the place of mining works. It is concluded that repeated analysis of the data on the rockbursts occurrence at the deposits worldwide on the basis of up-to-date geomechanical concepts will allow extending the statistical basis for search and identification of the anthropogenic seismicity regularities.

1. Introduction

Recently, in many countries, the rockbursts problem is transformed into a complex problem of anthropogenic seismicity. Along with strong rockbursts occurred in the course of the mining [1-6], seismic events occur at working of quarries [7] at the point of the mines closing [8]. While the prevention measures for relatively simple types of rockbursts, such as ‘strain bursting’, ‘bucking’, ‘pillar and face crush’ are well developed, the regularities of originating and occurrence of the induced earthquakes in the mining areas are poorly identified and studied. Examples of sudden occurrence of geodynamic hazard may be the largest anthropogenic Bachatsk earthquake in the Kuzbass (2013) that occurred in the area which previously was non-seismic, a strong rockburst at a copper mine in Poland (2016) which occurred despite the measures for seismological monitoring [5,7]. At that, the major geodynamic events and sudden seismic activity remain statistically rare that makes it difficult to study them and to identify...
the regularity. Uniqueness of the conditions for the rockbursts occurrence and, often, inaccessibility of information contributes to such state of affairs. Geodynamic hazard factors, acting together with other hazards associated with mining operations [9-14] creates a situation for the emergence in the mining areas of not only material damage but also social and environmental impact.

At that, rockburst are known since the late 19th century, and the largest of them, which by today's classification would be classified as anthropogenic earthquakes, occurred in the first half of the 20th century. Information on these rockburst occurrence is available in the published papers and special catalogues, but their analysis was performed from the point of view of out-of-date geomechanical concepts inasmuch as mines were closed more than 30 years ago [15-19]. Recently new data and reports on the state of rock massifs and progress in geomechanical and geodynamic processes were presented, models for geological data analysis are developed [20-21]. Among the mining science achievements of the last decades, scientists mention: experimental identification of tectonic stress field; identification of the relationship between global and local geomechanical and geodynamic processes due to human engineering activity; recognition of the existence of hierarchical geodynamic active block structure of rock massif and its impact on engineering constructions and conditions of the construction exploitation, etc. It seems that repeated analysis of the data on strong rockbursts occurrence from up-to-date point of view could contribute to a better understanding of the nature and mechanisms of anthropogenic earthquakes taking place today. In this connection there is the task of data re-use on rockbursts for the search of the regularities of anthropogenic seismicity origin.

2. Methodology
In the USSR and later in Russia, for a short time, by initiative of the Institute of mining geomechanics VNIMI, special catalogues of the rockbursts that occurred in ore deposits were produced, for example, Catalog, 1987 [16]. In the catalogue, for each case of rockburst, a "Rockburst card" which contains information on 15 items, including location and intensity of the rockburst, geological characteristics of the site, description of mining works, Commission's conclusions, are available (see Figure 1). According to the catalogues materials, rockbursts were selected for analysis by the following parameters: seismic energy (more than $10^6$ J), place, presence of tectonic faults, preliminary danger indications. Cases of severe rockbursts were selected according to the materials of bibliography index [15] and review papers [17, 19, 22] by the following parameters: destruction scale or seismic effect, location of the rockburst, presence of tectonic faults, preliminary danger indications.

3. Results
Preliminary analysis of the data from the catalogs, bibliography indexes and other publications on rockburst allows regarding some of geodynamic hazard cases as trends, but not anomalies.

3.1 Occurrence of geodynamic hazard at large distance from places of mining operations and reactivation of tectonic faults
Evaluation and analysis of the geodynamic hazard occurrence at large distance from mining is of great importance in addressing issues on secondary use of old mine workings, elimination of mines, functional zoning of the territories, etc. And while reactivation of tectonic faults in existing mines is one of the controllable factors, emergence of seismic activity areas at large distance from areas of mining operations (few kilometers or even tens of kilometers) is regarded as a geodynamic anomaly.

For example, during seismic activity in the Kuzbass in 2006-2009, in Polysaevo district, geodynamic events were recorded not only in the area of operating mines Oktyabr'skaya and Polysaevskaja, but in several places located in different directions from the area of mining operations at distances up to 10 km [7]. One cause of this situation may be activation under influence of human activities not only faults, but also blocks the earth's crust as a whole. Thus, according to the data of geodynamic zoning carried out in the Kuznetsk Basin in the 1980s-1990s, there is a spatial overlap of the block boundaries, revealed on the grounds of work performed in the 1980s, with the areas of seismic activation in 2006-2009 [21]. According to our data, one of the seismic activations arose in the zone of interference of the third rank block boundary in the area of an old mine working of the 7th of November Mine [23].
Published data analysis shows that occurrence of strong rockbursts far from the mines has been observed many times in different deposits worldwide. So, on 20.02.1987, at mine 15-15 of Severouralsk bauxite deposits, strong rockburst with energy of $10^8$ J occurred in the area where mining works has not been carried out for 10 years [16]. In the paper [17] an example of a strong rockburst in Tyrol mine (Austria) is given that occurred on Oct. 15, 1929 in VIII and IX levels in the area, where mining works has not been carried out for about 55-60 years. On Oct. 22, 1930, the extremely high strength rockburst occurred in footwall drift in VII eastern level, near the 1-st south throw where nobody worked for 42 years. On June 11, 1959, March 19 and 30, 1960, March 27, 1961, at the mines of Kolar field, there was a strong rockbursts with centers located far away from the ore veins [22, 24]. In the mines of Příbram (Czech Republic), in the period from 1910 to 1960, there were rockbursts located 20 km eastward of the workings, 10 km northward of the workings and 10 km southward of the workings. These rockbursts appeared as earthquakes and were observed at seismic stations of Prague, Pruhonice and Klodno.

It is clear that the chained facts are lined up, which indicates a hidden pattern, according to which there are some of the rock massif areas activating far from the mining sites.

3.2 Discussion on size of the strong rockbursts source zones
Data on size of the rockbursts source zones can be used to estimate the size of the activated earth's crust blocks what is important to know from both practical and theoretical points of view.
On 05.10.1984, at mine 15-15 of Severouralsk bauxite deposits, there was a rockburst with energy of $3.9 \times 10^8$ J and source zone size $r$ not less than 300 m in plan and not less than 150 m in vertical direction [16].

At the mine "Maks" located in the westernmost part of the Tirol deposit (Austria), there was a rockburst with the rock outburst in the area with length of 300 m, depth of 100 m and width of 40 m [17].

In 1930, there was a very strong rockburst at the mine "Maisor", Kolar deposit in India, between levels 974-600 m which caused 374 m destruction of workings in vertical direction. The shocks were observed on the ground surface within a radius of 16 km, and cracks appear in the buildings above the mine [24].

On 14 August 1964, there was a strong rockburst at the safety pillar of the Wright-Hargreaves mine in Canada; as a result, workings in all levels in the height range of about 600 m [18] were destroyed.

It can be seen that the sizes of strong rockburst source zone rare of several hundred meters that allows suggesting that mining works activate crustal blocks with sizes $R$ of several kilometers. Such comparative work has already been carried out at some deposit fields, and an analysis of historical data on massive rock bumps will help to reveal the pattern.

3.3 Strong rock bursts can occur without clear anticipatory signs

In general, the methods of forecasting rock bursts are well developed but for strong rock bursts, the problem of their forecast remains relevant. Such strong technogenic earthquake as an event on the Bachatsky open-pit on June 18, 2013, in the Kuznetsk Basin with a magnitude of about 6, a rock burst at the Rudna mine in Poland on November 20, 2016 [5, 7].

There are difficulties in recognition of the anticipatory signs of strong rock bursts – not only due to their focus location outside the area of mining. Very strong rock bursts occurred in the active mining areas without clear warning signs.

On August 14, 1964 [18] a strong rockburst with a magnitude of $M= 4.5-5$ was observed at the Wright-Hargreaves mine without anticipatory signs. This powerful rockburst occurred with no preliminary danger indications. Before the rockburst, works on driving of two producing levels 1080 and 1220 m were carried out for several months in the area of borehole pillar. These works were accompanied by some insignificant rockbursts which directly followed blasting operations. 6 hours before the rockburst, 70 drill holes were exploded in the mine without any subsequent rock burst.

The analysis of the rockbursts catalogues, such as [16], shows that a strong rockbursts at Severouralsk bauxite mine also happened with no preliminary danger indications what is confirmed by empty boxes in the correspondent columns of "Rockburst card".

3.4 Strong rockbursts happen with displacement of the tectonic faults wings

Rockburst at the Wright-Hargreaves mine occurred on August 14, 1964 was accompanied by a displacement of the tectonic fault wings near the base of the borehole [18,22], explains strong rockbursts at the Kolar mine in India with shift along Maisor fault. At the rockbursts in the Tashtagol deposit (Siberia) in 1986, a shift of the fault wing by 5 cm was observed [21]. In 1984-85, at Severouralsk bauxite mine, displacement along major faults happened in the course of strong rockbursts [6]. This information can be used for studying of regularities of global and local geodynamic processes interaction. The direction of wings dislocation during strong rockbursts can provide information about the active stress fields, which is of great importance for understanding their mechanism and appropriate conditions.

4. Discussion of the results

The data available in the catalogs and publications can be used for studying and confirming of some studying regularities related to the reactivation of tectonic faults, presence of tectonically strained zones, occurrence of geodynamic hazard far from the place of mining works. The prerequisites for re-use of rockbursts data include:
5. Conclusion

Repeated analysis of data on the rockbursts occurrence at the deposits worldwide on the basis of up-to-date geomechanical concepts allows extending of the statistical basis for search and identification of the anthropogenic seismicity regularities. Main fields for data re-use include:

- execution of works on data summarizing and searching for regularities;
- carrying out of research on geodynamic zoning, analysis of tectonic stress field in areas of strong rockbursts.
- repeated analysis of the data based on the results of additional work.

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