Factors Influencing Rock Burst Hazard in Deep Copper Ore Mine, SW Poland

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Abstract. In underground mines of copper ores, which are situated in Lower Silesia in SW Poland, the most common and dangerous threats pose seismic tremors and rock bursts. Copper ore exploitation is carried out in three mines, which are owned by KGHM Polish Copper JSC, i.e. Lubin mine, Rudna mine and Polkowice-Sieroszowice mine. Despite many rock burst preventive operations carried out over several decades of mining activity and aimed at countering seismic dynamic events, these phenomena have not been eliminated. The applied rock burst prevention measures only limit or mitigate the effects of seismic events. In mining, a concept of seismicity is used, which is defined as the tendency of an intact rock mass to seismic tremors induced by mining work in an area that was previously aseismic. Tremors and their results i.e. rock bursts affect not only excavations and underground infrastructure, but also the terrain surface. In the KGHM’s mines, seismic activity is monitored by the Mining Geophysics Stations. The number, coordinates and energy of tremors and rock bursts are registered, which helps determine the rock mass reaction to the adopted system and operation technology. The main purpose of the paper is to analyse seismic dynamic phenomena damaging mining excavations, i.e. rock bursts, in the Lubin mine, which took place from the beginning of the mine's operation in 1975 to 2016 (over 41 years) and to identify and investigate geological and mining factors (parameters) facilitating the growth of seismic and rock burst hazards. The following factors (parameters) favourable for the occurrence of dynamic phenomena with damaging effects in excavations were taken into consideration: the seismic activity of the rock mass (spontaneous and provoked tremors), the deposit depth and thickness, geomechanical properties of rocks, exploitation systems, the method of elimination of mined-out space, the occurrence of gobs, tectonic disturbances and the life time of excavations. The results of the observation of selected parameters made it possible to determine the causes of rock bursts as well as to evaluate the impact of the exploitation system including the technology and rock burst prevention on seismic and rock burst hazard. Moreover, seismic activity of the mining division with the highest number and energy of rock bursts was analysed. The effectiveness of rock burst prevention measures used in this division was assessed too. The results of the analyses indicated some interdependencies between factors that may affect the phenomena discussed.

1. Introduction

Three deep underground mines, namely the Lubin mine, Polkowice-Sieroszowice mine and Rudna mine have been extracting copper ores in Lower Silesia in Legnica-Glogow Copper District (LGCD) SW Poland for more than fifty years. They belong to KGHM Polish Copper JSC, which is one of the biggest copper and silver producers in the world and nowadays excavates mineral deposits not only in
Poland but in Canada, the USA, Greenland and Chile, too. Annually, more than 30 million tons of copper ores with about 2% of pure metal and substantial amounts of silver are excavated annually. The average copper content is about 1.8% and silver amount reaches around 51g/Mg [1].

In these three mines, rock bursts constitute the most dangerous threat associated with mining operations. To date, many preventive measures have been developed and implemented to counteract the rock burst hazard. However, seismic dynamic events have not been eliminated yet. Nowadays, the prevention activities is only able to reduce or mitigate the destroying effects of seismic phenomena. The rock burst prevention has to include monitoring and assessing the rock mass seismic activity, technological, active and organizational-technical methods for fighting, mitigating and reducing the seismic threat [2]. The seismic activity in the KGHM mines is monitored by means of the seismological network. Seismometers are mounted in underground excavations to receive every tremor, even so-called traces (tremors of very small energy). These signals are transmitted to the Mine Geophysics Station located on the surface. The Station registers and analyses the seismic activity i.e. the coordinates, energy and number of tremors and rock bursts. Such activities in subsequent and different time windows are compared, which allows one to assess the behaviour of the rock mass in relation with geological conditions, the exploitation system and technology as well as rock burst prevention effectiveness.

The prime purpose of the paper was to examine the dynamic seismic events which destroy excavation workings i.e. rock bursts and to identify and investigate the geological and mining factors increasing the rock burst hazard in the Lubin mine. Analyses covered 41 years (from 1975 to 2016) of mining operations. The seismic activity i.e. the number and energy of tremors and rock bursts (provoked and spontaneous) as well as other factors enhancing the seismic hazard such as the deposit depth, geomechanical properties of rocks, deposit thickness, tectonic disturbances, distance from gobs and remnants, life time of workings, rock burst prevention effectiveness and exploitation systems were considered. Observation of the aforementioned parameters may help assess their influence on the seismic hazard. Three mining divisions with the most number of rock bursts were selected to examine their seismic activity and rock burst prevention effectiveness.

2. Research area description

The construction of the Lubin mine started on January 1, 1960, and mining was undertaken only after eight years in 1968. This mine is the oldest one in LGCD and is located north of the city of Lubin. There are six mining areas in LGCD [3] i.e. OG (stands for mining area) Sieroszowice, OG Polkowice, OG Radwanice East, OG Rudna, OG Lubin-Malomice, and OG Głogów Gleboki Przemysłowy, (Deep-Industrial Głogów) which are presented in figure 1.

The Lubin mine exploits the Lubin-Malomice deposit with an area of almost 158 km². It covers in total three mining regions: West Lubin, Main Lubin and East Lubin. As of December 2015, the total amount of copper ore resources in this mine was 328 million tons. Extracted mineral contains 1.28% of copper. This plant stands out from the remaining three mines with a very high silver content of 54.5g /Mg. Annually 8 million Mg of ore are mined here and 68.33 thousand Mg of copper and 319 Mg of silver are produced. The copper ore deposit depth ranges from 368 to 1006 meters [3].

Two main types of exploitation system were implemented i.e. a one-stage room-and-pillar system with the roof self-deflection and a one-stage room-and-pillar system with hydraulic backfill. The appropriate roof control is to prevent the roof layers from lowering, which could cause a collapse in the excavation. Bolting system of the excavation supporting was applied. The systems have long working fronts (200 m) together with technological pillars that act as supports. In the room-and-pillar system, the deposit bed is cut into rooms and belts, which create technological pillars. In the rock mass, the operating pressure causes damages to these pillars, and then the post-critical state of work occurs. The deposit is excavated with the use of blasting technique [3, 4]. Nowadays, 8 mining divisions exploit copper deposit in 15 mining panels.
Figure 1. Mining areas in Legnica-Glogow Copper District (LGCD) and contours of the deposit depth [website www.geoland.pl].

The copper ore mine in Lubin, is exposed to a variety of hazards such as: high temperature (up to 40°C), water inflow, gases, hydro sulphide, gas and rock outbursts and seismic tremors which can cause rock bursts. The first seismic activity in this region caused by mining activities was recorded in the second half of 1968. On the 31.01.1972 the first violent tremor of high energy was recorded, which was noted even on the earth surface. Since then, such events have appeared more and more frequently. For example, from 1990 to 2013, 16137 tremors with energy of $1\cdot10^3$J and more were recorded. The total seismic energy reached $1.43\cdot10^{10}$J. The lowest number of tremors, 120, was noted in 1991, in 2006 there were as many as 1,888 tremors. The most active period were years 2005-2008, when the number of tremors exceeded more than 1000 in each year; 1,371 (2005), 1,463 (2007), 1,023 (2008). The tremor of the greatest energy of $2.91\cdot10^9$J was recorded in 2000 [5].

In the first years of the Lubin mine life, tremors were not recorded and analysed as accurately as at present. Initially, the observations took place only in selected mining divisions. In 1977, the first seismic station was established in this mine, which gave the possibility to accurately observe and assess the seismic hazard also in other divisions. Such a project had already been developed in the Polkowice mine. Accurate observation and analysis of tremors and rock bursts facilitate choosing the adequate preventive method to assess and limit the rock burst risk.

3. Results and discussions
The analysis covered the following factors (parameters) which may influence the number and energy of rock bursts: the number of recorded rock bursts, the type of rock bursts (spontaneous and provoked), seismic energy, the depth of rock burst location, coordinates (position) of rock bursts, exploitation system and the method for mined-out space management. Observation of these parameters makes it possible to determine the causes of the occurrence of rock bursts, to assess the impact of the exploitation system used, including technology and rock burst prevention on rock burst hazard as well as the impact of geomechanical properties of rocks or geological conditions.

The following definitions have been applied: seismic events of energy equal or bigger than $1\cdot10^3$J are considered as tremors and these of energy equal or bigger than $1\cdot10^5$J are called high-energy tremors. A tremor can destroy a mining working and such an effect is called a rock burst. Tremors and rock bursts which are induced by mining operations are called spontaneous and these deliberately triggered by means of blasting are called provoked.
3.1. Rock bursts in Lubin mine in years 1975-2016

In the Lubin mine, from 1975 to 2016 years, 109 rock bursts occurred (figure 2). By 1996, the majority of rock bursts were spontaneous, which may suggest that at that time the rock bursting prevention was not as well developed as it is at present. The situation began to change from 1997; over the next three years, up to the year 2000 there were 15 events and all of them were provoked, which proved that the stresses in the rock mass and release of elastic energy were under control. In years 2015-2016 there were 16 rock bursts at a depth of over 840 meters, i.e. in the deepest parts of the mine. The largest energy, which amounted to $2.5 \cdot 10^9$J, was associated with the spontaneous rock burst in 2000. The two-stage room-and-pillar operating system with a pillar cutting was used. Factors that probably could have influenced the appearance of such a strong shock included the stiffness of the pillar, large exploitation depth or fault.

The tremor with the smallest energy of $2.6 \cdot 10^4$J which caused a spontaneous rock burst occurred in 2012 at a depth of 740 meters, next to the shaft. In this area there was a network of faults, which could be one of the reasons for the rock burst. The last seven rock bursts in 2016 occurred in the north-eastern part of the mine at a depth of 850 meters. They were spontaneous events. No faults were noticed and the seismic activity was high. The reason for such a large number of spontaneous rock bursts could be a significant depth, but above all the strength of the rocks. The Zechstein carbonate series were found in the roof layers; the dolomite limestones and dolomites were also located directly above the roof of the deposit. These rocks are characterized by high strength and if the stress reaches their strength, a very violent tremor may occur, which can cause rock bursts. In addition, a large network of cracks was observed in the dolomites, which also increases the possibility of rock bursts appearance.

In the other mining division there were also a lot of spontaneous rock bursts, which were affected by geomechanical properties of rocks i.e. carbonate-dolomite rocks of 7.5-meter thickness in the roof and anhydrites over them. In the floor, there was also a hard sandstone, which also had high strength parameters raising the risk of a sudden tremor. An additional factor that could have caused spontaneous tremors was the fault network (two faults in the north and north-west and three faults in the south-east parts of the division) and cracks. The largest annual number of rock bursts occurred in 1997, 2015 and 2016 and amounted to eight each year. The total amount of rock burst energy in those years was not large. In 1978, 1985, 1990, 1991, 1992, as well as in 2013, no rock bursts were recorded.

The smallest total annual energy occurred in 1976 and was $8.4 \cdot 10^5$J. In 1975, i.e. the first year in which dynamic phenomena were registered, the total energy amounted to $4.2 \cdot 10^6$J, which was a little compared to other years in which the energy exceeded $1 \cdot 10^8$ or $1 \cdot 10^9$J. In each of 1975 and 1976 years one rock burst occurred. In the second half of the mine’s life, that is from 1997 the number of rock bursts increased but energy did not. Until 1996 there were several energy increases, while in the remaining years the annual energy was comparatively very small. In 2001, there were six rock bursts. It can be stated (figure 2) that energy was not related to the number of rock bursts; after the periods of low energy the seismic activity started to grow, which often resulted in rock bursts and after high-energy rock bursts seismic activity was low for a certain period of time. Over half of the rock bursts were caused by tremors with energy equal or bigger than $1 \cdot 10^7$J (figure 3).

Table 1 shows the number of rock bursts, the energy of the tremors that caused rock bursts, and the energy of tremors per one rock burst in particular decades from 1977 to 2016. In the 1997-2006 decade the most rock bursts occurred, i.e. 41, in 2007-2016 there were 35 ones, 20 rock bursts occurred in 1977-1986 and 11 in the 1987-1996 decade. The energy per one rock burst in the years 1987-2006 was in the order of $10^4$, in the decades of 1977-1986 and 2007-2016 in the order of $10^7$. The reduction of energy in the last decade may indicate that applied preventive measures were suitable and effective.
Figure 2. Number of rock bursts and their energy over the 1975-2016 period in Lubin mine.

Figure 3. Percentage of energy of particular order related to rock bursts over the 1975-2016 period in Lubin mine.

Table 1. Number of rock bursts and energy of tremors causing rock bursts in Lubin mine in particular decades of the 1977-2016 period.

| Years       | Number of rock bursts | Energy of tremors, J | Energy for one tremor, J |
|-------------|-----------------------|----------------------|-------------------------|
| 1977-1986   | 20                    | $1.38 \times 10^9$   | $6.89 \times 10^7$      |
| 1987-1996   | 11                    | $1.86 \times 10^9$   | $1.69 \times 10^8$      |
| 1997-2006   | 41                    | $6.44 \times 10^9$   | $1.57 \times 10^8$      |
| 2007-2016   | 35                    | $1.01 \times 10^9$   | $2.88 \times 10^7$      |

3.2. Influence of selected geological and technological factors on rock burst hazard

The following geological and mining factors favouring the occurrence of dynamic phenomena with effects in excavations were taken into consideration: seismic activity of the rock mass, depth of...
exploitation, exploitation system along with the method of liquidation of the mined-out space (roof management method).

3.2.1. Seismic activity, number and energy of rock bursts. Analysis of the seismic activity in relation to the number and energy of rock bursts covered 29 years (1987-2016 period). There were 19,780 tremors of total energy of $1.68 \times 10^{10}$J and 87 rock bursts connected with total energy of $9.31 \times 10^9$J. The number and energy of tremors varied in particular years, the periods of high and low seismic activity occurred. The number of tremors in the mine did not have a significant impact on the emergence of rock bursts. There may have been a lot of tremors, but it did not mean that a rock burst would occur. It was obvious that the energy of seismic tremors was related to the energy of rock bursts, because the rock burst is the result of a high energy tremor. However, not all tremors result in a rock burst. In addition, the emission of a large amount of energy could result in a decrease in the seismic risk, i.e. a decrease in the energy of tremors. The energy of tremors had no significant effect on the number of rock bursts. For example, in 2015 and 2016 the energy of tremors did not exceed $5 \times 10^8$J, and the rock bursts appeared 8 times in each year, in 2013 the energy of tremors was of the order of $10^7$J, but the rock bursts did not occur. Usually low-energy tremors do not result in rock bursts, with the increase of tremor energy the risk of their occurrence increases. 76% of tremors with energy of the order of $10^8$J and 100% of those with energy of $10^9$J caused a rock burst.

3.2.2. Exploitation depth. Excavations at the Lubin mine are located at a depth of approx. 490 to 950 meters. The 50-meter depth interval was considered in the analysis of the depth from 500 meters to 950 meters and years 1993-2016 (table 2). The least (2) rock bursts occurred at a depth of 500 to 550 meters. As the depth increased, the number of phenomena also increased. At a depth of 700-750 meters, there was a slight decrease in the number of these phenomena from 8 to 7, and from the depth bigger than 800 meters 51 rock bursts took place. The results of the analysis confirm the thesis that one of the causes of rock bursts is a large depth of exploitation. In the Lubin mine, this is not the main cause of the rock bursts, because the mine is the shallowest one among the three mines in KGHM Polish Copper JSC and hence the vertical stresses acting on the rock mass are the smallest, in contrast to, for example, the Rudna mine, where the exploitation depth reaches 1,300 meters.

| Exploitation depth | Number of rock bursts | Energy, J |
|--------------------|-----------------------|-----------|
| 500-550            | 2                     | $7.20 \times 10^6$ |
| 550-600            | 3                     | $2.05 \times 10^8$ |
| 600-650            | 3                     | $4.72 \times 10^7$ |
| 650-700            | 9                     | $3.20 \times 10^8$ |
| 700-750            | 8                     | $2.67 \times 10^8$ |
| 750-800            | 7                     | $6.82 \times 10^8$ |
| 800-950            | 51                    | $6.90 \times 10^9$ |
| **Total**          | **83**                | **8.42 \times 10^9** |

3.2.3. Exploitation system and mined-out space management. Available valid data made it possible to analyze the impact of the mining system on the rock burst risk for the years 2005-2016. At the Lubin mine, four types of the one-stage room-and-pillar operation system were used, differing in the method of liquidation of the mined-out space, i.e. liquidation with hydraulic backfill (D-P), roof self-deflection (J-UG) and roof deflection with increased slope up to 16° (J-UGN 1) and 35° (J-UGN 2). In addition to these four types, two more systems were used, now withdrawn, namely: a single-stage room-and-pillar system with roof self-deflection and a operational closing pillar (J-UGR-PS) and roof self-deflection for closing areas (J-UGZ). The operational closing pillars are deliberately left pillars, successively elongating, through which ore output is transported with a belt conveyor. Spontaneous rock bursts
were investigated. Such rock bursts took place when the J-UG, J-UGR-PS system and J-UGZ system were used (figure 4). In 2005-2016, 22 spontaneous rock bursts were registered. 19 rock bursts with a total energy of $4.82\cdot10^8$J occurred in the fields in which the J-UG system was used. Two phenomena with a total energy of $7.7\cdot10^7$J were recorded for the J-UGR-PS system. One rock burst with $1.5\cdot10^7$J energy appeared in the place of using the J-UGZ system. The J-UGZ system was used where the deposit occurs in complex geological and mining conditions which were connected with constrained mining along with retaining pillars and closing fields. This is most often where there is exploitation tied up with retaining pillars and closing fields. The safest system was a system with hydraulic backfill; no rock bursts were recorded. The system with liquidation of gobs by means of roof self-deflection was less effective in terms of the rock burst prevention, while the energy difference in its three types (J-UG, J-UGR-PS and J-UGZ) was small, which indicated that roof management applied in J-UG systems did not affect rock burst energy. Most of the spontaneous phenomena were connected with the J-UG system because it was used in most of the fields.

![Figure 4](image.png)

Figure 4. Number and energy of rock bursts for particular exploitation systems over the 2005-2016 period in Lubin mine.

3.3. Effectiveness of rock burst provocation by means of blasting techniques

The provoked seismic tremors are deliberately triggered by blasting works to release energy and thus to relax the rock mass, while spontaneous ones are those that occurred as a result of mining work and cannot be predicted. The provoked tremors are much more advantageous for the mine than the spontaneous ones because the time and place of their occurrence can be planned and monitored.

The effectiveness of rock burst provocation was calculated as a percentage of the number and energy of phenomena provoked in the number and energy of all rock bursts. The effectiveness of provoking the rock bursts with respect to their number was 47.71% and that with respect to their energy was 45.51% (figure 5), which allows one to state that blasting works were very effective in provoking the rock bursts and the mine had control over the rock mass behaviour.

3.4. Effectiveness of rock burst prevention in one selected mining division

The #6 mining division was chosen for the analysis since it was the most active division in the Lubin over the period of 1975-2016. The division, have been conducting mining works for over 35 years. Currently, the division exploits, among others, the field in the north of the mine and previously it exploited nine fields in the north-western part of the Lubin-Malomice deposit. In years 1975-2016 the depth of exploitation reached 840 meters, the length of the front fluctuated between 340 and 550 meters, the thickness of the deposit thickness ranged from 2.2 to 2.6 meters in the fields already abandoned, but currently it changes from 1.0 to 4.0 meters. Mining operation was carried out with the
J-UG exploitation system. The rock bursts occurred in 1981-2016, although not every year. There were 40 rock bursts, which constituted 36.7% of all such phenomena. Total energy reached $6.56 \times 10^9$ J and it was also the highest energy among all divisions. The effectiveness of provocation in relation to the number of rock bursts was 60% and in relation to their energy amounted to 49%, so it was very high.

![Figure 5](image_url)

**Figure 5.** Effectiveness of rock burst provocation with blasting: (left) number of rock bursts; (right) energy connected with rock bursts in Lubin mine in years 1975-2016.

### 3.4.1. Seismic activity and effectiveness of active and technological prevention methods.

The most seismic activity in the #6 division took place in 2002 and 2015-2016 years. In 2002 there were 86 tremors of energy of $1.39 \times 10^9$ J, in 2015 there were 291 tremors of $2.12 \times 10^8$ J energy, and in 2016 there were 245 tremors of $8.14 \times 10^7$ J energy. In 2002 and 2015 there were 4 rock bursts in each year and in 2016 one rock burst occurred.

The effectiveness of active methods in reducing the rock burst hazard was assessed on the ground of the percentage share of the number and energy of tremors triggered/provoked by blasting in the number and energy of all tremors (table 3). Tremor provocation by blasting works and thus the control of their occurrence time and place enabled the increase of the work safety to a quite small extent. In 2002, the effectiveness of provocation connected with the tremor number was 34%, and that referred to the tremor energy reached 99%. In 2015, the effectiveness of provocation in relation to the tremor number was not very high and amounted to 19%, and that with respect to the tremor energy was only 9%. In 2016, the effectiveness connected with the number of tremors was 15% and that related to their energy amounted to only 16%. The effectiveness of tremor provocation was satisfactory in 2002 but it decreased significantly in 2015-2016 years. Such situation might have been connected with the increasing exploitation depth, fault zones, constrained mining conditions and difficult roof conditions like high strength of roof rocks and numerous cracks. In 2002 all rock bursts were provoked. However, the rock bursts which occurred in 2015-2016 were spontaneous, hence the provocation effectiveness was equal 0%. Such situation might have been connected with the increasing exploitation depth, fault zones, constrained mining conditions and difficult roof conditions like high strength of roof rocks and numerous cracks.

**Table 3.** Effectiveness of group blasting works related to number and energy of provoked tremors in 2002, 2015 and 2016 in the #6 mining division.

| Years | Number of Provoked tremors | Effectiveness (number of tremors) % | Energy of provoked tremors, J | Effectiveness (energy of tremors) % |
|-------|-----------------------------|-------------------------------------|-------------------------------|------------------------------------|
| 2002  | 29                          | 34                                  | $1.38 \times 10^9$           | 99                                 |
| 2015  | 55                          | 19                                  | $1.86 \times 10^7$           | 9                                  |
| 2016  | 37                          | 15                                  | $1.31 \times 10^7$           | 16                                 |
To evaluate the effectiveness of technological methods, the location of the epicentres of spontaneous seismic tremors in relation to the working front was examined (table 4). The aforementioned epicentres can occur in the following three zones of the exploitation field: A - ahead of the operation front (in the solid), B - on the operation front, C - in the gobs. The technological preventive methods aim to conduct exploitation and control the roof to release energy slowly and gently. The occurrence of seismic tremors in the gobs (C) is the most expected, while the most hazardous are tremors located ahead of the front (A); they often trigger strain rock bursts. The place and time of the occurrence of tremor epicentre in zone B is predictable to a certain degree. However, they increase the seismic hazard in the mining panel. The percentage of the number and energy of tremors in each zone was calculated to assess the reduction of stress accumulation zones resulted from applied mining technology.

In 2002, tremors with the epicentre located on exploitation fronts predominated, there were 41 (79%) with total energy of 5.73·10$^6$ J (90.4%). There were 8 (15%) tremors with a total energy of 5.99·10$^5$ J (9.4%). There were 3 (6%) tremors in the gobs with energy of 1.21·10$^4$ J. In 2015, 214 (92%) tremors with energy of 1.93·10$^8$ J (99.72%) had their epicentres on the working fronts. Occasionally, tremors appeared ahead the front line or gobs. These tremors were characterized by the very low energy. In 2016, 196 (97%) tremors with energy of 6.82·10$^7$ J (99.98%), had the epicentres on the operational front. There were no tremors ahead of the fronts while there were 3 tremors of low energy in the gobs.

It can be concluded that the effectiveness of technological prevention was satisfactory for reducing the seismic hazard. The largest number and energy of tremors were found on the operational fronts and hence at a predictable location.

Table 4. Effectiveness of technological prevention related spontaneous tremors in 2002, 2015 and 2016 in the #6 mining division in the Lubin mine.

| Zone | Year | Number of tremors/Percentage | Energy of tremors, J/Percentage |
|------|------|-----------------------------|--------------------------------|
| A    | 2002 | 8/15%                       | 5.99·10$^5$/9.4%               |
| B    |      | 41/79%                      | 5.73·10$^6$/90.4%              |
| C    |      | 3/6%                        | 1.21·10$^4$/0.2%               |
|      | 2015 | 6/3%                        | 4.86·10$^8$/0.25%              |
|      |      | 214/92%                     | 1.93·10$^9$/99.72%             |
|      |      | 13/5%                       | 4.97·10$^5$/0.03%              |
|      | 2016 | 0/0%                        | 6.82·10$^7$/99.98%             |
|      |      | 196/97%                     | 1.66·10$^4$/0.02%              |
|      |      | 7/3%                        |                                |

4. Conclusions
The dynamic phenomena with damaging effects in mining excavations, i.e. bursts, are the consequence of many geological and mining factors influencing their occurrence frequency and their energy size, which was confirmed by the results of analyses carried out for nine different mining divisions of the Lubin mine over forty-one-year period (from 1975 until 2016). Different conditions in each of the divisions along with different exploitation systems and rock burst prevention measures had an impact on the seismic hazard in the entire mine. The following factors were analysed: seismic activity, depth of exploitation, rock strength properties, exploitation system along with the method of mined-out space management. For 41 years the number and energy of rock bursts was very diverse. No bumps were recorded in some years and places. In the second half of the mining operation life, the number of rock bursts increased while the energy was stable. It was found that the same number of rock bursts could trigger emission of both high and low total energy from the rock mass. The seismic activity should pose a factor which influences the occurrence of rock bursts. In the Lubin mine over the years 1987-2016 it was very diverse. At 19,780 tremors, 87 of them caused rock bursts, which means that the number of tremors did not affect the occurrence of rock bursts. There was also no
relationship between the energy of tremors and the number of rock bursts. The most rock bursts were caused by tremors with energy equal or bigger than $1 \cdot 10^7$J, which was connected with the huge amount of energy emitted by such tremors.

In the years 1975-2016, the Lubin mine provided the very good effectiveness of rock burst provocation with the use of blasting techniques. Unfortunately, the effectiveness of provocation of tremors in the mining division selected for analysis was at a low level in 2015-2016. However, the effectiveness of technological methods, in this division, was satisfactory; the majority of spontaneous tremors took place on the exploitation fronts. It was found that the greatest impact on the occurrence of tremors, and therefore rock bursts, had roof rocks with high strength and proneness to rock bursts. These rocks were mainly carbonate rocks (dolomites, limestones) or those with a carbonate bond. The tectonic involvement was another factor that could have been important, but it was not the prime cause, because in many mining fields where numerous rock bursts took place there was the little tectonic involvement. However, with the increase in the depth of exploitation, the number and energy of rock bursts, especially below 850 meters, increased. Until 1997, a two-stage exploitation system with a roof deliberate collapse caused a significant rock burst threat. After the introduction of the one-stage system with the roof self-deflection, the threat decreased. It was found that the safest way to eliminate the mine-out space was the hydraulic filling and the liquidation of gobs by means of roof self-deflection had a minor impact on the number and energy of rock bursts. The phenomenon of rock bursts is complex and multifactorial. For this reason, it is important to conduct comprehensive analyses of geological and mining conditions in which rock bursts occurred.

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