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The influence of regional geological settings on the seismic hazard level in copper mines in the Legnica-Głogów Copper Belt Area (Poland)

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Abstract. The current level of rockburst hazard in copper mines of the (LGOM) Legnica- Głogów Copper Belt Area is mostly the consequence of mining-induced seismicity, whilst the majority of rockbursting events registered to date were caused by high-energy tremors. The analysis of seismic readings in recent years reveals that the highest seismic activity among the copper mines in the LGOM is registered in the mine Rudna. This study investigates the seismic activity in the rock strata in the Rudna mine fields over the years 2006-2015. Of particular interest are the key seismicity parameters: the number of registered seismic events, the total energy emissions, the energy index. It appears that varied seismic activity in the area may be the function of several variables: effective mining thickness, the thickness of burst-prone strata and tectonic intensity. The results support and corroborate the view that principal factors influencing the actual seismic hazard level are regional geological conditions in the copper mines within the Legnica-Głogów Copper Belt Area.

1 Introduction

Major natural hazards in copper mining in Poland include rock bursts and tectonic movements [1-2]. Most rock bursts and rock mass destressing events registered in the (LGOM) Legnica-Głogów Copper Belt Area have been the consequence of high-energy events whilst the current rock bursting hazard level is associated with mining induced seismicity. Potential of high-energy tremors is an inherent feature of copper fields within the LGOM area mostly due to the occurrence of burst-prone roof rock strata over the worked-out fields and periodic faulting movements, these impacts are further exacerbated due to current mining activities [2-5].

The analysis of seismic readings registered in recent years in the LGOM area suggests that Rudna is the most tectonically disturbed of the mines in the area [6], which is the result of natural conditions (mining depth, thick-layered rock mass structure, faulting) and the need to mine plots in areas already disturbed by extensive mining operations.

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2 Local settings of the Rudna mine

The Rudna mine is one of the three mines of the Polish Copper Corporation KGHM Polska Miedź S.A. located within the Legnica-Głogów Copper Belt Area, to the north of the town Polkowice, its mineable horizon being 77.8 km2 (Fig 1). The average production capacity now is about 12 mln tons of copper per year [7].

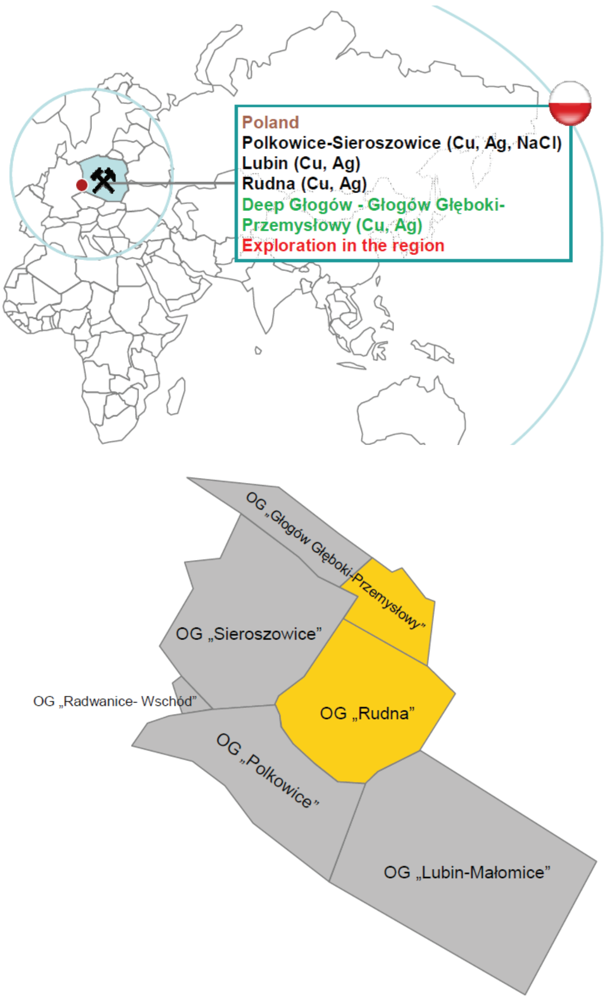

Fig. 1. Copper mines within the LGOM area in Poland [7].

The Legnica-Głogów Copper Belt Area is a part of the Fore-Sudetic Monocline and its geological structure and tectonic features are determined by particular stages of sedimentation processes and rock mass dislocations [8]. The copper ore deposit there is tectonically disturbed, experiencing seismic activity. There are some major faults with a throw of 100 m as well as associated groups of rolls and smaller faults that have the throw of only about 10 m. Of particular importance are the faulting zones in the Rudna Główna site (Central Rudna) and in Biedrzychowa [7].

Copper ore deposits include three rock types with different lithology: red footwall sandstone, illite-dolomite shales and zechstein dolomites. The deposit thickness within the Rudna mine varies from 0.5 to 20 m (4.3 m on the average), 20% of these being thick beds with thickness exceeding 10 m. Roof rock strata include dolomites and limestone 12.2-

106.3 m in thickness, their compression strength up to 25 m over the roof varies from 30 to 250 MPa (113 MPa on the average) [7].

Mining operations are continued in three mine areas: Central Rudna (RG), Western Rudna (RZ) and Northern Rudna site (RP). There are 11 shafts accessing the deposit and mining operations are carried out at the depth 850-1250 m [7].

Copper deposit in Rudna is mined by the room and pillar method with the roof control strategy for deposits up to 7 m in thickness, whilst hydraulic backfill system is used to facilitate the mining of thicker ore zones (more than 7 m). The blasting technology is used during the development and preparatory works as well as in the course of regular mining activities [7].

3 Seismicity

The historical frequency of seismic activity in the mine field areas of the Rudna mine site is investigated, covering the years 2006-2015 [6]. The level of seismic activity, measured by the number of tremors N in particular energy categories (A_s>10^3 J), the total number of tremors ΣN, the total seismic energy ΣA_s and the energy expense (in relation to the output level) J, is shown in Table 1. Total seismic energy and the energy expense in the analysed mine regions are illustrated in Fig 2 and Fig 3.

Table 1. Seismicity in the proximity of the Rudna mine over the years 2006-2015.

Mining area	Number of tremors N [-]							ΣN	ΣA_s	J
	10^3	10^4	10^5	10^6	10^7	10^8	10^9	[-]	[GJ]	[J/Mg]
Central Rudna	6188	2294	816	283	57	5	1	9644	5.7	137.5
Western Rudna	5272	2236	738	194	54	2	-	8496	2.6	72.5
Northern Rudna	3363	1509	492	157	55	3	-	5579	2.5	76.8

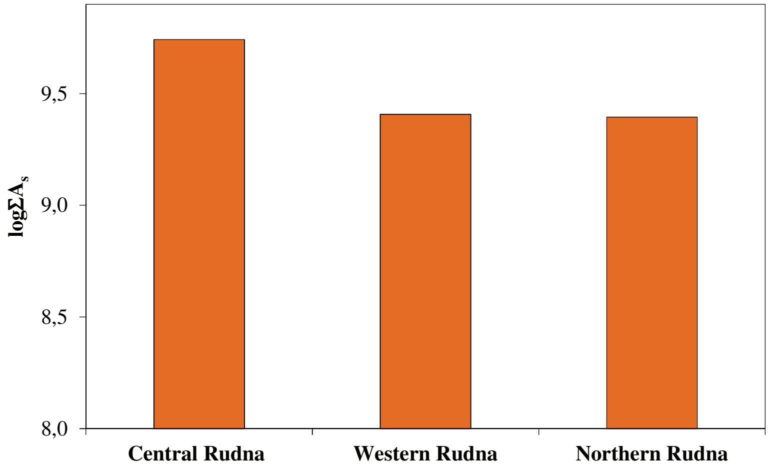

Fig. 2. Total seismic energy within the Rudna mine over the years 2006-2015.

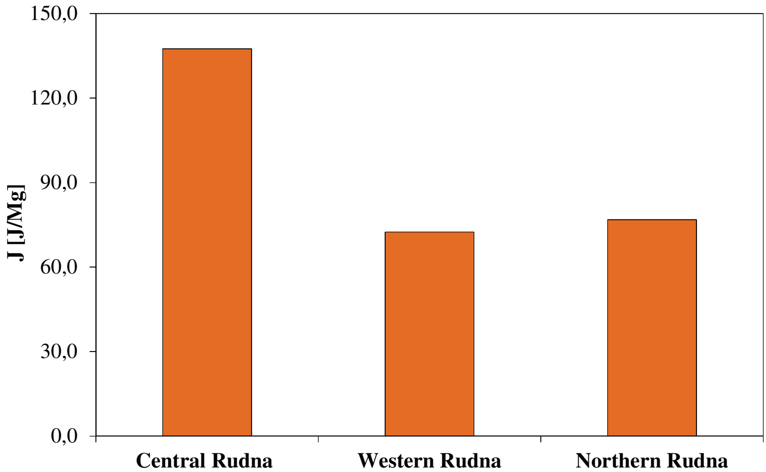

Fig. 3. Energy expense indicator in the Rudna mine site over the years 2006-2015.

It appears that the seismic hazard level in particular mines sections varied over the years 2006-2015. No matter which seismicity parameter was considered, the highest level of seismic hazard would be registered in the Central Rudna site whilst the hazard levels in the Western Rudna and Northern Rudna sites were lower (both in quantitative terms and in terms of energy expense). In terms of unit energy expense, the ordering of the two latter sites would be reversed (Northern Rudna, Western Rudna).

4 Influence of geological settings

Questing the reasons for varied seismic hazard level in the Rudna site, reference is made to geological settings in the context of the mining thickness associated with the ore deposit thickness, actual thickness of rock strata in the proximity of the mining operations and tectonic intensity.

4.1 Ore deposit thickness

A principal factor influencing the seismic hazard level is the ore deposit thickness and associated height of cut. A body of data gathered in the LGOM copper mines and in research reports indicates that increasing the cutting height and removing the old excavations by the same strategy results in enhanced seismic hazard levels [2,4,9].

The study of representative geological profiles (Fig 4) supported by a brief summary of mining activities to date (Table 2) yields the effective mining thickness in particular sites within the Rudna mine [7]:

- from 5.1 to 16.5 m (11.9 m on the average) in Central Rudna;
- from 3.7 to 14.6 m (5.5 m on the average) in Western Rudna;
- from 2.8 to 18.3 m (8.4 m on the average) in Northern Rudna.

These findings are in agreement with the effective mining thickness distribution in the worked-out field section in the Rudna mine (Fig 5) [6].

Recalling the previously derived dependence and the seismic readings data, it is reasonable to suppose that greater ore deposit thickness and height of the cut in the Central Rudna region may be responsible for the highest seismic hazard level compared to other mine sections.

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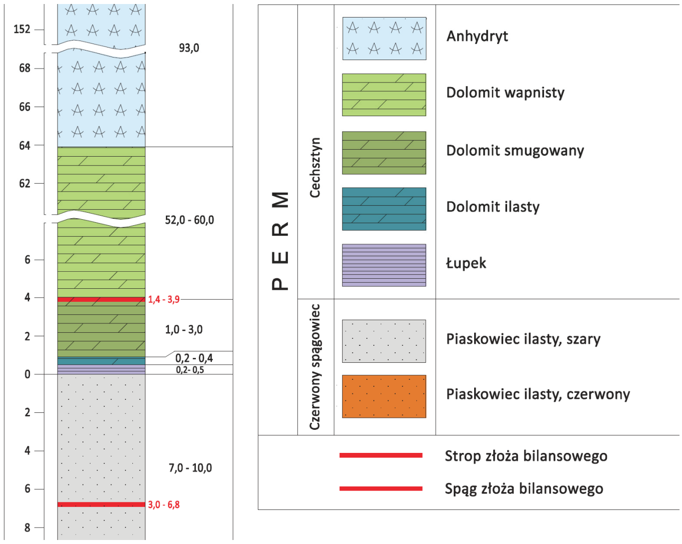

Fig. 4. A geological profile of the deposit in the Rudna mine [6].

Table 2. Effective mining thickness in various section of the Rudna mine.

Mining area	Section	Mine field	Mining thickness [m]	Ripped dolomite strata [m]	Residual dolomite [m]
Central Rudna	G-1	XII/1	14.1	2.5	87.5
		XII/2	12.4	0.6	86.9
	G-2	XVII/1	12.9	0.8	71.1
		XVII/2	8.3	1.5	72
		XI/1	10.7	3.4	60
		G-15/10	5.1	1.8	40
	G-3	G-3/4	13.6	2.9	77
		G-1/7 Blok A	16.5	1.2	95
	G-7	G-7/5	16.1	2	70
		XIV/2	9	2	85
Western Rudna	G-11	XIX/1	5.7	1.6	17.7
	G-12	XIX/2	4	1.4	17.9
	G-14	XXV/2	4.4	1.2	9.8
	G-15	XVI/1	14.6	1.4	57.6
		XV/2	4	0.8	57.2
		XXV/1	3.7	1	14
	G-17	XV/1	4.9	2.3	18.6
		XV/4	4.5	1.9	12.5
		XV/5	3.7	0.8	10
Northern Rudna	G-23	XXI/1	5.6	0	54.4
		XXI/2	11.7	0.2	67
	G-24	XXIII/2	4.6	1.4	18.7
	G-25	XXVIII/1	2.8	0.3	15.7
	G-26	XXIII/3	18.3	3.7	45
		XXIII/4	7.4	2.7	30

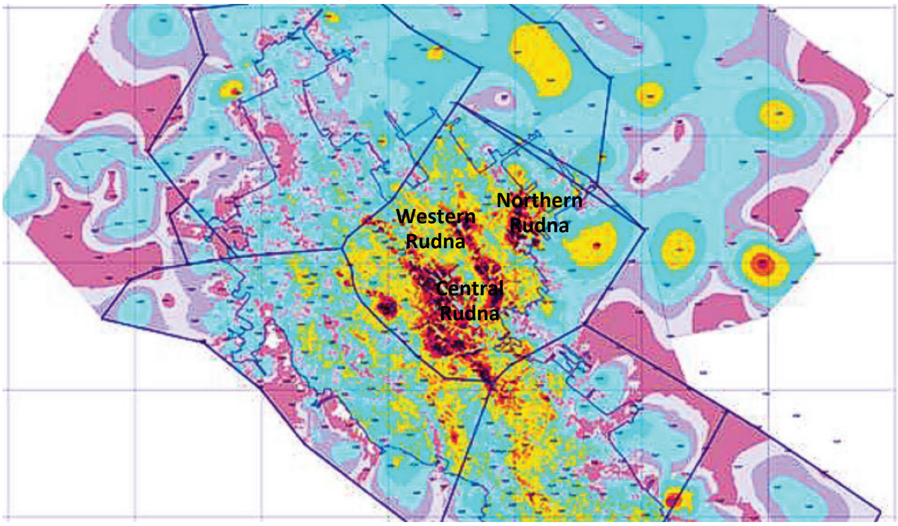

Fig. 5. Cutting height distribution in the Rudna mine [6].

4.2 Thickness of burst-prone strata

Another major determinant of the seismic hazard level is the occurrence of burst-prone high-strength roof rock strata with considerable thickness above the mining horizon. As a result of mining operations, these strata tend to bend and crack. The presence of such strata and associated occurrence of rock burst events depends on the thickness of this roof strata which, in turn, determines the amount of seismic energy generated during the cracking. The thicker the damaged strata, the greater seismic energy would be released during the tremor [9]. Burst-prone strata in the Rudna mine are dolomite strata with the compression strength of about 100 MPa. The thickness of dolomite strata varies, ranging from 12.2 m in the north-west part of the ore deposit (Western Rudna) to 106.3 m in the western and central part of the ore deposit (Central Rudna); its thickness rapidly decreases from 40-60 m to less than 20, in the north-west part of the mine field [6,7]. The summary of excavated and abandoned dolomite rock strata (Fig 4) in recently mined fields in the Rudna mine (Table 2) indicates that their thickness falls in the range [6]:

- from 40 to 95 m (74.5 m on the average) in Central Rudna;
- from 9.8 to 57.6 m (23.9 m on the average) in Western Rudna;
- from 15.7 to 67 m (38.5 m on the average) in Northern Rudna.

It is considered likely that smaller thickness of dolomite rock strata in this area is influential in causing lower seismic activity in the Western Rudna and Northern Rudna sites.

4.3 Tectonic movements

The occurrence of faulting zones in the Rudna mine, which can be displaced during the mining operations thus generating high-energy shocks, in the major factor determining the seismic hazard level. Seismic data on the mine sections abutting the faulting zones of the Central Rudna (striking north-west – south east) and in Biedrzychowa (striking NNE-SSW) (Fig 6) indicate that the seismic hazard level measured by the proportion of high-energy events in the faulting zones was higher than in the remaining sections of the Rudna mine [4]. One has to bear in mind that the fault zones occur in the active mining areas of the Rudna mine (Fig 6), so the high level of seismic hazard in the area is also the consequence of intensive tectonics.

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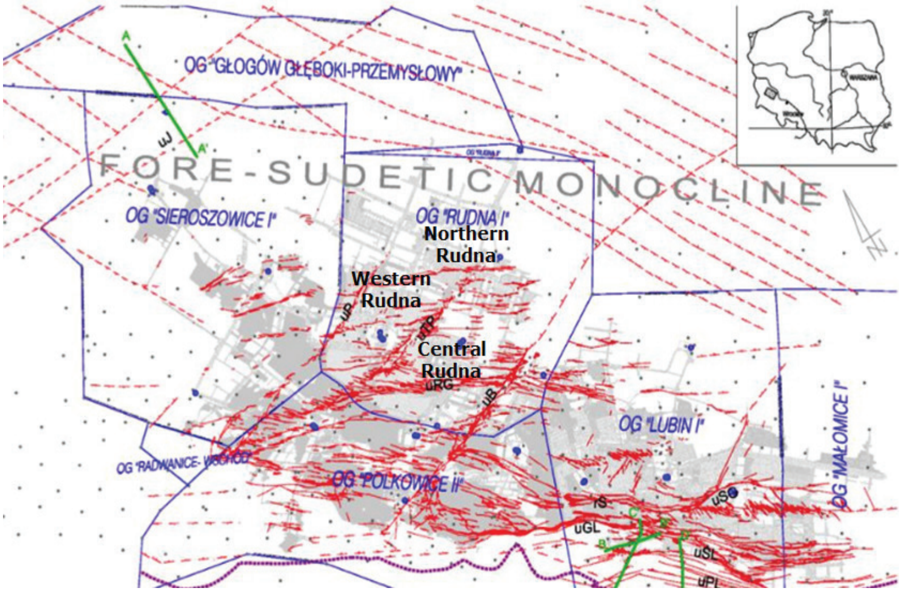

Fig. 6. Fault zones in the Rudna mine [4].

5 Conclusions

The study of seismicity in the Rudna mine over the period 2006-2015 leads us to the following conclusions: –

– The seismic hazard in the entire mine, measured by the number of registered seismic events, the total seismic energy released by the rock strata and the unit energy expense, remained on a high level, comparable in recent years.

– The level of seismicity of rock strata in active mining areas within the mine was varied. The highest seismicity was registered in the Central Rudna section, seismicity levels in Western Rudna and Northern Rudna were lower, which can be attributed to the differences in effective mining thickness and in thickness of burst–prone roof rock strata as well as varied tectonic intensity in those areas.

This study confirms the view that the principal factors influencing the seismic hazard level in the LGOM copper mines are regional geological settings. It is worthwhile to mention, therefore, that the high level of seismic and rock burst hazard in LGOM copper mines, including Rudna, is the consequence of the mining depth as well as most difficult mining conditions: intensive mining operations, mining the residues as well as support and protecting pillars and ore mining in the areas abutting old excavations.

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