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Rockburst prevention *via* destress blasting of competent roof rocks in hard coal longwall mining

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Synopsis

Although the application of destress blasting as an active rockburst mitigation measure is not yet commonplace in hard coal longwall mining, the method is assuming heightened importance due to increases in mining depth and high horizontal stresses in the rock mass. The main goals of destress blasting are the softening of competent rock layers, the reduction of strain energy storage, and rock mass stress release, which together contribute to minimizing rockburst occurrence and risk. One such region in which destress blasting in competent rock is applied is the Upper Silesian Coal Basin, mainly in its Czech part.

Here a case study of destress blasting is presented and evaluated in terms of rockburst prevention, focusing on a thick coal seam (about 5 m) subject to longwall mining under very unfavourable geomechanical conditions (great depth – 1200 m, competent rigid rocks between coal seams, unfavourable stress field due to long-term mining). Destress blasting stages were carried out in groups of between four and eight boreholes 95 mm in diameter, with the total explosive charge ranging from 2100 kg to 3750 kg, detonated regularly at distances of 43 m to 114 m ahead of the advancing longwall face. Evaluation of destress blasting based on seismic monitoring revealed that the longwall blasts were very successful in terms of rock mass stress release and decreasing the rockburst risk, with only one rockburst occurring on a roadway 210 m from the longwall face. The following longwall section was mined safely without rockburst occurrence.

Keywords

rockburst, destress blasting, longwall mining.

Introduction

In the hard coal reserve of the Upper Silesian Coal Basin (USCB), which is shared by the Czech Republic and Poland, longwall mining is the dominant underground mining method. The Czech part of the USCB, known as the Ostrava–Karvina Coalfield (OKR), lies in the northeastern part of the country (Figure 1). The exhaustion of the upper seams due to the continuation of coal mining for around 200 years has shifted activity to a greater depth (> 800 m). Under existing mining and geological conditions in the Karvina sub-basin of the USCB, underground extraction of coal is typically accompanied by rockbursts, the first of which occurred in 1912 (Pelnar, 1938). A number of attempts have been made to address rockburst activity in both the Czech (Straube *et al.*, 1972; Holecko *et al.*, 1999; Takla *et al.*, 2005; Holub, Rušajová, and Holecko, 2011) and Polish parts of the USCB (Dubinski and Konopko, 2000; Drzewiecki and Kabiesz, 2008).

There are various rock mechanics challenges associated with the underground mining of deep-seated coal seams (Singh *et al.*, 2011; Yang *et al.* 2011; Konicek *et al.*, 2013). Analysis of geotechnical data from different mines (Chase, Mark, and Heasley, 2002; Konicek, Saharan, and Mitri, 2011; Konicek *et al.*, 2013) has revealed that the nature of the overlying strata plays a significant role in the success of such mining, with rockbursts considered the major problem encountered during the underground mining of deep coal seams under strong roof strata (Figure 2). Furthermore, the presence of rigid overlying rock strata typically results in dynamic loading during their caving, which also increases the chance of rockburst occurrence.

Both active and passive approaches have been adopted in order to control the increasing frequency of rockbursts in the working horizon. In certain mines the consequences of rockbursts can be reduced using passive approaches such as improvements in mining and support systems, the restriction of miner presence in underground openings, and blocking access to selected roadways. However, for a difficult site such as coal seam no. 3, an active approach (destress blasting in competent roof rocks) is needed in order to reduce rockburst frequency. Destress blasting, which is predominantly employed under conditions of high rockburst risk in underground ore mining, has been used in the Czech part of the USCB since the 1980s to

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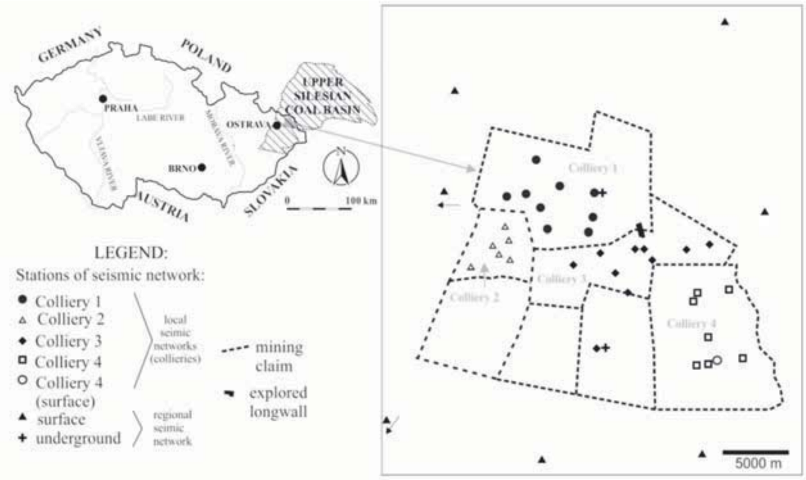

Figure 1—USCB location and map of seismic networks

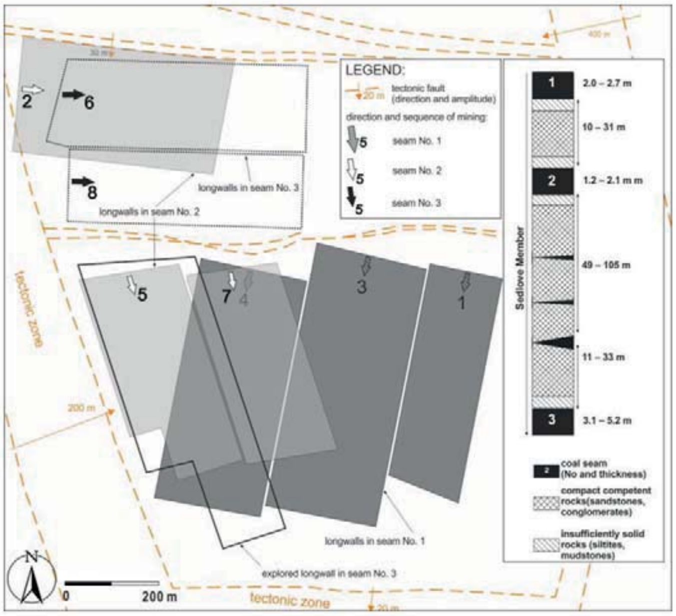

Figure 2—Sequence of mining in the described mining block and the lithological profile of the rock mass

prevent rockbursts (Dvorsky *et al*., 2003; Przeczek, Dvorsky, and Konicek, 2004; Dvorsky and Konicek, 2005; Konicek and Przczek, 2008; Konicek, Saharan, and Mitri, 2011; Konicek *et al*., 2013), with more than 2600 such blasts carried out in the region between 1990 and 2014 (Konicek, 2016).

Site details

The borders of the mining block in which the longwall is situated are formed by tectonic faults or fault zones with amplitudes ranging from 20 to 400 m (see Figure 2). Mining in this area covers three thick coal seams (nos. 1, 2, and 3) that were mined in the past at distances up to 200 m above the explored longwall panel (coal seam no. 3) in the bottom coal seam of the Sedlove Member (seam no. 3 in Figure 2) and which were subject to the evaluation of the rock mass according to official rockburst prevention guidelines (OKD, DPB, Inc. 2005). Further seams mined in higher overburden were not considered in the evaluation of rockburst risk level and thus are not described in this paper. The sequence and direction of mining are illustrated in Figure 2.

Seam no. 1 (Figure 2) was mined by three longwalls running from east to west (direction of mining north to south for every longwall) with thicknesses ranging from 2.0 to 2.7 m. The unmined part of the seam was left in the forefield of the terminated longwall no. 1 in Figure 2 as a consequence of a split in the coal seam and an increase in the thickness of the siltstone parting in the coal seam, while the northern part of the mining block was not mined due to the low thickness of the coal seam. Mined areas of coal seam no. 1 are situated around 75 to 169 m above coal seam no. 3.

Seam no. 2 (Figure 2) was mined in two isolated areas due to the local tectonic structure and the development of coal seam thickness. One longwall panel was mined in the northern area of the mining block from west to east, and two longwalls were mined in the southern part of the mining block from north to south (Figure 2). The thickness of the coal seam ranged from 2.1 to 2.6 m. Unmined pillars were left in the southern part of the mining block in the forefield of the longwall panels as a consequence of coal seam splitting and an increase in the thickness of the siltstone parting. Mined areas in coal seam no. 2 are located 60 to 138 m above coal seam no. 3.

Seam no. 3 (Figure 2) has been mined until the present day in the northern part of the mining block. Two longwall panels (nos. 6 and 8 in Figure. 2) were mined from west to east, with mining thickness ranging from 3.9 to 5.4 m. The selected longwall panel was mined from north to south in the southern part of the mining block, but was interrupted (after about 3 months) due to spontaneous combustion. After this incident the longwall face was shortened in length (106 m) up to the termination line.

Geology

The selected longwall is situated in coal seam no. 3, which is part of the Sedlove Member in the Karvina Formation of the USCB (Carboniferous age, Namur and Westphal). The ground border of the Karvina Formation in the Sedlove Member is aligned with the bottom of coal seam no. 3. Within the study area the development of the Sedlove Member is characterized by the alternation of fine- and coarse-grained sandstones with the siltstone and coal seams. The thickness of sandstone varies from 15.2 m between seams no. 1 and 2 up to a maximum of 63.6 m between seams no. 2 and 3. In between there exist siltstone layers up to 3 m thick, which also include coal strips accompanied by layers of root siltstones with thicknesses ranging from 1 to 2.4 m. The coal seams within the surrounding layers vary in thickness, with seam no. 1 ranging from 1.1 m to 2.7 m, seam no. 2 at around 2.6 m, and seam no. 3 from 3.9 to 5.4 m. The proportion of competent rocks between seams is estimated to be about 95%, based on cores drilled in the area (see Figure 2). The layers of the Sedlove Member are sub-horizontally deposited from southwest to northeast, with a total thickness of 274 m in the studied profile, which dips in the same direction at an approximately 12° angle. The studied longwall was excavated at depths ranging from 1115 m to 1160 m below surface level.

The area's tectonic structure is very complex due to the Variscian and Alpine orogenic stages that involved the initial sedimentation and subsequent alteration of the USCB (Grygar and Waclawik, 2011). The studied longwall is situated alongside a large southwest-northeast trending tectonic fault zone to the west with an amplitude of 200 m and angle of 70°, as well as a significantly smaller fault to the north with an amplitude of 4 m and angle of 75° running in a south-north direction.

Mining

The colliery responsible for the studied mine in the USCB adopted longwall mining to extract underground coal from the explored panel of the bottom coal seam of the Sedlove Member. The length of the coalface panel was 520 m and the width varied from 106 m to 190 m (Figure 2). Mining of the panel began in November 2015 and was completed in January 2017. The entire thickness of the panel coal seam, which ranged from 4.0 to 5.4 m, was extracted via a fully mechanized longwall face with caving.

The selected panel was the third longwall worked in the mining block of seam no. 3 (Figure 2). Mining of this panel took place near the tectonic zone and in an area impacted by the edges of previously extracted longwall panels in seams no. 1 and 2 (Figure 2) via overburden. As mentioned above, the goafs of the two overlying coal seams, with average heights of 84 m and 122 m, respectively, also likely influenced the development and concentration of stress during longwall mining of coal seam no. 3. Importantly, the positions and orientations of the extracted panels in both of the overlying coal seams were not superimposed in the same direction, mainly due to irregularity of coal seam thickness. Average daily longwall advance varied from 0.4 to 4.4 m according to site conditions during different longwall phases (see Figure. 4). Seismic activity response to longwall advance is described later in the section entitled 'Seismic monitoring'.

Rockburst risk

In the Czech part of the USCB, potentially hazardous mining locations are subject to an official rockburst prediction system and prevention methods in order to provide the safest possible environment for both workers and equipment. The prediction system is designed to determine if the rock mass presents a rockburst hazard, based on studies of the geomechanical properties of the coal and surrounding rocks. A system of preventive methods, both active (*e.g.* water injection into coal seams, destress blasting, *etc.*) and passive (*e.g.* mining strategy or improvement in mining and support system, restriction of access by miners, *etc.*), was prepared, aimed at reacting appropriately to hazardous conditions in the mine.

According to the rockburst classification system, the Sedlove Member is described as potentially rockburst-hazardous, and as such a three-level classification scheme (Takla *et al.*, 2005) was applied for coal seam no. 3 and the selected longwall. Based on the depth (up to 1160 m below the surface) at which coal was excavated and due to the presence of the edges of previously excavated coal seams (nos. 1 and 2), which put additional stress on roof rocks, the longwall was classified as belonging to the third level of rockburst risk, representing the most hazardous.

In order to set rules for continuous rockburst prognosis based on possible longwall conditions, individual observations and test drilling were carried out. A drilling-yield test was conducted daily on the face via boreholes 13 m in length (19 m in areas of overstressed pillars) and 42 mm in diameter. The typical spacing between these holes was kept at 28 m. Tests were also conducted at least twice a week both at the gateroads in the mining-induced stress zone and at the longwall coalface. The dimensions and spacing of the boreholes at the gateroads were similar to those along the coalface (weekly cycles at distances of 20, 50, 80, and 114 m ahead of the advancing longwall). All other activities that could potentially influence the stability of the rock mass were prohibited during the drilling-yield tests; continuous seismic monitoring was also carried out and is described in a separate section below.

As the main passive measure of rockburst prevention, a rockburst danger area was established (comprising the longwall face, longwall gates at a distance of 114 m ahead of the longwall face, and all gates ahead of the longwall face during the period of longwall termination) within which miner movement and numbers were restricted, mainly during periods of active mining at the longwall face.

As an active preventive method, destress blasting in roof rocks was considered to be the most effective, based on the area's mining history and conditions (see next paragraph). Coal wetting was also implemented as a basic active rockburst mitigation measure in the coal seam, covering the entire area of the longwall panel using infusion boreholes drilled from the gates (diameter 75 mm, length 90 to 96 m, spacing 10 m, pumped volume of water 530 l per metre of borehole).

Destress blasting

The main goal of destress blasting was to weaken the strength/massiveness of the overlying competent rock strata prior to the commencement of underground mining. After the horizon of the competent overlying strata was identified based on the previously procured core samples, different sets of predefined, long boreholes were drilled from the gateroads, targeting both these competent strata and existing mining activity in and around the panel. Design of the destress blasting programme was informed by an earlier destress blasting project (Kratky and Vlcek 2015).

Very similar problems of the softening of competent rocks are described by authors from South African mines. For instance Lightfoot *et al.* (1996) described work aimed at softening the rock on the excavation plane, as opposed to the roof rock as described in this paper, but the fundamental mechanisms are the same as in the case study from the USCB. Latilla *et al.* (2007) described softening of a problematic dolerite sill in the overburden at Matla Colliery, South Africa.

A schematic diagram (of both the section and the plan) of the adopted design of long borehole drilling carried out for destress blasting in the panel is shown in Figure 3. All of these boreholes were drilled upwards at angles of between 13° and 25° from both of the longwall gateroads (part of the starting area of longwall mining near the crosscut and in the area of the longwall termination) and from the main gate (the central part of the longwall panel). Perpendicular boreholes from the gates were suitably complemented by oblique boreholes drilled into the area of the tectonic zone west towards the longwall and in the area of perpendicular borehole stemming. Borehole length varied from 47 m to 90 m. In view of the calculated amount of explosive required for destress blasting, the diameter of these boreholes was set at 95 mm and the spacing at 10 m. Due to the suitable length and angle combinations of these boreholes, the bottoms (ends) of all boreholes were situated in a similar horizon inside the roof, nearly 28 m above coal seam no. 3.

All of the upward-drilled boreholes were charged pneumatically using the plastic gelatine explosive Perunit E (heat of explosion 4100 kJ.kg^{-1}), with sand employed for the stemming. The length and amount of explosive in each borehole varied according to the surrounding geo-mining conditions, with the length of charge ranging from 27 m to 65 m, length of sand stemming from 15 m to 25 m, and the percentage loaded length from 55% to 72%. Individual groups of loaded boreholes, typically ranging from four to eight in number, were fired in advance according to the predefined firing order. All of the charged boreholes in each group were fired simultaneously, without any delay, with the weight of explosive charge in the different holes varying according to the borehole diameter and length, from 225 kg to 550 kg. The total amount of explosive (for the four to eight boreholes in each group) blasted at any one time in the panel varied from 2100 kg to 3750 kg (Table I).

According to the site conditions, boreholes no. 92–101 and 1–11 (Figure 3) were employed to create a network of fissures in the competent strata overlying the commencement area of the longwall panel. Boreholes no. 1–47, 59–70, 74–87, 104–116, and 120–130 were used to dilute the influence of the edges between the mined and unmined parts of the seams in the overburden, as well as to dilute the influence of the nearby tectonic zone to the west towards the longwall. Boreholes no. 59–70, 102, 103, and 117–119 covered the area of the stemmings of the perpendicular boreholes. The competent strata over the remaining pillars situated between the main gate and the tectonic zone were managed via boreholes no. 74–87. Blasting in boreholes no. 40–47, 104–116, and 120–130 was carried out to decrease additional stress ahead of the advancing longwall face in the area of the longwall panel termination. The competent overlying rock strata, which were continuously fractured due to these blasts, were also observed to be caving-friendly. The decision to blast different individual groups of boreholes at different stages was made according to not only the surrounding

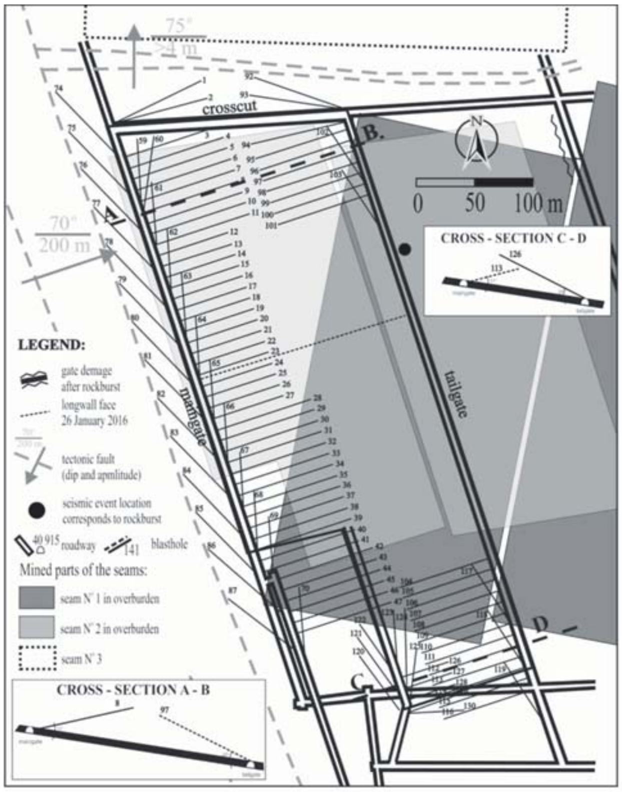

Figure 3—Design of destress blasting in overlying rocks

Table I

Parameters of destress blasting

Stage no.	Borehole nos.	Date and time	Explosive charge (kg)	Registered seismic energy (J)	Seismic effect	Percentage shear/total volume change (maximal) in the focal area (%)
1	1–5, 74, 75	3.11.2015, 16:37	2775	6.30E+04	12.2	43.9
2	6–8, 59, 60, 76	6.11.2015, 15:19	2725	9.70E+04	19.1	29.3
3	92–98, 102	8.11.2015, 15:42	3750	8.70E+04	12.5	79.3
4	99–101, 103	17.11.2015, 14:01	3725	2.04E+05	29.4	35.2
5	11–15, 62, 78	22.11.2015, 14:43	2700	8.10E+04	16.1	28.6
6	16–19, 63, 79	6.12.2015, 16:11	2100	5.20E+04	13.3	32.1
7	20–22, 64, 80,81	20.12.2015, 14:53	2150	8.00E+04	20.0	34.6
8	23–26, 65, 82	3.1.2016, 15:07	2275	9.60E+04	22.7	18.8
9	27–30, 66, 83	17.1.2016, 15:22	2850	9.70E+04	18.3	31.9
10	31–34,67, 84	31.1.2016, 15:24	2975	2.20E+05	39.8	41.4
11	35–38, 68, 85	7.2.2016, 16:19	2925	2.00E+05	36.8	42.1
12	39–42, 69, 86	28.2.2016, 15:12	2675	1.50E+05	30.1	41.2
13	43–47, 70, 87	24.4.2016, 15:23	2900	9.70E+04	18.0	35.1
14	104–109, 117	8.5.2016, 14:21	3225	1.70E+05	28.3	43.3
15	110–111, 118, 121-124	2.10.2016, 18:02	2750	4.70E+04	9.2	33.6
16	112–114, 120, 125-126	16.10.2016, 15:21	2200	6.40E+04	15.6	30.8
17	115–116, 119, 127-130	22.11.2016, 15:49	2275	2.30E+04	5.4	33.3

workings and strata, but also the development of seismic activity during mining and the advance of the longwall face. Based on expert knowledge of the area and valid legislation (OKD, DPB, Inc. 2005), the distance the boreholes were fired ahead of the longwall face was in the range of 43 to 114 m. The amount of charge fired was dependent on the boreholes selected for firing, which itself was based on mining conditions, natural conditions, and the development of registered seismic activity as per the above legislation.

The effectiveness of destress blasting is connected to, among other factors, stress release in the rock mass. This stress release was here evaluated using the seismic effect (SE) index, a methodology first established in the Czech part of the USCB and subsequently verified by Konicek *et al.* (2013) and Konicek (2016). The seismic effect (SE) is defined as the ratio of seismic energy released in the rock mass when blasting, to the energy of the particular detonated charge (Konicek *et al.*, 2013). It can be calculated according to the following formula:

$$SE = \frac{E_{ICM}}{K_{ICM} Q} \qquad [1]$$

where:

E_{ICM} is the seismic energy calculated by the seismic network in the investigated coal mine (J)

Q is the mass of the explosive charge (kg)

K_{ICM} is the coefficient characterizing the conditions in the assigned mine (J.kg^{-1}).

The employed method of coefficient determination is described in detail in Konicek *et al.* (2013). According to the latest verification of this coefficient by Konicek (2016), the results of which were implemented in the OKR rockburst prevention rules, K_{ICM} = 1.86 for the seismic effect calculation presented in Table I. The classification index developed to evaluate SE values (based on Konicek *et al.* (2013) and verified by Konicek (2016)) using the criteria obtained from the distribution of SE probabilities and according to Equation [1], is presented in Table II.

Examination of Table I reveals that all the calculated seismic effect values were high; most can be classified as excellent in terms of stress release (only one was evaluated as very good and four as extremely good). This means that the stress release strategy carried out in coal seam no. 3 was successful in all stages of destress blasting, especially stages 2, 4, 5, 7-14, and 16.

Seismic monitoring

As one of the methods developed to ensure miner safety, seismic monitoring was employed to analyse the geomechanical activity of the rock mass. Such nondestructive methods are very popular because of the large amount of information that can be gathered regarding seismic activity taking place during mining, such as the number and energy levels of tremors in the area.

For the studied longwall, three systems were employed in order to gather the maximum amount of relevant information. Firstly, data from the regional seismic monitoring network (SP) was used (see Figure 1). This network consists of ten triaxial short-period WDS seismometers (f = 0–2.0 Hz), six of which are located in boreholes (depth 30 m), three installed underground in active mines, and one situated in a short gallery at the Ostrava-Krasne Pole seismic station. The frequency range of the network is f = 2–32 Hz and the dynamics of the recorded

Table II

Seismic effect evaluation

Seismic effect	Evaluation of seismic effect (success of stress release)
$SE < 2.5$	Insignificant
$2.5 \leq SE < 4.1$	Good
$4.1 \leq SE < 7.0$	Very good
$7.0 \leq SE < 13.6$	Extremely good
$SE \geq 13.6$	Excellent

seismic signals around 120 dB, with sampling frequency 125 Hz. Secondly, data from the local seismological network (see Figure 1) of active mines was used. The stations comprising this network are situated in the local mine and are equipped with monoaxial, low-frequency and low-periodical vertical SM-3 seismometers. The basic parameters of these seismometers are as follows: input sensitivity 16–5 mV, amplification maximum 74 dB, frequency range 1.5–20 Hz, and sampling frequency 100 Hz. Finally, a seismo-acoustic monitoring system was used (not discussed in the present paper). According to local legislation, such a system must be employed in longwalls (such as that analysed here) that are classified as subject to the third level of possible rockburst occurrence.

In order to evaluate the collected seismological activity data, graphs of daily registered seismic energy sum and the weekly slope of registered seismic energy were constructed (Figure 4). From these graphs, four phases (A, B, C, and D in Figure 4) can be identified that are characterized by the most significant weekly energy variations.

The first stage (A) is distinguished by a rapid increase in seismic activity, in this case clearly connected with the initialization phase of the longwall run based on the similar shape of the two curves (daily and weekly seismic activity). During this initial stage of excavation the longwall in question was situated in a location where additional stress was generated from earlier longwalls in seams no. 1 and 2.

During phase B, when the longwall advanced into a partly protected area made by the previously excavated longwalls in the upper coal seams, seismic activity began to decrease. Also during this phase, weekly variations in seismic activity mirrored the longwall's daily advance, although with a lower order of energy.

In the third phase (C), seismic activity was generally at a minimum because of the break in mining progress caused by the spontaneous combustion of coal. Even during the second half of phase C, activity remained low due to the presence of an existing protected area from seams no. 1 and 2.

In the final phase (D), seismic activity increased significantly. This is likely connected to the fact that the longwall reached a position similar to that of phase A, with no protected area and subjected to additional stresses derived from the mining edges of earlier excavated longwalls and other mining works (roadways *etc.*) ahead of the longwall. After the re-initiation of longwall mining, seismic activity rose, decreasing only some time after the termination of mining works.

Figures 4 and 5 illustrate the clustering of seismic event locations over the study period. During phase A, a number of both high- and low-energy events were localized north of and adjacent to the longwall; this seismic activity was likely caused by existing additional stress from the mining edges of seams no. 1 and 2. During phase B, the distribution of seismic events was uniform across the entire excavated area, while the total number of events decreased. However, most high-energy events were localized in the eastern part of the longwall during its advance, probably due to additional stress from the mining edges and the absence of a protected zone, unlike on the western side. During phase C, the decrease in the number of events was significantly greater and event distribution was correlated mostly with the longwall's position, with events also recorded in the goaf, related to the stabilization of the rock mass. A few high-energy events occurring during this phase were localized to the south due to the resumption of mining in this area. In the final phase D, the localization of events closely corresponded with the advance of the longwall to the south, during which time the longwall moved out of the protected zone and was subject to additional stress from mining edges. Event distribution was homogenous, with most events taking place around the position of the longwall, in addition to random occurrences in the goaf.

An analysis was also carried out regarding the focal areas of each round of destress blasting and every high-energy seismic event (with energy greater than 10^4 J). In this evaluation, the directions of shear plane poles were studied by construction of polar diagrams, with volume changes in the focal areas also calculated (Figure 6), indicating the main directions of the shear planes and the total sum of radiated energy and energy used by the shear mechanism, respectively. The proportion of shear/total volume change (maximal) in focal areas (see Table I) was determined in

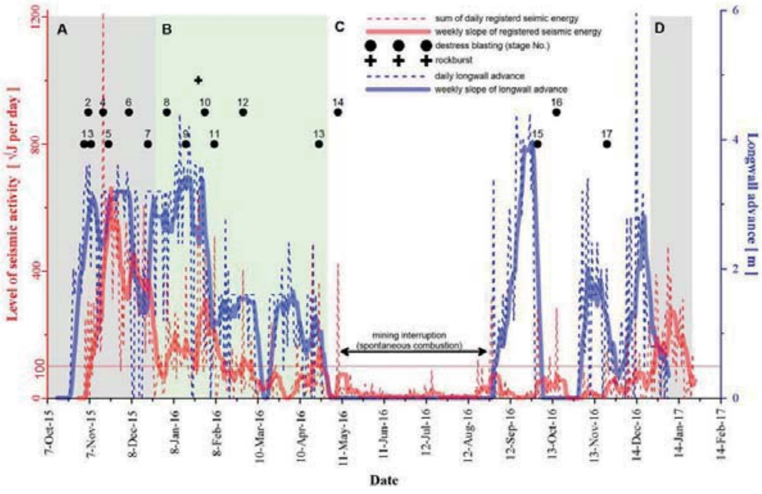

Figure 4—Registered seismic activity and longwall advance

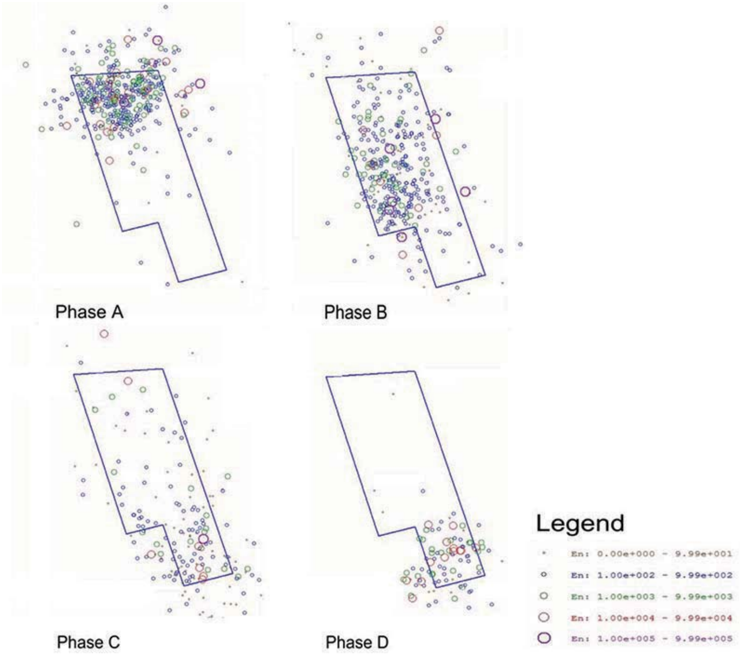

Figure 5—Location map of seismic events registered during different longwall phases (see Figure 4)

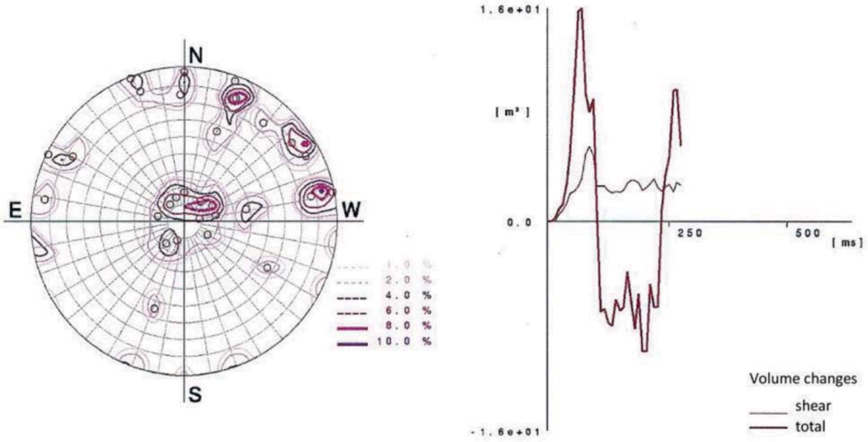

Figure 6—Example evaluation of the focal area of the registered seismic event corresponding to destress blasting stage no. 4. Right—volume changes, left—contour diagram of poles of shear planes; equal angle projection, lower hemisphere, N = 113

order to confirm stress release, with high levels of shear volume changes corresponding to shear failure considered as important stress release evidence by a number of authors (*e.g*. Stec and Drzewiecki, 2012; Wojtecki *et al*., 2016). A comparison of SE values and the proportion of shear/total volume changes in the focal areas (Table I) of seismic events corresponding to destress blasting reveals that in many cases both parameters are indicative of stress release in the rock mass. Based on an evaluation of specific seismic events with radiated energy greater than 10^4 J registered during the excavation period, it can be stated that most of these events had a positive impact on stress conditions in the rock mass, promoting the release of accumulated stress according to the energy required for shear failure. Examination of Figure 6 reveals the reverse pattern of the phases, with the explosion represented in the first part of diagram, followed by implosion and a final increase. The total amount of radiated energy in these cases was higher than the energy required for shear failure, which leads to the conclusion that the blasts were effective in achieving stress release.

Despite all the above efforts, in January 2016 a strong-motion seismic event (registered energy 3.13 E+05 J, magnitude 1.66) classified as a rockburst occurred close to the longwall face but mainly manifested (roadway deformation, one fatality, and several minor injuries) approximately 210 m east of the longwall (see Figure 3) in an area of additional stress due to edges of previous mining in overburden – see Figure 2. The event was located 104 m above the mined coal seam (in approximately the stratigraphic position of seam no. 2 in the overburden – see

Figure 3). Rock mass damage was recorded relatively far from the epicentre of the event but not in the vicinity of the longwall. This could be due to softening of competent rocks in the overburden due to destress blasting, as well as a decrease in the stress level in the protected as a result of previous mining of seam no. 2 in the overburden of the longwall. On the other hand, we also have to take into consideration the accuracy of the seismic event location (around 100 m).

Conclusions

Systematic planning and design of a destress blasting programme carried out in roof rocks enabled safe longwall mining in a rockburst-prone area. The amount of explosive used at different stages during the destress blasting process varied from 2100 kg up to a maximum of 3750 kg. The proposed classification of destress blasting based on the value of the seismic effect was also validated through seismic observations. Out of the total of 17 stages comprising the destress blasting of the longwall panel, one stage was categorized as achieving very good stress release (SE 5.4), four stages as extremely good (SE varied from 9.2 to 13.3), and the remaining 12 as excellent (SE varied from 15.6 to 39.8). The success of stress release based on SE evaluation is also supported in most cases by the evaluation of shear percentage/total volume changes in the focal area of seismic events corresponding to destress blasting. Despite the adverse conditions only a single rockburst event occurred. Many more rockbursts would have been expected if the competent rock has not been softened by destress blasting stages. The success of the energy release strategy is demonstrated by the SE values and the fact that only one burst was recorded. Although mining was undertaken in very unfavourable geomechanical conditions, the longwall panel was mined safely even after initial rockburst problems, with no further issues encountered.

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