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DYNAMIC EVENTS AT LONGWALL FACE, CSM MINE, CZECH REPUBLIC

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ABSTRACT: Presented here are the details of the seismic events that occurred at longwall 11 located at the CSM mine in the Ostrava coal region, Czech Republic. This longwall was excavated in a very complex area located within the shaft protective pillar and adjacent to the 50 m wide and steeply inclined fault zone at a depth of 850 m. In addition, 10 longwalls were extracted below each other over many years in several sloping seams located on the other side of the large sloping fault zone resulting in complex stress fields and large subsidence. The immediate roof above longwall 11 was a very strong sandstone and sandy siltstone with a uniaxial compression strength of 80 – 160 MPa. When the longwall started, continuous seismic monitoring of the longwall area indicated 470 small seismic events with energy smaller than <10^2 J. The first high energy event of 3.3*10^5 J occurred when the longwall advanced 85m past the starting line. Some 30 minutes later a rockburst occurred registering energy of 2.2 *10^6 J, causing significant rockburst damage at the tailgate located near the large tectonic zone. The roadway steel arches were significantly deformed and the maximum floor heave reached up to 1.5 m. To investigate the complex strata behavior in that area, a large FLAC3D model 0.27 km^3 in volume was constructed and 10 longwalls were extracted in several sloping seams adjacent to the large fault zone. The model under construction is now ready to study the complex strata behaviour and the associated stress fields together with the dynamic strata behaviour to match the modelled seismic events with those measured underground.

INTRODUCTION

The success of mining operations is heavily dependent upon controlling the fractured ground especially in coal mine areas where complex sedimentary strata exist. In nature, the mechanisms of rock failure can be typically a dynamic phenomenon that up to now has not been fully understood. The numerical models of rapidly developing failures can be predicted numerically including the rock or coal bursts. They are more appropriate in depicting the reality as the exact mechanisms of strata failure in stressed rock cannot be fully observed. These predictions can be highly beneficial during the mine planning stages where identification of possible dynamic occurrences could minimise potential hazards.

A collaborative research project between the Institute of Geonics, the Academy of Science of Czech Republic and the University of Wollongong was set up to research strata failure zones around excavations. The aim of this project was to numerically simulate various types of strata behaviour and rock failure in both hard rock and coal mines. Previous research of the coal bursts done at the University of Wollongong indicated suitability of both the FLAC2D and

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FLAC3D software to simulate various types of strata failure including the dynamic events in underground environments.

GEOLOGICAL AND MINING CONDITIONS

The assessed area in this case study is quite complex from a geomechanical point of view. There are several faults of regional importance which divide the rock mass amongst separate mining blocks (see Fig. 1). There is the wide tectonic zone of the Albrechtice Fault with a total throw of up to 420 m located in the western area. The dip of this fault ranges from 60° to 70° towards the west. In the central area Fault "A" is present with a throw of up to 100 m and a dip of 60° towards the north. Fault "X" in the northern part of the area has a throw of up to 350 m with a dip of 60° towards the south. The significant regional tectonic fault zone "Eastern Thrust" (Grygar & Waclawik, 2011; Waclawik, Ptacek & Grygar, 2013) is located in the southern part of the studied area. The Eastern Thrust has a very small dip ranging from 10° to 35° with strike in the northeast-southwest direction and dip towards the northwest. Vertical displacement fluctuates around 5 m, but the range of horizontal displacements is usually much greater and can vary from tens to hundreds of metres.

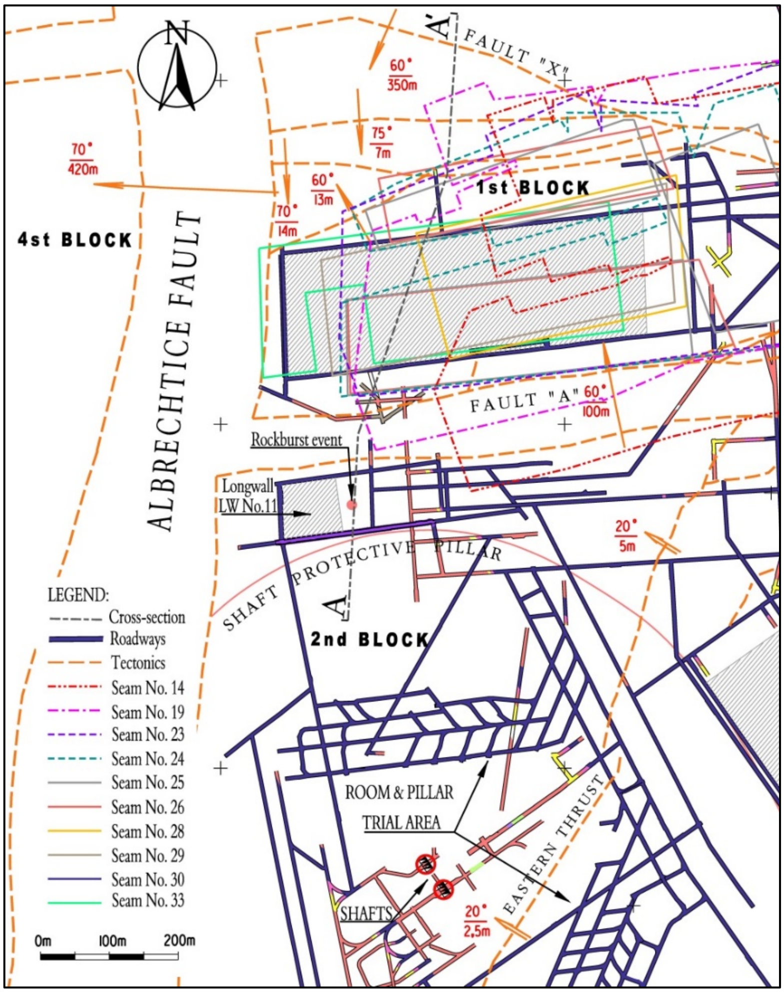


Figure 1: Tectonic situation and location of longwall panel No. 11

Concerned longwall panel No. 11 is located near the shaft protective pillar in the footwall of the wide tectonic zone Fault "A". This latest panel was mined in the coal seam No. 30+31 at a depth of approximately 830 – 880 m below the surface. Above the coal seam there is a 400 m thick complex carboniferous rock mass with an overlying tertiary sedimentary rock strata which is 450 m thick with approximately 20 m thick quaternary soil overburden. The strata dip oriented in the northeast direction ranges from 8° to 17°. The roof rocks are represented by the rhythmical alternations of sandstone, siltstone and mudstone layers typically for lithological development of Sucha member (Dopita et al., 1997). The immediate roof of targeted seam No. 30 is formed by a very strong sandstone and sandy siltstone with a uniaxial compression strength of 80 – 160 MPa (average 115 MPa).

The longwall panel No. 11 was extracted by a fully mechanised longwall face (drum shearer SL 300, mechanical support FAZOS 15/33). The thickness of the coal seam ranged from 4 m to 5 m within the area of the longwall panel. The longwall panel was very small with a length of 100 m and a 75 m wide face. Geo-mining details of the longwall are summarized in Table 1.

Table 1: Geomining details of the longwall panel No. 11

Parameters	Description
Location of panel	2nd mining block
Seam thickness	4.2 – 5.0 m
Depth of cover	830 – 880 m
Average dip of seam	12°
Panel size	7600 m^2
Working height	3.3 m
Average daily advance	5 m per day
Mining technology	Fully mechanised longwall with caving
Immediate roof	Sandstone, Sandy Siltstone,
Immediate floor	Coal, Siltstone

Ten coal seams (No.14 to No.33) were progressively extracted north of the longwall 11 panel in the 1st mining block. These coal seams were gradually mined from 1977 (seam No.14) to 2011 (seam No.33). The longwall panel No.11 was extracted over three months in 2018. The mutual positions of the extracted longwall panels are shown in Figures 1 and 2.

According to the effective local methodology (OKD, 2006), the rockburst risk in the area of the 2nd mining block (area of longwall panel No.11) was classified as "without risk". Nevertheless, continuous seismic monitoring was used to analyse the geomechanical activity of the rock mass during mining. Currently, there are two seismic networks that monitor seismicity caused by mining activities and evaluate these events for the purposes of rockburst prevention. This monitoring provides detailed information obtained at individual mining operations from the local network of seismic stations in mines, and information from a wider area within the currently mined Karviná portion of the Czech section of the Upper Silesian coal basin via the regional seismic network. The current local mine network has 30 mining stations and the regional seismic network has 10 surface and mine stations. This combined seismic network system provides very reliable data for registration and evaluation of seismological activity during longwall advance.

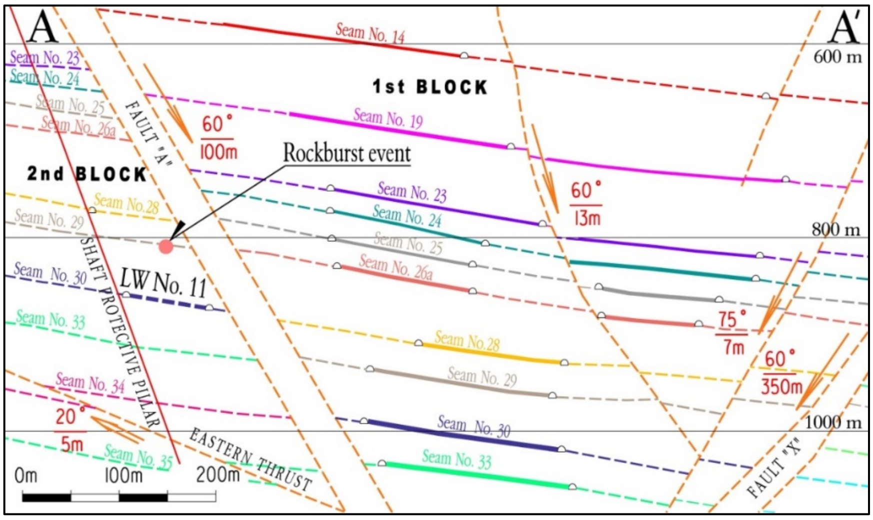


Figure 2: Strata cross-section across the studied area

SEISMIC ACTIVITY DURING MINING

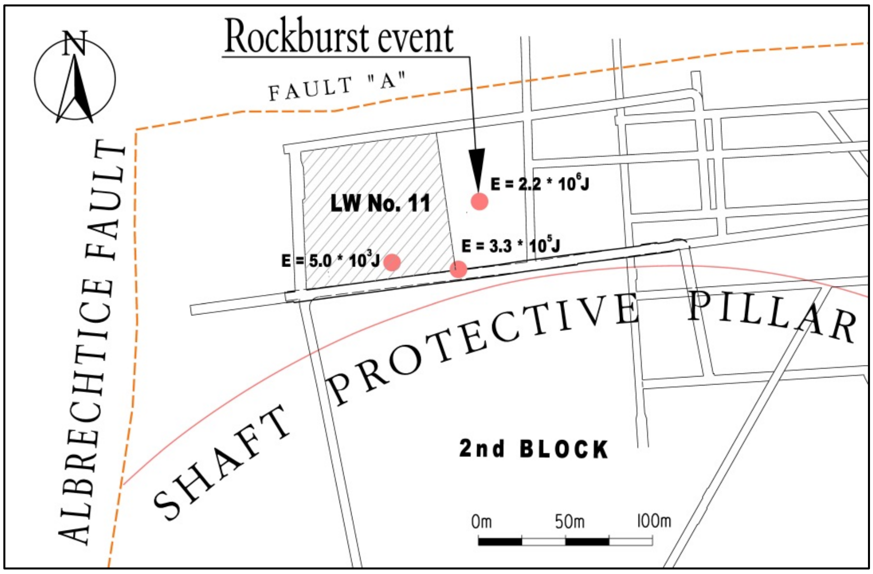


Figure 3: Locality of significant seismic events - longwall 11 area

During the first month of longwall No.11 mining (20.3. 2018 – 13.4. 2018) predominantly low-energy seismic events with energy smaller than <10^2 J were registered nearby. The daily advance of the longwall panel was approximately 5 m per day. During that time a total number of 470 small seismic events were recorded. Only 130 seismic events with energy higher than 10^1J (10^1 to 10^2 J) were registered. However, during this time, the weekly energy sum variation increased every day (see the graph in Fig. 4). The graph of weekly energy sum variation helps to identify the anomalies. The seismic events ($5*10^3$ J and $3.3*10^5$ J), the second with considerable energy, were registered on 13.4. 2018 (see Figure 3). Finally, the rockburst occurred only 30 minutes after previous stronger seismic events was registered. At this stage, the longwall face was 85 m from the installation gate. This seismic event registered energy of $2.2 *10^6$ J. Significant rockburst damage was recorded at the tailgate located near the tectonic zone Fault "A" where roadway steel arches were significantly deformed with maximum floor heave reaching up to 1.5 m (see Fig. 5), while no slippage was recorded. In the maingate, the maximum floor heave was 1.0 m with minimum deformation of steel arches and slippage of around 0.15 m. Floor heave of around 0.5 m was also recorded at the longwall coal face. After repairs mining continued for almost a month after the rockburst but with implemented active and passive rockburst preventative measures. The daily advance of the longwall face was regulated to a maximum of 2 m per day. During this phase of mining only low-energy seismic events with energies smaller than $<10^2$ J were measured in the surrounding area.

The focal mechanism of registered rockburst has the characteristic combination of an initial multiple phase primary failure and a low significant shear failure followed by a significant expansion phase accompanied by a shear failure. Vertically inclined shear planes may correspond to the directions of significant tectonic zones in the area (Fault "A" and Albrechtice Fault).

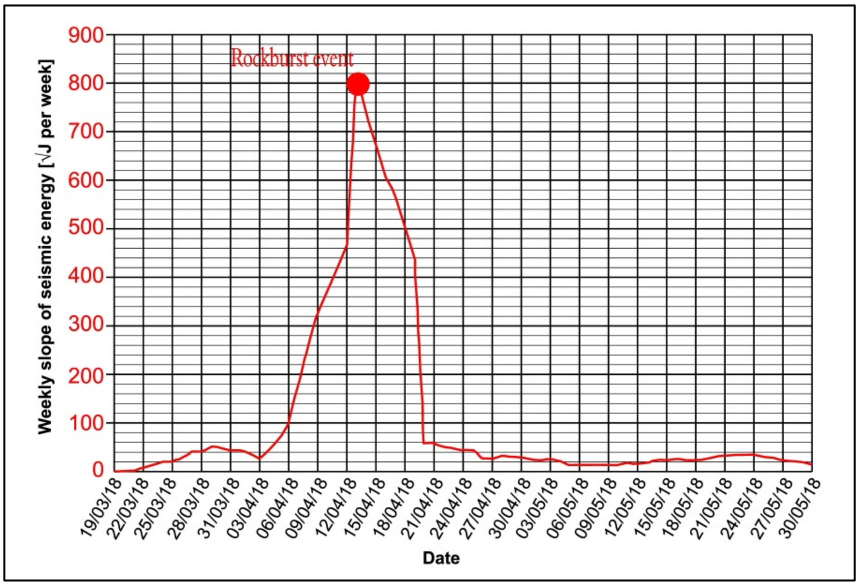


Figure 4: Summary of weekly energy sum variations in area of longwall panel No.11

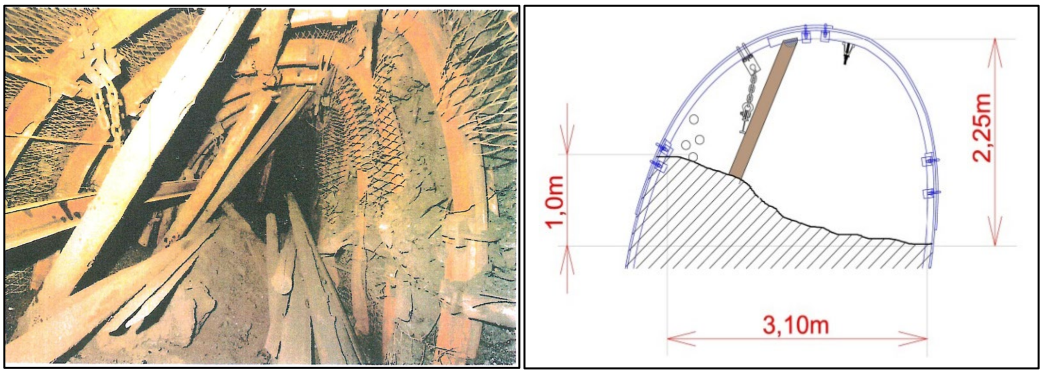


Figure 5: Impact of rockburst at the tailgate

NUMERICAL MODEL

Part of this project is to study the complex strata behaviour and changing stress fields in the multi-seam operation in a CSM coal mine. A large FLAC3D model (Itasca, 2012) 0.27 km^3 in volume was constructed encompassing several sloping coal seams to model numerous longwall excavations. A steeply inclined 50 m thick fault "A" zone intercepted all seams. The model was constructed to investigate the probable stress fields and strata movements due to past mining. This is needed for future dynamic modelling to see whether the seismic events that occurred at longwall 11 can be numerically simulated. Due to the complexity of the inclined multi-seam extraction geometry adjacent to the steeply dipping fault zone, the model had to be very large to reveal the complex stress fields and large subsidence that occurred due to 10 previously excavated goafs. Considerable time and effort was spent to construct the working model shown in Fig 6. This was mainly due to writing lengthy subroutines using the FISH software to automate the input of the geometry, in-situ stress, progressive mining of the inclined seams involving excavations of the individual zones in the steeply dipping seams as the mining progressed shear by shear while monitoring the roof to floor contacts to control the goafs, among other things. Most of the progressive excavations and cavity contacts were done using the internal FISH software commands to speed up the execution time of the models.

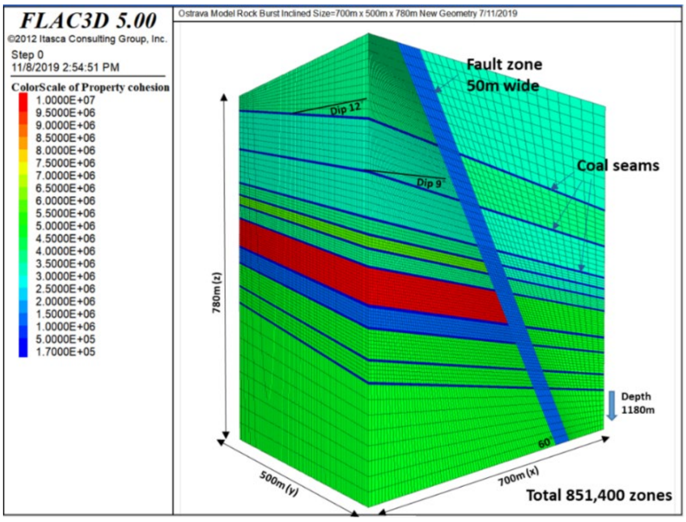
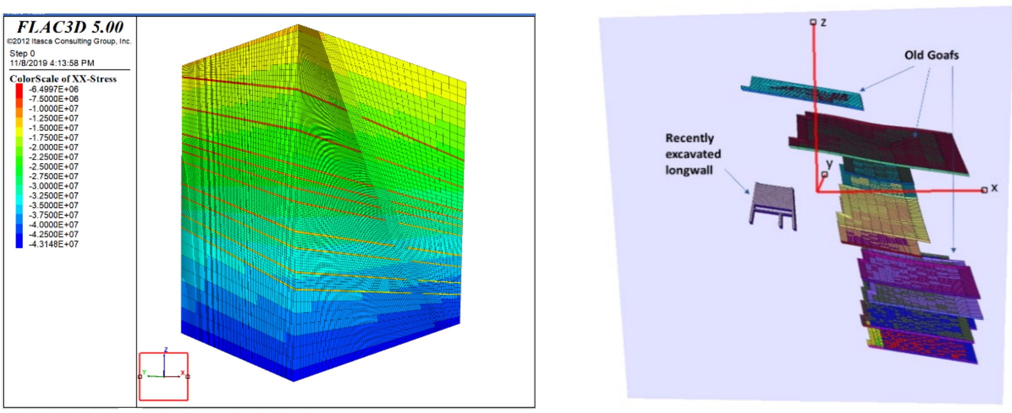


Figure 6: Geometry of the inclined multi-seam mining at CSM Mine, Czech Republic

The initial in-situ pre-mining stress was calculated and inserted into each zone using FISH software subroutines noting that the magnitude of lateral stress was calculated according to the Young's modulus. This is apparent in Figure 7 (a) where a lower Young's modulus in coal attracts lower lateral stress. Ten old multi-seam goafs were progressively extracted, zone by zone, starting from the upper goaf while time-stepping. All goafs were gradually excavated as was the case underground. The direction of all old longwalls advance was down with a dip of 12˚.



(a) **(b)**

Figure 7: (a) Lateral stress in x-direction before mining, (b) 10 sequentially excavated old longwall goafs inside the model including the recent longwall

The modelled rock and coal seam properties were derived from the laboratory rock core tests and are presented in Table 2. The thickness and rock mass characteristics are given in Tables 2 and 3.

Table 2: Rock properties used in the model

Strata	E	v	K	G	d	c	t	Φ
Siltstone	23	0.14	10.67	6.67	2500	3.74	2.9	38
Sandstone	35	0.15	10.67	6.67	2500	4.52	3.5	38
Mudstone	18	0.18	10.67	6.67	2500	3.0	1.0	35
Fault Zone	18	0.18	10.67	6.67	2500	3.0	1.0	35
Coal	2.6	0.25	1.60	0.53	1400	0.17	0.1	33

E= Young modulus in GPa, v= Poisson ratio, K= Bulk modulus in GPa, G=Shear modulus in GPa, d=density of rock mass in kg/m^3, c=cohesion in MPa, t=tension in MPa, Φ= Angle of internal friction in degree.

Table 3: Layers characteristic in the model

LEFT SIDE OF MODEL				RIGHT SIDE OF MODEL			
Layer Nr.	Seam Nr. Nr.	Rock type	Thickness of excavation [cm]	Layer Nr.	Seam Nr.	Rock type	Thickness of excavation [cm]
L1LF	-	sandstone		L1R	-	sandstone	
L2LF	35	coal	0	L2R	33a	coal	300
L3LF	-	sandstone		L3R	-	sandstone	
L4LF	34	coal	0	L4R	30+31	coal	370
L5LF	-	sandstone		L5R	-	sandstone	
L6LF	33	coal	0	L6R	29	coal	520
L7LF	-	sandstone		L7R	-	siltstone	
L8LF	31	coal	120*	L8R	28b	coal	
L9LF	30	coal	210	L9R	28	coal	180
L10LF	-	sandstone		L10R	-	sandstone	
L11LF	29	coal	0	L11R	26	coal	180
L12LF	-	siltstone		L12R	-	siltstone	
L13LF	28	coal	0	L13R	25	coal	220
L14LF	-	sandstone		L14R	-	mudstone	
L15LF	26	coal	0	L15R	24	coal	310
L16LF	-	siltstone		L16R	-	mudstone	
L17LF	25	coal	0	L17R	23	coal	140
L18LF	-	mudstone		L18R	-	mudstone	
L19LF	24	coal	0	L19R	19	coal	260
L20LF	-	mudstone		L20R	-	siltstone	
L21LF	19	coal	0	L21R	14	coal	290
L22LF	-	siltstone		L22R	-	mudstone	

* mined together – total thickness 3.3 m

The applied stresses were extrapolated from the overcore stress measurements (Waclawik et al. 2016a) and (Kumar et al. 2019) undertaken in the modified room and pillar trial (see Fig. 1) and are shown in Table 4.

Table 4: The overcore stress measurement values

Stress	MPa	Bearing [°]	Dip [°]
σ_1	19.2	9^0	-67^0
σ_2	3.9	205^0	-23^0
σ_3	0.3	113^0	-6^0

At this stage no results from the numerical model are reported here due to various uncertainties that exist in the complex strata environment in the CSM mine. It is expected that the large fault “A” zone behaviour together with the 10 previously excavated goaf areas will have a profound influence on stress changes, overall strata movement and rock/seam behaviour adjacent to longwall 11. The unknown fault zone properties would probably produce a gradual fault slippage occurrence over the years of mining. An accelerated fault slip may have been experienced due to longwall 11 extraction. Such slip can produce a significant moving shear stress zone where the longwall 11 was situated. This was already indicated in the preliminary numerical model investigations. Numerical trials have already begun using varying fault zone properties to study fault slip movements and their effects on surrounding strata.

SUMMARY AND CONCLUSIONS

The studied area located at a considerable depth within the CSM mine is quite complex with several major faults of regional importance which divide the rock mass amongst separate mining blocks. These fault zones can significantly influence mining geometry and strata control and must be taken into consideration for mine planning purposes. The seismic events commonly occur in this mine and require careful planning of mining activities. The strata properties, mining geometry, fault zone details, stress state, previous rockbursts, interpretation of seismic monitoring and historical experience need to be known to implement safe mining.

The seismic monitoring used in the mine is very comprehensive and ideal to assist with rockburst predictions. This study has clearly demonstrated that the seismic energy events that occurred during the longwall 11 extraction showed a strong relationship between the seismic frequency, seismic energy levels and the rockburst.

The available numerical model is probably the only tool that can predict the 3-dimensional stress state in the area where the complex geological environment exists. This is a significant step forward in understanding strata behaviour in a complex stress environment. The dynamic option of the model can be very useful to simulate the past rock burst occurrences leading to future predictions of such events.

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