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## Study on characteristic of overburden movement in unsymmetrical isolated longwall mining using microseismic technique

CAO An-ye<sup>a</sup>, DOU Lin-ming<sup>a\*</sup>, LI Fu-chen<sup>b</sup>, JIANG Heng<sup>a</sup>, QU Yun<sup>b</sup>, HAN Rong-jun<sup>a</sup><sup>a</sup>*School of Mines, State Key Laboratory of Coal Resources and Mine Safety, China University of Mining & Technology, Xuzhou, Jiangsu 221116;*<sup>b</sup>*Baodian Coal Mine, Yanzhou Coal Mining, Zoucheng, Shandong 273513)*

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### Abstract

Based on the key stratum theory, overlying strata structures above a typical unsymmetrical isolated working face (LW10302) was analyzed, and a microseismic monitoring was also applied to characterize the fracturing propagations associated with overburden movement in mining progress. The results show that the overlying strata above LW10302 can be divided into key strata of different grades, and the formed “O-X” fracturing structure have the main and inferior “O-X” ones. The spatial evolution of seismic events demonstrated that seismic activities fits very well with the overburden fracturing patterns and stress manifestation around the longwall face. In the mining process, most of the events located within the surrounding strata of LW10301 and 10302 while low energy events distributed mainly in multiple roof and floor strata, and the strong tremors occurred almost within the super-thick primary key strata and appeared to be related to shear fracturing of large-scale overburden movement. Additionally, seismic signals corresponding to different failure mechanisms show different characteristics in waveform features. The study in this paper indicates that microseismic monitoring can provide invaluable information to characterize the mining-induced seismicity and reveal the failure patterns within strata associated with mining, which will greatly benefit the alleviation and prevention of rock burst hazards in mines.

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*Keywords:* unsymmetrical isolated face; overburden structure; strong tremor; microseismic monitoring; rock burst; spatial evolution

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\* Corresponding author. Tel.: 0516-83995904; fax: 0516-83995904.

E-mail address: [dlmcumt@163.com](mailto:dlmcumt@163.com).

## 1. Introduction

The safety and productivity of underground mining can be severely impacted by seismic activity. Mining-induced seismic events, which are induced by the sudden release of elastic strain energy in coal/rock mass, are related to not only large geological discontinuity, affected by the extent and means of mining, but also associated with strata structure movement triggered by new stress concentration with mining operations<sup>[1]</sup>. Rock bursts are particular cases of seismic events induced by mining activity that results in damage to underground workings and in some cases, injury and loss of life<sup>[2-4]</sup>. In China, rock bursts have been encountered in many coal mining groups with hard strata structure, such as Xinwen, Yanzhou, Yima, Datong, et al. From the analysis of strata in previous rock bursts, it appears that a considerable number of rock bursts and strong tremors are associated with the movement of hard roof and floor structures, especially under conditions of hard-thick sandstone roof strata.

Plenty of researches and practices have shown that the pressure behavior are not only induced by rupture of main roof, but also affected by other high-layer inferior or primary key strata, which even have significant effort on rock bursts<sup>[5-10]</sup>. Actually, duo to the restriction of monitoring technique, the investigation of failure modes and microseismic characteristics of high-layer thick key strata is still a challenge now, and limited researches have focused on the relationship between destruction and instability of key strata and intensity of tremor or rock burst.

Microseismic monitoring, which has retained the attention of much of the scientific and engineering communities this years, has been proven as a powerful tool to quantify mining-induced seismicities and can contribute valuable information to the studies on fracturing pattern of strata and dynamic hazard prevention. The significant advantages of this technique are its remote, safe and real-time monitoring, accurate 3D location and multiple parameters determination.

In the last 10 years, rock bursts and strong tremors exist in several coal mines in Yanzhou Mining Group, and the problems become progressively more severe as the mining depth and the volume of extraction increase. In this paper, a research work has been carried out to have a better understanding of the fracture propagation and high-layer overburden movement in an isolated working face (LW10302) in B.D. Coal Mine, by theoretical analysis and microseismic monitoring.

## 2. Description of the site

B.D. Mine has a coal production history for about 20 years and the production now has exceeded 6 Mt per year. As the mining depth and intension increase, strong mining-induced tremors have been a major underground dynamic hazard in recent years. The strongest tremor monitored by the local seismology network on Sep 6th, 2004 had the magnitude  $ML=3.7$ , which shook the ground and made the abutment pressure underground increased largely.

LW10302, which mined the Upper No.3 coal seam, is an unsymmetrical isolated working face surrounded by three sides mined areas in its early mining period. As shown in Figure 1, LW10301 on the north (the first face mined in No.10 Mining District) has mined both the Upper and Lower No.3 coal seams, while LW10303, 10304 and 10305 on the south side have just mined the Upper No.3 coal seam. After LW10302 was retreated about 570m (Since 1 Jan, 2009), both the Upper and Lower No.3 seams in LW10303 and other faces on the south side haven't been mined.

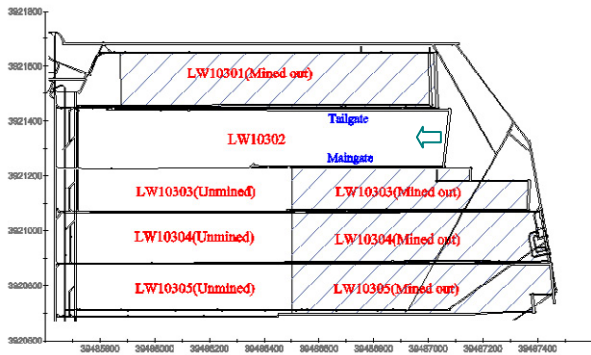


Fig. 1. Layout of LW10302 and surrounding faces

The Upper No.3 coal seam of about 5.8m thickness is being mined some 460m below the ground surface. The immediate roof of about 3.56 m thickness is mainly composed of siltstone, while the main roof strata (which is called No.1 inferior key strata) is composed of medium sandstone, with the thickness of 18.02m. Especially, there is a key fine sandstone stratum of nearly 200m in thickness (which is called primary key strata), approximately 135m above the coal seam. In addition, there is also a fine sandstone stratum of about 19.45m (which is called No.2 inferior key strata) between the main roof and the primary key strata. The strength of the three key strata is quite high with UCS values over 70 MPa. The properties of coal-rock masses can be seen in Table 1.

Table 1. Rock property

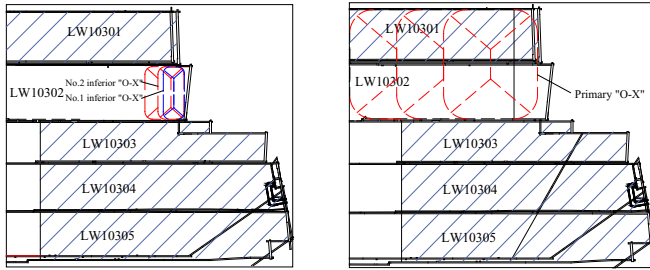
Rock strata	Thickness /m	Compressive strength /MPa	Tensile strength /MPa	Elasticity modulus /GPa	Volume force /(kN.m <sup>-3</sup> )	Key strata
Topsoil	120				18	
Fine siltstone	200	70	9	5	26	Primary key strata
Middle strata	34					
Fine sandstone	19.45	70	10	5	26	No.2 inferior key strata
Middle strata	52					
Medium sandstone	18.02	90	10	6	27	No.1 inferior key strata
Siltstone	3.56	50	3	4	26	
Coal seam	6.09	30	2	2	14	

### 3. Analysis of the fracturing pattern of overlying strata

Based on the key stratum theory<sup>[11]</sup>, as the working face advances, the overlying strata can be divided into key strata with different grades based on the lithology and thickness, and all the key strata will rupture as the structures of “O-X”. Meanwhile, because of the difference of caving intervals, the formed fracturing area of “O-X” structure may increase gradually from low to high layer. Thus, the initially formed “O-X” fracturing structures can be divided into primary “O-X” one and inferior “O-X” ones. In addition, the “O-X” structure of the super-thick primary key strata can be formed above one or even several faces.

According to roof property of LW10302, the overlying strata can be divided into three key strata after the face mining (Seen in Table 1). The first and periodic weighting of main roof and fine sandstone

with thickness of 19.45m will form No.1 and No.2 inferior “O-X” structure (Seen in Figure 2(a)), respectively, while the rupture of the primary key strata (200m in thickness) above LW10301 and 10302 will form primary “O-X” structure.



(a) inferior “O-X” structure; (b) primary “O-X” structure

Fig. 2. The “O-X” fracturing structure of LW10302

Although both the Upper and Lower No.3 coal seam had been mined out in LW10301, the ratio of width to depth of the goaf is less than 0.5, which means the fracture height had just developed about 100-150 above the coal seam and there was almost no obvious fracturing in the super-thick primary key strata because of the limited mining area. Conversely, the total goaf area of LW10303, 10304 and 10305 is so large and the ratio of width to depth of the goaf is large than 1.2, which means nearly all the overlying strata had caved and ruptured fully, and the fracturing height had developed to the ground surface[5,6]. Therefore, the overlying strata on the south side had nearly no dynamic impact (strong tremor or rock burst) during the mining of LW10302. After LW10302 was mined for a period, the overlying key strata with different grades above LW10301 and 10302 would move together, especially the primary “O-X” structures will be formed periodically during the first and periodic weighting of primary key strata, which will have significant effort on the occurrence of strong tremors, even rock bursts. Figure 3、Figure 4 have shown the simple vertical cross-section view of the fracturing structure of the overlying strata before and after LW10302 was mined, respectively.

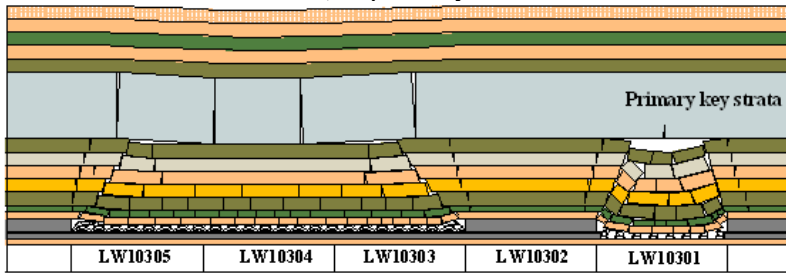


Fig. 3. Vertical cross-section view of the strata structure, along vertical direction of the face, before LW10302 was mined

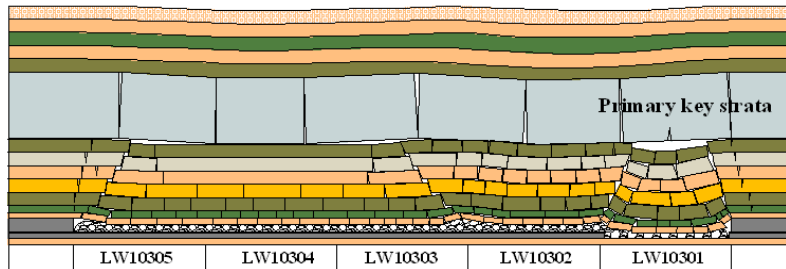


Fig. 4. Vertical cross-section view of the strata structure, along vertical direction of the face, after LW10302 was mined

## 4. Microseismic effort of overburden movement during mining process

### 4.1. Microseismic monitoring layout in LW10302

Microseismic monitoring study was carried out to characterize the overburden movement in B.D. Mine since 1 Jul, 2008. The monitoring system “SOS” can provide an efficient tool for transmission, recording and analysis of seismic events that occurred in mining process. It is comprised of 20 single component geophones, receiving station and seismic recording system. Fifteen of the geophones were installed underground on the bolt inserted and glued into the floor to a depth of 1.5 m, while other five ones (N0 9, 10, 18, 19, 20) were installed on the ground surface. The microseismic data captured by the geophones was transmitted in the form of current signals via cables to the receiving station which is connected with the seismic recording system. The geophone configuration covers major mining areas (especially No.10 Mining District) and it was hence expected that the strata fracturing associated with mining progress can be detectable. The configuration of the seismic monitoring can be seen in Figure 5.

The microseismic system was in good operational condition during the monitoring period. During the whole mining process of LW10302, more than 8200 seismic events associated with roof and floor breakages were recorded and located, revealing detailed fracturing patterns around LW10302 and surrounding faces.

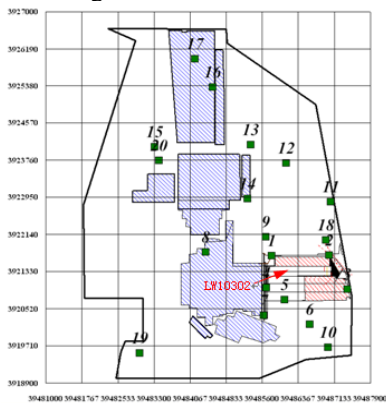


Fig. 5. Configuration of the geophone stations in B.D. Mine

### 4.2. Spatial evolution of microseismic activities

As shown in the plan view of seismic events (102~107J) relative to mining process (Fig.6), from 15 Jul, 08 to 30 Apr, 09, most of the events, from low energy events to strong tremors, occurred mainly within the roof and floor area of LW10301 and 10302. From 15 Jul to 31 Aug, 08, an event evolution trend can be viewed with an angle leaning backward about LW10302 and small amount of events started to occur within LW10301. Starting from 1 Sep, 08, more events propagated within the surrounding strata of LW10301, and all the events moved forward along with mining advance. Since 1 Dec, 08, events occurred in a trend forward ahead of the faceline, which means the strata fractures extended gradually from caving zone to the abutment pressure zone. Since 1 Jan, 09, when the face was retreated over the terminal mining line of LW10303, LW10302 changed from the layout surrounded by three mined areas to two ones, and a small part of events started to occur within the strata of LW10303, near the headentry side of LW10302. The event distribution and evolution provided detailed fracturing patterns within LW10302 and its surrounding faces.

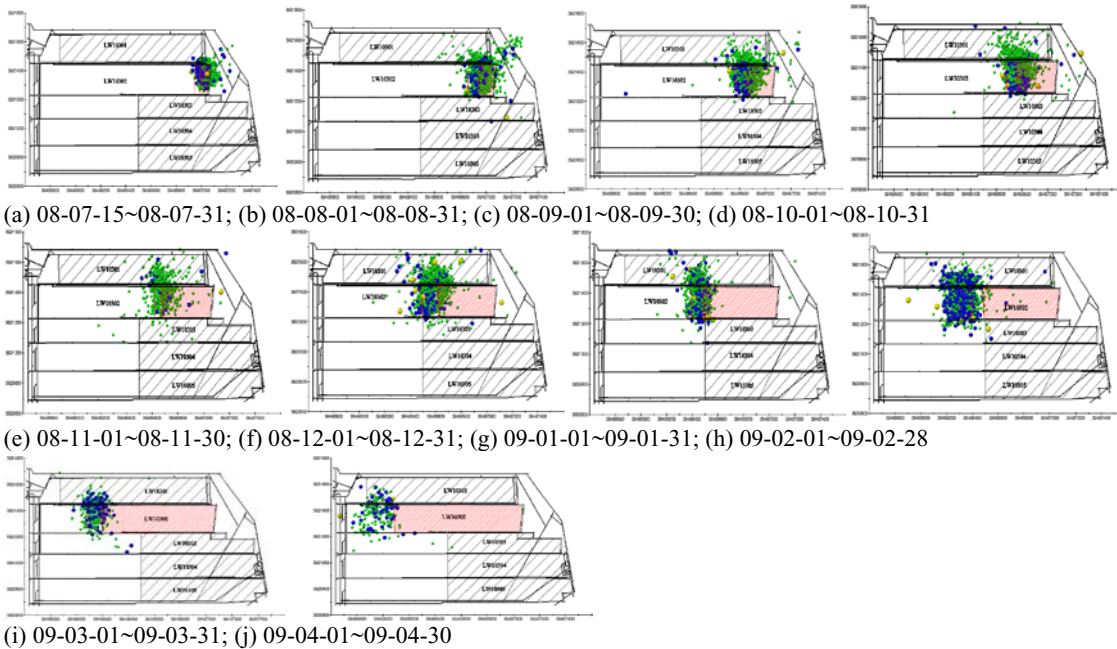
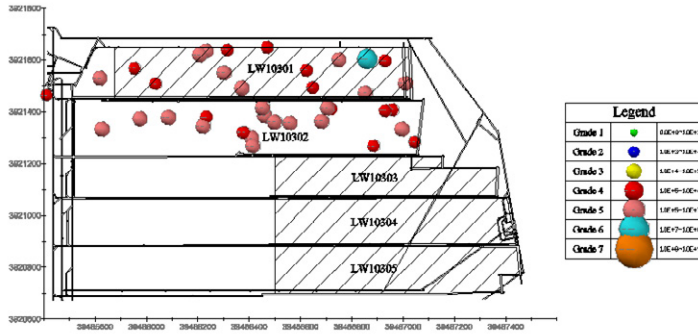


Fig. 6. Plan view of seismic event locations in the mining process of LW10302, for the period from 15 Jul, 08 to 30 Apr, 09

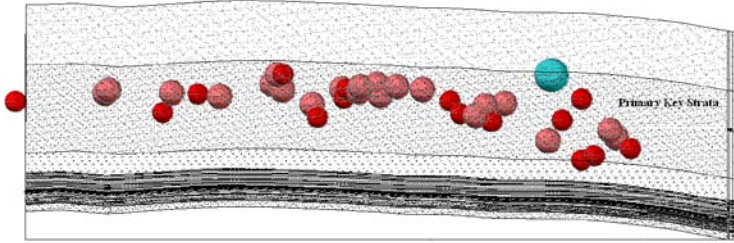
Unlike the low energy events distributed within multiple roof and floor strata, the strong tremors were mainly associated with the large-scale movements of the super-thick primary key strata. During the whole mining period of LW10302, about 40 strong tremors with seismic energy over  $10^5\text{J}$  were recorded. As shown in the strong tremor locations (Fig.7), all of the tremors occurred within the area of LW10301 and 10302 in the plan view, and in the super-thick primary key strata on the vertical cross-section. Actually, strong tremors which are mainly related to large-scale strata movements may be induced where the face interaction can provide enough deformation or motion space for key strata as faces interacted. Therefore, large-scale overburden above LW10301 and 10302 moved together after the excavation of LW10302, then the primary “O-X” structures were formed, and strong tremors occurred correspondingly.

Meanwhile, the strong tremors always occurred first ahead of LW10302, and then located above the goafing area of LW10301 and 10302, which approximately described the “O-X” fracturing process of primary key strata as the face retreated. In addition, the tremors located gradually upward within the key strata, and then downward again, which fits well with the changes of mining geometry of the interacted longwall faces.

As a whole, the space evolution of above seismic events revealed the specific overburden movement of LW10302, a typical unsymmetrical isolated longwall face.



(a) Plan view of the strong tremors



(b) Vertical cross-section view of the strong tremors

Fig. 7. Locations of strong tremors, for the period 15 Jul, 08- 30 Apr, 09

### 4.3. Characterization of seismic events

The signals corresponding to different failure mechanisms of strata show different characteristics in frequency, duration, energy released, et al. According to the analysis of waveform features, large amounts of low energy events with energies ranging from  $10^2 \sim 10^4$ J, are characterized by dominant frequency of 0-40Hz, short waveform duration of 500~2000ms and maximum amplitude order of  $10^{-6} \sim 10^{-5}$ m/s (Fig. 8), which have demonstrated mainly duo to tensile fracturing of the surrounding rock, such as roof caving, horizontal tensile crack, delamination, et al. The events with released energies from  $10^4 \sim 10^5$ J, which may be the results of rupture of inferior key strata, are mainly characterized by low dominant frequency of 0-20Hz, long waveform duration of 1000~3000ms and maximum amplitude order of  $10^{-6} \sim 10^{-4}$ m/s. The strong tremors are characterized by lower dominant frequency of 0-5Hz, quite longer waveform duration, and much higher energy ranging from  $10^5 \sim 10^7$ J (Fig. 9).

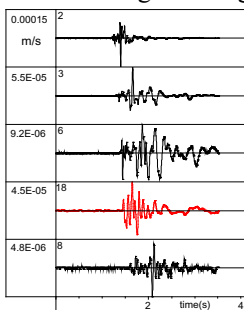


Fig. 8. Typical low energy events recorded at 11:02:07 on 14 Nov, 08 ( $E=7.20 \times 10^3$ J,  $E_S/E_P=3.6$ )

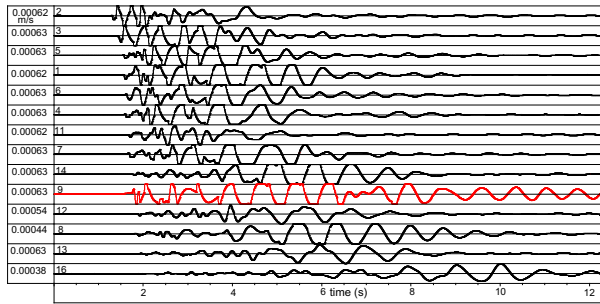


Fig. 9. Typical strong tremor recorded at 01:37:45 on 15 Aug, 08 ( $E=5.32 \times 10^6 J$ ,  $E_s/E_p=43.3$ )

**5. Controlling method to reduce burst effort of strong tremors on longwall mining**

Considering the superposition of high static underground stress around the isolated face and dynamic load of mining-induced tremors, the rock burst risk in the mining operation of LW10302 may be strong. In order to reduce the static stress level and dynamic disturbance of tremors, essential controlling measures should be taken to reduce the burst risk level. Therefore, before the face being mined, pressure relief in big-diameter boreholes were carried out in two entries for pressure pre-relieving, seen in Fig. 10. Additionally, during the mining process, deep-hole relieving shots in coal seam were also implemented around the risk area according to the monitoring results. The charging structure in blasting borehole is shown in Fig. 11.

By using above methods for intensity weakening, the integrity and intensity of coal-rock mass were destroyed and the static stress was reduced. Moreover, the artificial “loose and weak structure” was formed in the goafing area and coal seam, which can absorb and scatter seismic energies radiated by mining-induced tremors in high-level key strata greatly. Thus, because of the large coal-rock media damping effort and long-distance seismic wave geometry spreading, the dynamic disturbance of tremors were decreased efficiently.

During the mining process, the occurrence of strong tremors always made the building on the ground shake slightly and the abutment pressure underground increase with different degrees. Fortunately, these tremors didn’t induce rock burst hazard and cause no injury underground. The controlling methods achieved efficient relieving effort.

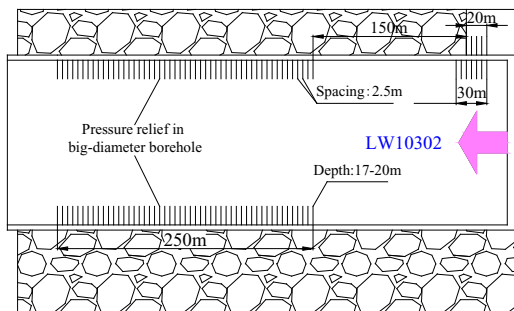


Fig. 10. Pressure relief in big-diameter borehole in LW10302



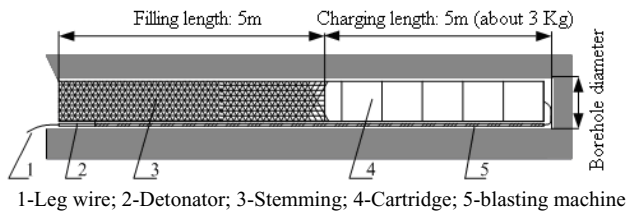


Fig. 11. Charging structure in blasting borehole

## 6. Conclusions

The fracturing patterns of overlying strata and microseismic efforts in an unsymmetrical isolated working face, LW10302 in B.D. Coal Mine, were analyzed in this paper. The main results are as follows:

- Based on the key stratum theory, the initial and periodic weighting of two inferior key strata above LW10302 will form inferior “O-X” structures, respectively, while the rupture of super-thick primary key strata above LW10301 and 10302 will form primary “O-X” fracturing structures.
- The analysis of spatial evolution of seismic events demonstrated that seismic activities fits very well with the overburden fracturing patterns and stress manifestation around the face. In the mining process of LW10302, most of the events located within the surrounding strata of LW10301 and 10302. In general, low energy events distributed in multiple roof and floor strata, while the strong tremors occurred almost within the super-thick primary key strata and appeared to be related to shear fracturing of large-scale overburden movement.
- Different waveform characteristics were discussed between low energy events and strong tremors. Low energy events are mainly characterized by relative high frequencies, short waveform durations, clear P-wave arrivals, while strong tremors present much lower dominant frequencies, quite longer waveform durations, developed coda waves and strong S-wave components.
- Reasonable controlling methods were carried out to reduce the static stress and dynamic disturbance, before and during the exaction of LW10302. No rock burst hazard was induced during the whole mining process, which means the applied methods got efficient relieving effort.
- The study indicates that microseismic monitoring can provide invaluable information to characterize the mining-induced seismicity and reveal the failure patterns within strata associated with longwall mining. Meanwhile, that source location is quite essential for the determination of strata movement, thus the improvement in source locating accuracy is still an important issue in microseismic monitoring. Undoubtedly, more knowledge of the failure modes associated with mining will greatly benefit the alleviation and prevention of rock burst hazards in mines.

## Acknowledgements

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