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TECTONIC STRESS ENVIRONMENT OF COAL-ROCK DYNAMIC HAZARD IN KAILUAN MINING AREA, CHINA

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ABSTRACT: Using HI (Hollow Inclusion) method, the *in-situ* stress of Kailuan mining area was measured in the field. The characteristics of the *in-situ* stress field and the relationship to regional structures are analysed systematically. Then the relationship between *in-situ* stress field coal-rock dynamic hazard, include coal and gas outburst, rockburst and water inrush, is analysed. Studies show that *in-situ* stress field in Kailuan mining area is a high stress zone of Earth dynamical field, with the horizontal tectonic stress being dominant. The magnitude and azimuth of the stress regime is controlled by Kaiping syncline. *In-situ* stress is the highest in Kaiping synclinal axis section, and as far away from the axis, the stress decreases gradually. The orientation of the maximum principal stress is approximate perpendicular to the axis of Kaiping syncline. The tectonic stress field also controls coal structure, gas content, coal permeability and other parameters. In the Kailuan mining area, coal and gas outburst and rock burst occurred in synclinal axis section of Kaiping syncline where *in-situ* stress is the highest, whilst water inrush occurred in the wing of Kaiping syncline where *in-situ* stress is the lowest. Coal-rock dynamic hazard in Kailuan mining area has almost identical tectonic stress environment.

INTRODUCTION

Coal-rock dynamic hazard, including coal and gas outburst, rockburst and water inrush, is an serious threat to the safety in mining and underground engineering. Although many scholars have different opinions about the occurrence mechanism of these hazards, the idea that the hazard is a mechanical process of coal and rock mass deformation and failure, energy accumulation and release is commonly accepted by all scholars (Skochinski, 1954; Cook, 1965; Huoduote, 1966; Zhou, *et al.*, 1991; Zhang, *et al.*, 1991; Yin, *et al.*, 1997; Qi, *et al.*, 1997; Li, *et al.*, 2005).The failure modes and energy release characteristics of coal and rock depend on two conditions, one is the physical and mechanical properties of coal and rock mass, the other is external boundary and loading conditions. In order to study the mechanism of coal - rock dynamic hazard, the physical and mechanical properties, structural features and tectonic stress environment of coal and rock related could be analysed to understand the mechanism and controlling conditions of coal-rock dynamic hazard. Kailuan mining area had been mined for 130 years, and during this period, coal and gas outburst, rockburst and water inrush occurred frequently in mining. Jiang, *et al.* (2005), Liu, *et al.* (2006), Qi, *et al.* (2006), Meng, *et al.* (2009) and Wang (2011) had respectively studied the geological factors of coal and gas outburst, rockburst and water inrush in Kailuan mining area. In this study, the authors investigated the coal-rock dynamic hazard of Kailuan mining area according to geological background, structure characteristic and *in-situ* stress field. The relationship between coal-rock dynamic hazard and tectonic stress field of Kailuan mining area was discussed in detail.

AN OVERVIEW OF COAL-ROCK DYNAMIC HAZARD IN KAILUAN MINING AREA

Kailuan mining area is located in the east of Hebei Province with a mining area of 670 km^2. Coal seam exists in the four groups of Permo-Carboniferous Period. From top to bottom, the groups are Lower Permian Tangjiazhuang Group, Damiaozhuang Group, the Upper Carboniferous Zhaogezhuang Group and Kaiping Group. Damiaozhuang includes 4 to 6 coal seams, 5th coal, 8th coal and 9th coal are the major mining seams. Zhaogehuang Group includes 3 to 5 coal seams, 12th coal is major mining seam. At present, there are ten mines in Kailuan mining area, with an annual coal production of nearly 30 million tons. Among these coal mines, Majiagou is a coal and gas outburst prone mine, whilst Zhao Gezhuang mine is coal and gas outburst and rockburst mine, Tang shang mine has rockburst hazard risk, and Fangezhuang and Donghuantuo mine are water inrush mines (Figure 1). Majiagou Mine is located in the northwest of Kaiping syncline, formation dip is more than 45°. Coal and gas outburst has occurred more

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than 55 times since it started mining operation. The first outburst occurred in the 9th coal seam in September 9th, 1964. The most severe outburst involved 370 t coals and 7500 m^3 gas. The 9th coal and 12th coal are the main working seams with gas outburst prone hazard.

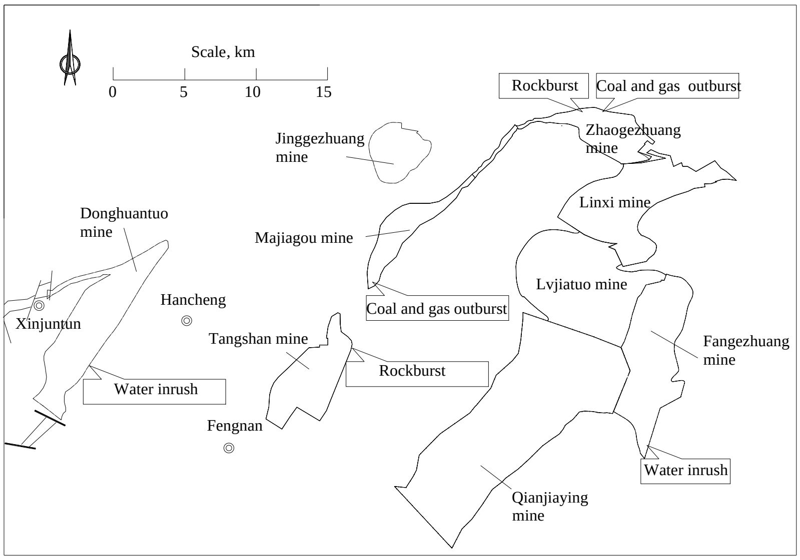

Figure 1 - Coal mine of Kailuan mining area

Zhaogezhuang mine is in the northeast edge of Kailuan syncline. The dip of the coal seam in east is about 30°and in west is from incline to steep until overturned. Coal and gas outburst occurred first in 1955. Until today, outburst incident has occurred for nearly 30 times. The most severe coal and gas outburst occurred on September 15th 1973 with the ejection of 100 tons of coal and 3000 m^3 gas emission. The 9th coal and 12th coal are main coal and gas outburst seams. Rockburst first occurred on June 24th 1995. As mining depth extends continuously, the frequency and strength of rockburst increases with it, rockburst has occurred for 23 times. Tangshan mine located in southwest of Kaiping syncline, rockburst has been more and more serious with the increase of mining depth since the first rockburst occurred in June 7th, 1964. Up to now, rockburst has occurred more than 90 times. Rockburst mainly occurred in 5th coal seam and 8th coal seam under 520m depth. Fangezhuang mine located in the southeast of Kaiping syncline. Water inrush had occurred for 49 times. Among these water inrushes, there is 24 times roof water inrush, 18 times floor water inrush, 5 times karst collapse column water inrush, twice fault water inrush. The most severe water inrush made shaft flooded. Water source of inrush in Fangezhuang mine mainly consists of sandstone group fracture confined aquifers between 12th and 14th coal seam. Donghuantuo mine located in the west of Kaiping syncline and its hydrogeology condition is extremely complex, maximum water inflow has reached 62.84 m^3/min during its construction. 11 water inrush incidents have been reported since 2000.

THE STRUCTURE CHARACTERISTICS OF KAILUAN MINING AREA

The Kaiping coal field is a large and compound coal-bearing syncline structure. It is a representative permo-carboniferous system in north China. There are four coal bearing structures, namely, the Kaiping syncline, Chezhoushan syncline, Jinggezhuang syncline and Xigangyao syncline. Both Kaiping syncline and Chezhoushan synclines belong to long axial oblique, in the middle of them is the Beiziyuan concealed anticline (Figure 2). The main structure of Kaiping coal field is an ejective fold and its axial is NE trending. From east to west is Kaiping syncline, Beiziyuan anticline, Jinggezhuang syncline, Gangyao syncline and Chezhoushan syncline. Kaiping syncline is the main structure, and its main axial trending for 30°~60° and as it approaches to the Guye district, the trending gradually turns to east-west almost.

Most folds in the Kaiping coal field are asymmetric, strata dip is great in the north-west wing of syncline and even reverse, the south-east wing is mild, and anticline is opposite (Figure 3, Figure 4).

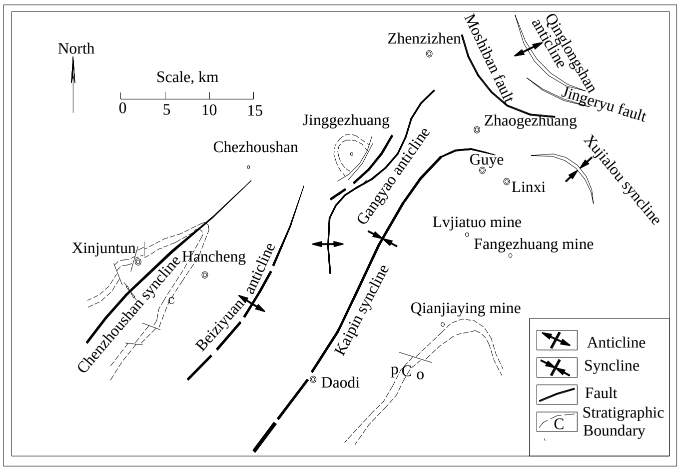

Figure 2 - Sketch of geologic structure in the Kailuan mining area

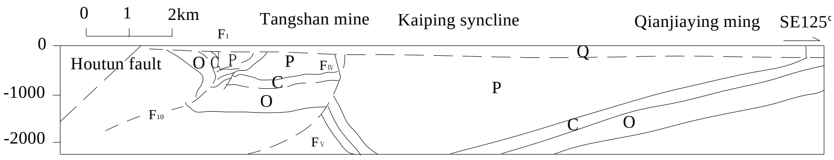

Figure 3 - Profile of Tangshan mine - Kaiping syncline - Qianjiaying mine

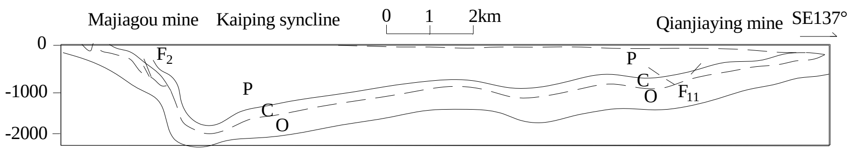

Figure 4 - Profile of Majiagou mine - Kaiping syncline - Qianjiaying mine

IN-SITU STRESS FIELD OF KAILUAN MINING AREA

A large number of *in-situ* stress measurements had been conducted in Kailuan mining area with a hug amount of important raw data. Measurement sites included Jinggezhuang mine, Qianjiaying mine, Fangezhuang mine, Lvjiatuo mine and Donghuantuo mine, Zhaogezhuang mine, Linxi mine and Tangshan mine from 2009 to 2012. Figure 5 shows a comprehensive plot of *in-situ* stress field measurement results in Kailuan mining area.

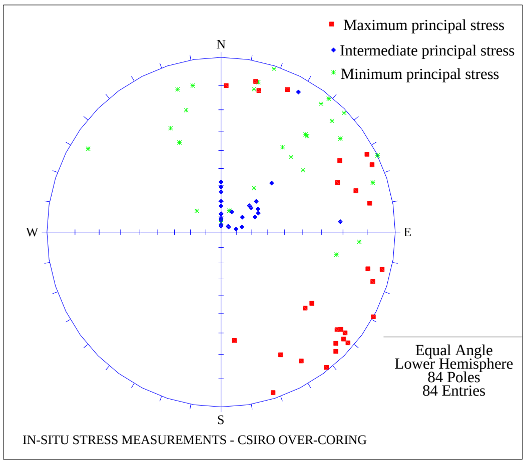

Figure 5 - *In-situ* stress of Kailuan mining area

From the distribution of the maximum principal stress in Kailuan mining area, the highest stress is in Linxi mine which located in the north axis section of Kaiping synclinal. The stress of Qianjiaying mine which located in the south wing of Kaiping synclinal is higher relatively, the stress of Fangezhuang mine which is slightly away from the axis of kaiping syncline is comparatively lower. By examining the distribution characteristics of the *in-situ* stress, it appears that the magnitude of *in-situ* stress of Kailuan mining area is mainly controlled by Kaiping syncline. The site close to the Kaiping syncline axis is the high stress area, with the transition to two wings of syncline, the magnitude of the *in-situ* stress gradually reduces (Figure 6). This observation is in agreement with the theoretical analysis results (Han, *et al.*, 2008).

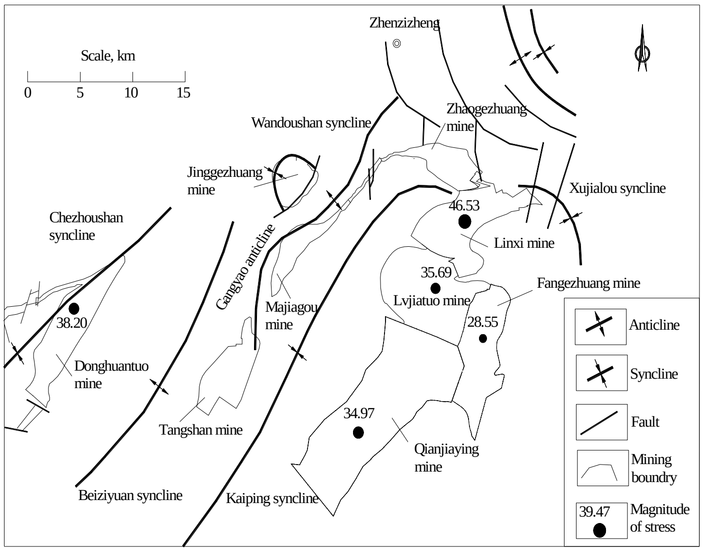

Figure 6 - The max principal stress at -1000 m depth of Kailuan mining area

It is closely related between the azimuth of maximum principal stress and Kaiping syncline axis. The position of maximum principal stress is approximate perpendicular to the Kaiping syncline axis. In the northeast of Kaiping syncline, Zhaogezhuang mine and Linxi mine, the azimuth of maximum principal stress is nearly south-north. In the southwestern of Kaiping syncline, Tangshan mine, Qianjiaying mine, Lvjiatuo mine and Fangezhuang mine, the azimuth of maximum principal stress is north-west. In the area where the Kaiping syncline axis transits from north-east to north-south, the azimuth of maximum principal stress is also gradually transit from north-west to nearly north-south. It reflects that the *in-situ* stress field of Kailuan mining is controlled by Kaiping syncline (Figure 7).

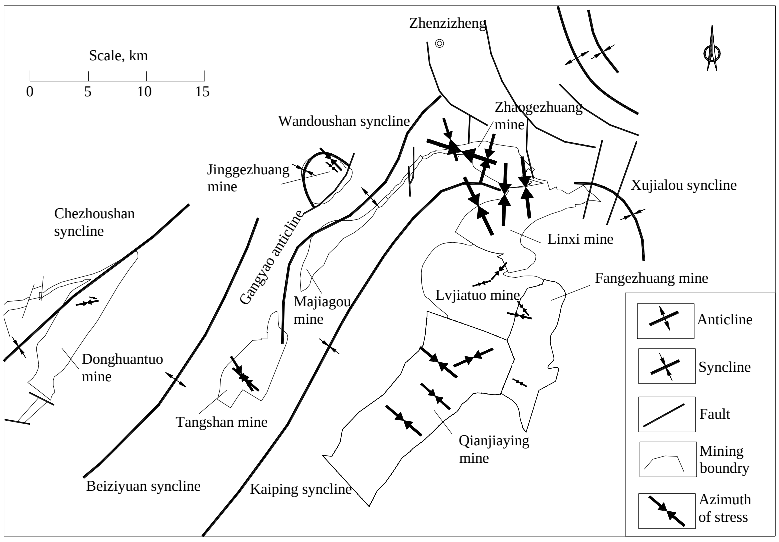

Figure 7 - Azimuth of max principal stress of Kailuan mining area

The general rock engineering indicates the *in-situ* stress in 20~30 MPa as high *in-situ* stress (more than 800 m deep). Because of different rocks have different elasticity modulus, the storage performance of rock is also different, according to GB50218-94(the Chinese Classification standard of rock engineering):

$R_C/\sigma_{Max} < 4$ is extremely high stress, and
$R_C/\sigma_{Max} = 4\text{-}7$ is high stress.

where R_c is UCS (uniaxial compressive strength) of rock; σ_{Max} is maximum principal stress. The relationships between the maximum principal stress and depth in Kailuan mining area is
$\sigma_{Max} = 0.000008\ h^2 + 0.0407\ h + 4.8826$

Thus the mean value of maximum principal stress is 32.32 MPa in - 800 m of Kailuan mining area. If judged by the depth, the *in-situ* stress in Kailuan mining is high stress level because it is more than 30 MPa. The UCS of rock was tested in laboratory. The R_C/σ_{Max} is 0.61 - 2.91, all less than four, therefore the *in-situ* stress of kailuan mining area is in high *in-situ* stress level. In addition, the core disking during the *in-situ* stress measurement of - 1300 m depth in Zhaogezhuang mine is an important indication of high stress.

TECTONIC STRESS ENVIRONMENT OF COAL-ROCK DYNAMIC HAZARD

Tectonic stress environment of coal and gas outburst

The research shows that multilayer flexure rock's stress and strain system depend on the system consisting of the coal seam and roof and floor (Han, *et al.*, 2008). In the syncline structure formation system, the soft coal seam often forms shear action, whilst the surrounding rock has bending effect as a hard layer. Coal's structure under shear action was broken and a lamellar or lay-like tectonic coal was developed (Figure 8). Tectonic coal development degree was correlated with coal seam relative sliding and the state of stress. Tectonic development reduces the strength of coal and the needed energy for triggering coal and gas outburst.

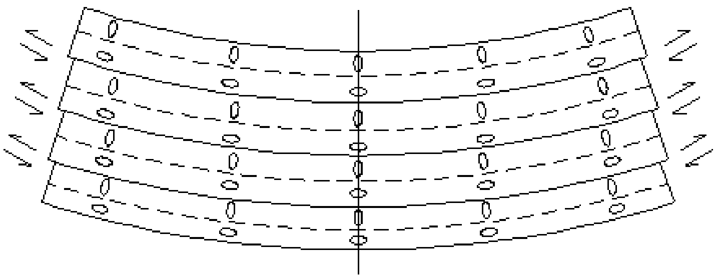

Figure 8 - Relative and unattached strain system in multilayer's bend and glide

The coal seam dip of Kaiping syncline west wing was higher and the slide of coal seam was greater, so tectonic coal exists widely. Especially in the Kaiping syncline west wing where geological structure further damaged the coal seam structure. Majiagou mine and Zhaogezhuang mine are located in the axis of Kaiping syncline west wing nearby, tectonic coal developed and coal permeability is low. Coal's consistence coefficient is 0.14-0.50, the Index (∇p) of initial diffusion rate of coal gas is generally less than 10 mm Hg. In addition, the thick 9^{th} coal (average thickness is 3.47 m, and finally reached 10.00 m), was damaged most seriously in the syncline forming process. Other mines like Qianjiaying mine located in Kaiping syncline's east wing and away from synclinal axis, coal seam dip angle is small and the coal body structure damage slightly.

The gas content of coal seam has distinct characteristics in the wings and axis of Kaiping syncline. In Majiagou mine gas pressure of 9^{th} coal seam was 2.27 MPa and gas content is 15.0 m^3/t. In Zhaogezhuang mine, the highest gas content is near the axis of Kaiping syncline, and the gas content of the 9^{th} coal seam is 8.5 m^3/t, the western average is 7.0 m^3/t, gas pressure is 1.1-1.4 MPa. In Tangshan mine gas content of 9^{th} coal seam is 8 m^3/t. The gas content of Qianjiaying mine, Lvjiatuo mine and Zhaogezhuang mine which are far away from the axis of Kaiping synclinal is very low (gas content is 0.15-1.69 m^3/t) (Figure 9).

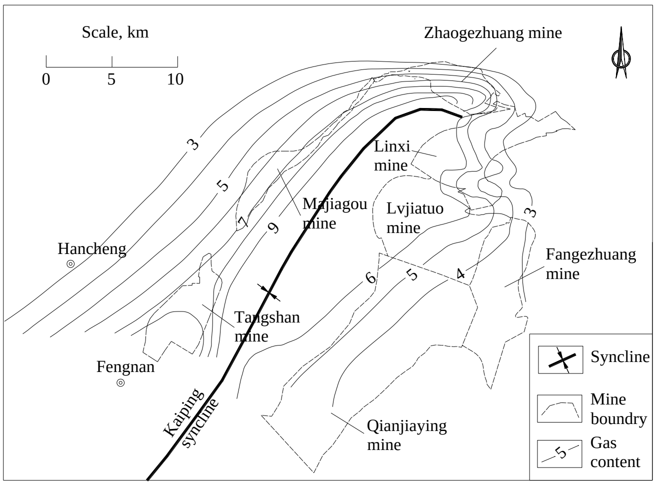

Figure 9 - Gas content of No.9 coal seam in Kailuan mining area

High tectonic stress makes coal seam high gas content and low permeability characteristics in the axis of syncline, and coal's strength is reduced at the same time. Hence the axis section of the syncline has coal and gas outburst danger, and the mines in the wing section of syncline, because of relatively weak tectonic stress.

Tectonic stress environment of rockburst

Rockburst in Laohutai mine, Tianchi mine, Mentougou mine, Fangshan mine and Huating mine showed that the axis section of fold was a rockburst prone zone. The high *in-situ* stress plays a key role in triggering the process of rockburst.

In-situ stress in the Kaiping syncline axis section is higher, which provides a dynamic environment for rockburst. Zhaogezhuang mine and Tangshan mine located in Kaiping syncline axis section, both have higher *in-situ* stress than other mines that are far away from the syncline axis section. In addition, the *in-situ* stress azimuth has a significant effect on rockburst. In Kailuan mining area, because of Kaiping syncline and the maximum principal stress are approximate vertical the mining drivage direction and the maximum principal stress are approximate vertical, this is the roadway under high tectonic stress action. The existence of Kaiping syncline resulted in the heterogeneous characteristics of Kailuan mining area tectonic stress distribute in three-dimensional space. Near the Kaiping synclinal axis section, the tectonic stress enables the rock to accumulate a large number of elastic energy. High i*n-situ* stress provides a dynamic condition and energy source for rockburst.

Tectonic stress environment of water inrush

According to the hydraulic fracturing mechanics principle, during the crack formation, if there is enough fracturing fluid and pressure that can make the crack open and dilated, then fracture will extend along the line of least resistance. The pressure that can extend fracture not only depends on the minimum principal stress, but also the fracture type, size and rock formation property. Theory of water inrush explains as: floor water inrush is the interaction result of the mining pressure and floor confined water pressure, the mining pressure leads to the fracture onset in floor water-resisting layer at certain depth, thus reducing the rock mass strength and the impervious performance, which redistribute the floor stress field. When the rock mass is softened by the confined water that further infiltrates the fracture, this leads to the inductive water fracture continue to expand, till the interaction reduces the minimum principal stress of the floor water-resisting layer rock mass below the confined water pressure, then fracture dilation will occur and induce water inrush. This can be expressed as:

$I=P_w/\sigma_{hmin}$,

where I is water inrush Critical index, P_w is water pressure of floor water-resisting layer rock mass, and σ_{hmin} is minimum principal stress of the floor water-resisting layer rock mass.

If the confined water pressure (P_w) is less than the minimum horizontal principal stress (σ_{hmin}), it will not produce fracturing expansion effect and water inrush. Only confined water pressure (P_w) is more than the minimum horizontal principal stress (σ_{hmin}), there will be fracturing expansion effect and water inrush.

The research of *in-situ* stress stress in Kailuan mining area identified the high stress area close to the Kaiping syncline axis section, the low stress area away from the axis section, and the low *in-situ* stress area in Fangezhuang Donghuantuo mine. Figure 4 showed that at -800m depth, the maximum principal stress reached 44.2 MPa in Linxi mine and 25.0 MPa, 25.33 MPa and 31.7 MPa respectively in Fangezhuang mine and Donghuantuo mine. The minimum principal stress is 6.5-13.9 MPa in Fangezhuang mine and Donghuantuo mine, the minimum principal stress is in a relatively low level. According to water inrush theory, areas with low minimum principal stress will have a high water inrush risk. Thus the mine far from Kaiping syncline axis has more water inrush risk.

CONCLUSIONS

Based on the stress test results in Kailuan mining area, the tectonic stress environment of coal and gas outburst, rockburst, water inrush was analysed. The results show that coal and gas outburst, rockburst, water inrush is mainly controlled by the stress field in Kailuan mining area.

The compression of tectonic stress field in Kailuan mining area led to high gas content and low permeability in the syncline axis section of the coal seams. Combined with low coal mass strength caused by tectonism, the syncline axis section is more prone to coal and gas outburst. Coal mines located in the syncline wing have relatively high permeability, low gas content due to relatively low *in-situ* stress. Thus these coal mines do not have coal and gas outburst conditions.

The Kaiping syncline axis section is an area with high *in-situ* stress, which provides the dynamic conditions for the occurrence of coal- gas outburst and rockburst. As Zhaogezhuang and Tang Shan located Mine are both located near the Kaiping syncline axis section with high *in-situ* stress, they have more serious coal and rock dynamic conditions.

The lower the minimum principal stress, the higher the risk of water inrush, thus coal mines located far away from the syncline axis section will have higher water inrush risk. The water inrush in Fangezhuang mine and Donghuantuo mine is caused by the rupture formed by fault structure relief and mining failure in the low tectonic stress environment.

ACKNOWLEDGMENTS

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REFERENCES

Cook, NGW, 1965. The failure of rock. *Int J Rock Mech Min Sci*, 389-403.

Han, J, Zhang, H and Huo, B, 2008. Discussion of coal and gas outburst mechanism of syncline. *Journal of China Coal Society*, 33(8): 908-913 (in Chinese).

Jiang, Y, Liu, W and Zhao, Y, 2005. Study on surrounding rock stability of deep mining in Kailuan mining group. *Chinese Journal of Rock Mechanics and Engineering*, 24(11):1857-1862 (in Chinese).

Jiang, Y, Zhao, Y and He, M, 2007. Investigation on mechanism of coal mine bumps based on microscopic experiments. *Chinese Journal of Rock Mechanics and Engineering*, 26(5): 901-907 (in Chinese).

Li, T, Cai, M and Wang, J, 2005. Discussion on relativity between rockburst and gas in deep exploitation. *Journal of China Coal Society*, 30(5): 562-567 (in Chinese).

Liu, W, Jiang, Y and Shan, X, 2006. Analysis on induced factors of pressure bump occurred in deep mine roadway of Zhaogezhuang mine. *Coal Science and Technology*, 34(11): 60-63 (in Chinese).

Meng, Z, Yi, W and Lan, H, 2009. Water inrush characteristics of Fangezhuang coal mine field in Kailuan and its geological condition analysis of water inrush from coal seam floor. *Chinese Journal of Rock Mechanics and Engineering*, 28(2): 228-237 (in Chinese).

Qi, L, Lin, B and Zhi, X, 2006. Study on the mechanism of coal and gas dynamic phenomenon in Majiagou mine. *China Safety Science Journal*, 16(12): 30-34 (in Chinese).

Qi, Q, Shi, Y and Liu, T, 1997. Mechanism of instability caused by viscous sliding in rockburst. *Journal of China Coal Society*, 22(2): 144-148 (in Chinese).

Skochinski, A A, 1954. Modem concepts on the nature f sudden outbursts of gas and coal and control techniques, *Ugol.* 7:4-10 (in Russian).

Wang, R, 2011. Study on water inrush geomechanical condition and its water inrush risk of coal roof and floor. Ph.D thesis (unpublished), China University of Mining and Technology, Beijing (in Chinese).

Yin, G, Xian, X and Jin, L, 1997. The effect of crustal stresses on rock burst and evaluation of zone prone to rock burst. *Journal of China Coal Society*, 22(2):133-137 (in Chinese).

Zhang, M, Xu, Z and Pan, Y, 1991. A united instability theory on coal (rock) burst and outburst. *Journal of China Coal Society*, 16(4):48-53 (in Chinese).

Zhou, S and He, X, 1990. Rheological hypothesis of coal and methane outburst mechanism. *Journal of China University of Mining and Technology*, 19(2):1-8 (in Chinese).