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The Influences of Structural Deformation on Coal and Gas Outburst Types

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Geological structure is the main control factor of coal and gas outburst. Characteristics and types of coal and gas outburst usually have great different in regions of different structural deformation patterns. Based on the research of the characteristics of structural deformation in the coal and gas outburst zones, and combined the gas geology theory and the gas geology parameters, the influences of structural deformation on coal and gas outburst types was also further analyzed. The results show that the structural deformation can be divided into three types according to its different formation mechanisms, and it was respectively called as press-out type, press-in type and superposed type in this paper. The coal and gas outburst type is different in areas of different structural deformation type.

1. Introduction

Coal and gas outburst is a complicated geological dynamic phenomenon. The outburst of more than eighty percent occurs in the fracture zones of geological structures (Peng and Yuan, 2009), and the coal and gas outburst tends to occur in the place of intense structural deformation (Wei et al., 2015). Considering the influences of the structural deformation on the coal and gas outburst, many studies had been conducted on the relationship between the structural deformation types and the coal and gas outburst, and great achievements had been made. For example, the relationship between the bedding slipping structure and the coal and gas outburst (Li, 2001), the influences of the fold deformation on the coal and gas outburst (Han et al., 2011), the influences of fault strike on coal and gas outburst (Jia et al., 2013) The coal and gas outburst can be divided into three types, coal extrusion, coal dump and outburst. If the coal and gas outburst type are different, the structural environment and the control factor are different too. Therefore, the forecast and prevention measures are different as well (Yu, 2005). It is insufficient to study the relationship between structural deformation and outburst when thinking of these three outburst types as one. The coal and gas outburst disaster in Xinan coalfield is serious. However, the outburst of different type in this coalfield has prominent zoning features. In this paper, the outburst areas in Xinan coalfield are taken as research object, and based on the study of the characteristics of coal-rock strata structural deformation, the formation mechanism of the structural deformation were analysed, and combining with the gas geology theory and the related parameters, the relationship between the structural deformation and outburst types is further studied.

2. Geologic background of Xinan coalfield

Xinan coalfield locates in the western of Henan of China (Fig.1). It belongs to the north margin of Qinling orogenic belt. It includes four coal mines: Xinan, Xinyi, Yian, Mengjin, and the total area is 179km^2. In this region, the large or medium-sized geological structure is less and mainly locates in the border of coalfield (Fig.2). Xinan syncline is the major structure of the coalfield, and the geological structure in Xinan coalfield is simple. It is a wide flat monoclinal structure. The coal measures of this area were formed in the late Carboniferous and the early Permian periods. It mainly experienced the tectonic movement of Indosinian, Yanshanian and Himalayan. The structure generated in Himalayan is mainly of NE-trending in the adjacent areas (Yuan, 2010). The large or medium-sized geological structures of NE-trending don’t exist in this area (Fig.2). It suggests that Himalayan tectonic movement was not strong in this area. Moreover, the large or

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medium-sized geological structure mainly spread in SN and NWW trending, and it shows that the Indosinian and Yanshanian tectonic movements were the primary control factors for the generation of geological structure. However, the multi-stage tectonic movements generated much small-sized fold structure, and resulted in drastic changes of the coal thickness (Fig.2). The average value of variation coefficient of the coal thickness reaches up to sixty-eight percent, and rises up to seventy-nine percent in some areas. The coal-body structure was badly damaged for the effects of multi-stage tectonic movements，the granular and scaled coal is the primary components of the coal seam. The coalfield contains four coal mines (Fig.2), and they were all identified as coal and gas outburst mine.

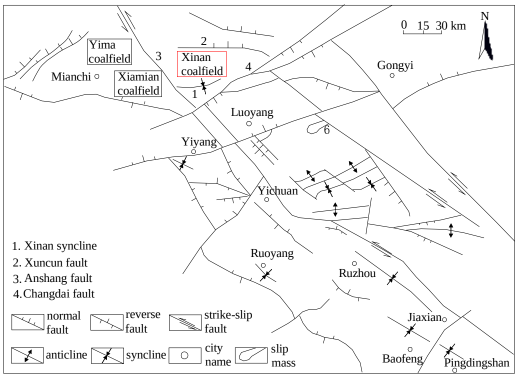

Figure 1: Structural sketch of Western Henan

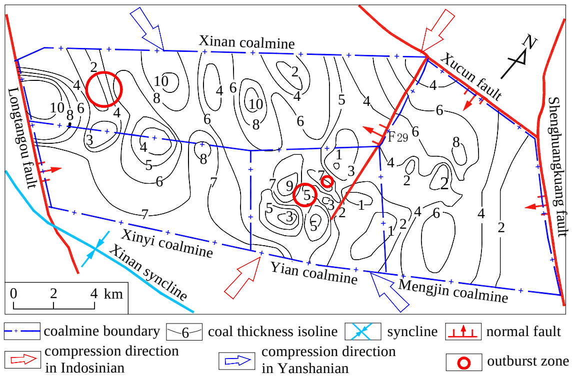

Figure 2: Structural sketch of Xinan coalfield

3. Structural deformation characteristics and formation mechanism

3.1 Position and distribution of outburst zones

Coal and gas outburst is a complicated geological dynamic phenomenon. According to the outburst dynamic characteristics and the control factors, the coal and gas outburst can be divided into three types, coal extrusion, coal dump and outburst. The extrusion is characterized by the overall movement of the coal. Moreover, the tectonic stress is the dominant factor to control the extrusion, and the gas pressure occupies a second place. The dump is characterized by a larger amount of coal outburst and a less amount of gas emission. The gravity action is the primary factor to control the dump. The outburst is characterized by a larger amount of gas emission and a less amount of coal outburst. The gas pressure is the dominant factor to control the outburst (Yu, 2005). The four producing mines of Xinan coalfield are all identified as the coal and gas outburst mine. The coalfield had happened fifteen times coal and gas outburst, fourteen times of them occurred in Xinan mine and Yian mine, it concentrated distribution in three regions (Fig.1). In the three regions, the coal and gas outburst types distinguish obviously. The region 1 locates in the western of Xinan mine, the coal and gas outbursts that were all the extrusion occurred seven times (Fig.3a). The proportion of the extrusion is one hundred percent. The region 2 locates in the central of the Yian mine, the coal and gas outburst occurred four times, three times of which were the outburst, one times of which was the extrusion (Fig.3b). The proportion of the outburst is seventy-five percent. The region 3 locates in the north-central of Yinan mine, the coal and gas outburst were the entire dump and occurred two times (Fig.3b). The proportion of the dump is one hundred percent.

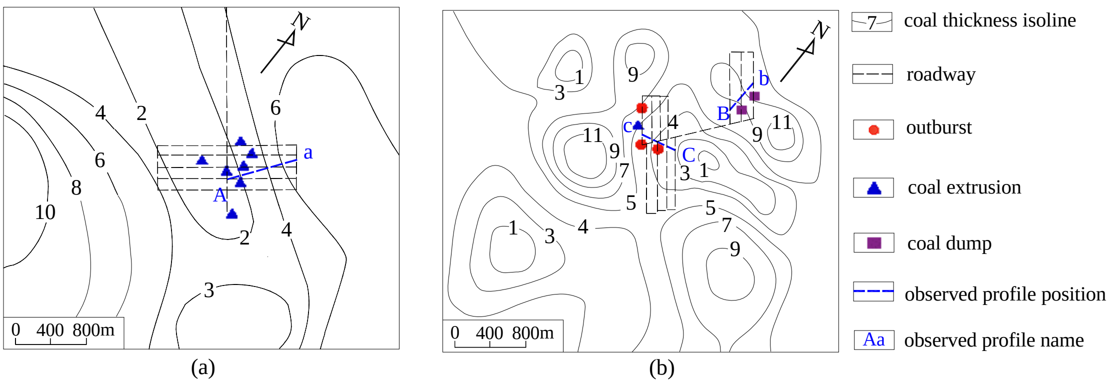

Figure 3: Distribution of coal and gas outburst in Xinan coalfield

3.2 Structural deformation characteristics

The structural deformation in each coal and outburst zone has significant difference. It mainly shows as the regional changes of coal thickness and the distribution of deformed coal (Tab 1). In the region 1, the thickness isoline looks like as thin strips, it means that the coal seam shows as various NWW trending coal belts in the space, and the coal thickness changes in NNE direction (Fig.3a). In the observed profile A-a (Fig.4a), coal thickness increases obviously. It increases from 2.3m to 6m between 400m. The deformed coal presents as belts. In the area which close to the thinnest of the coal seam, the coal body structure damaged seriously, and it often appeared granular coal belt of full thickness. The coal protodyakonov coefficient was measured mostly under 0.25. With the increase of the coal seam thickness, the coal body structure goes better. It changes to scaled coal belt of full thickness, and the coal protodyakonov coefficient increased to more than 0.3.

In the region 2, the coal seam shows as various coal belts in EW trending, and the coal thickness changes in nearly NS direction (Fig.3b). But the overall coal thickness is much bigger than the region 1. In the observed profile B-b (Fig.4b), the coal thickness increases from 5m to nearly 10m between 400m. The deformed coal is mainly scaled coal and presents as multiply layers, and the protodyakonov coefficient was measured mostly over 0.3. In the middle of the coal seam, granular coal of thin layer often appears, and the thickness of the granular coal mostly below 1.5m. The dip angle of the granular coal layer increases with the coal thickness (Fig.4b), and it can reach as big as 70° at the fold axis.

In the region 3, the thickness isoline shows as many closed loops (Fig.3b). It means that the coal seam presents as convex or concave structure. In the observed profile C-c (Fig.4c), the coal thickness increases in EW treading, but the range of the increased thickness is much smaller than the region 2. It increases only from 3m to nearly 5m between 500m, but the damage degree of the coal body structure is the worst compared to the other regions. It often appears mylonitic coal of full thickness, and the protodyakonov coefficient was measured below 0.18.

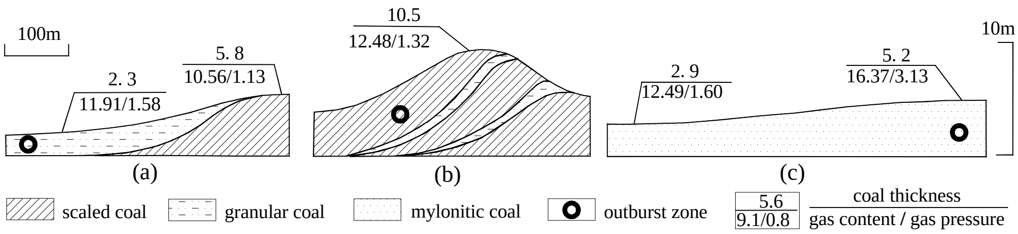

Figure 4: Characteristics of deformed coal and gas content in different outburst zones. (a) observed profile of A-a. (b) observed profile of B-b. (c) observed profile of C-c

Table 1: Coal structure characteristics in different deformation region

Region	Coal thickness (m)	Coal body structure characteristics			
		Deformed coal type	Deformed coal thickness (m)	*f*	*ΔP*
General region	4-6	Cataclastic coal	4-6	0.35-0.64	8.6-16.4
Region 1	2.3-5.8	Scaled coal	3-5.2	0.27-0.48	10.3-18.1
		Granular coal	1.9-3.4	0.13-0.25	15.6-25.2
Region 2	5-11	Scaled coal	3-9	0.36-0.49	10.4-18.1
		Granular coal	0.4-2.1	0.19-0.31	12.6-22.7
Region 3	1.6-5.2	Mylonitic coal	1-5	0.09-0.15	20.5-29.7

3.3 Formation mechanism

Based on the analysis of the geologic background, the formation mechanism of the structural deformation of the three regions was studied in this section, and according to its own characteristic, it can be divided into three types: press-out type, press-in type and superposed type. The formation mechanism of each type was showed as follows.

(1) Press-out type: In region 1, the coal thickness belts spread in NWW treading which perpendicular to the compression direction of Indosinian period (Fig.2). It indicates that the compression movement in Indosinian was the primary cause to generate the deformation. With the compression of the tectonic stress, the rock stratum occurred to deform in buckling fold form, and the rock compression direction towards the coal seam (Fig.4a). At the fold axis, the compression degree of the rock is the largest, and the stress generated by the deformation in coal seam is also the largest. The coal body structure damaged seriously. When away from the

fold axis, the compression degree reduced gradually, and the coal body structure goes better. On the whole, the compression of the rock stratum pressed out the coal from the hinge zone of the fold. As a result, the thickness of coal seam decreased seriously.

(2) Press-in type: In region 2, the coal thickness belts also spread in nearly NWW treading which perpendicular to the compression direction of Indosinian period, and the compression movement in Indosinian was the primary cause to generate the deformation too. But the rock compression direction away from the coal seam (Fig. 4b). In the axis zone of the fold, the compression of the rock stratum is the lowest. At the limb zone of the fold, the compression generated by the deformed rock in the coal seam is the largest. On the whole, the compression of the rock stratum pressed in the coal from the limb zone to the hinge zone of the fold. As a result, the thickness of the coal seam increased rapidly.

(3) Superposed type: In region 3, the coal thickness isoline shows as many closed loops which mean that the coal seam presents as convex or concave structure (Fig.3b), and it a representative deformation form of dome-basin structure (Wang, 1999). Combined with the geologic background of the coalfield, it indicates that the superposition of the structural deformation in Indosinian and Yanshanian periods was the main reason to create the deformation of this type. In Indosinian period, the coal seam suffered the rock compression which direction towards the coal seam. It made the coal seam thickness decreased along the NS trending and damaged the coal body structure seriously, and generated the mylonitic coal of full thickness. In Yanshanian period, the compress direction of the rock stratum transformed to away from the coal seam, and the coal seam became to increase along the EW trending, as a result, the thickness of the mylonitic coal which generated previously in Indosinian period increased with the coal seam, finally, the thickness of the mylonitic coal reached to 5.1m above (Fig.4c), which is the highest in all regions.

4. Influence of structural deformation on the coal and gas outburst types

4.1 Structural deformation of press-out type controls the extrusion

In the structural deformation area of press-out type, the extrusion mainly occurs in zone of thin coal seam (Fig.4a). The dynamic characteristics of the seven times extrusion accidents were statistically analyzed, the results show that the weight of the the extrusion coal is less; most of the extrusion is characterized by the overall movement of coal in the heading face. The movement distance is mostly more than 1.5 meters, and it reaches as high as 2.4 meters (Tab 2). Moreover, the rib spalling often happens. It illustrates that the compression action of tectonic stress is the primary reason to result in the extrusion (An and Cheng, 2014). According to the structure deformation characteristics and the formation mechanism, the compression action of the ancient tectonic stress field in Indosinian generated the fold deformation. It caused the rock roof deformed seriously in the area of thin coal seam. The rock mass suffered destruction, the measured value of uniaxial compressive strength is as low as 63MP, and the elasticity modulus is as low as 32GP (Fig.5). Comparing with the close general region, the damage degree of the rock mass increases, and the rock elasticity rises (Fig.5). It's more likely to occur in fold deformation and extrude the coal. It generates the phenomenon of the tectonic stress concentration, and provides the primary power for the extrusion. Meanwhile, the coal in this area was damaged seriously. Granular coal of full thickness often appeared, and the thickness of the granular coal is often below two meters. The protodyakonov coefficient of the coal is often below 0.25 (Table 1). The anti-pressure ability of the coal decreases, and reduces the resistance of the coal extrusion greatly. The comprehension action of the two factors makes the extrusion accident easy to occur in this area.

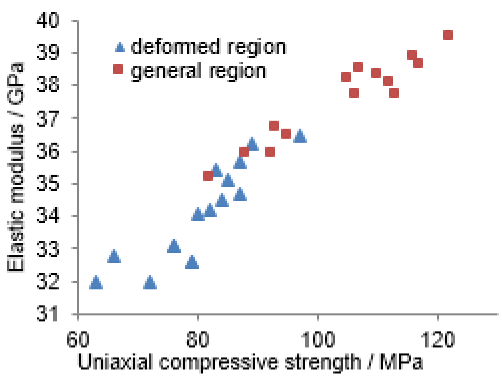

Figure 5: Rock mechanics parameters in structural deformation area of press-out type

Table 2: Extrusion features in Xinan coalfield

Extrusion position	Substance of extrusion		Dynamic features	Distance of coal seam move / m
	Gas (m^3)	Coal (t)		
13 returen airway	281	9.6	coal seam move	1.5
14151 roadway	53	2	rib spalling	—
14181 roadway	3500	50	rib spalling	—
14191 roadway	117	2.8	coal seam move	2
14190 roadway	265	5.9	coal seam move	1.8
14 tansport tunnel	1380	28	coal seam move	2.4
14 returen airway	560	12.5	coal seam move	2.1

4.2 Structural deformation of press-in type controls the dump

In the structural deformation area of press-in type, the dump all occurred in the thick coal zones (Fig.4b). In the two times dump accidents, the weight of the dump coal was about twenty tons (Tab 3), the gas emission is less. The dump coal shows as natural repose angle, it represents that the coal fall off the coal seam naturally, and the coal gravity is the major reason to lead to accidents (Yu, 2005). According to the structure deformation characteristics and the formation mechanism, the compression action of the ancient tectonic stress field in Indosinian makes the direction of the fold deformation of the rock roof far away from the coal seam. The compression of the rock stratum pressed in the coal from the limb zone to the hinge zone of the fold, and the coal thickness reaches up to twelve meters above (Fig.4b). In the fold axial, the coal seam doesn't suffer the extrusion stress of the rock strata in the vertical direction. However, the rapid increase of the coal seam thickness leads to the increase of coal seam gravity, which provides dynamic condition for the coal dump. Meanwhile, in the structural deformation area of press-in type, the coal body structure is mainly the scaled coal. It often develops a lot of structure fractures, which makes the coal soft and easy to fall off. Moreover, the dip angle of the granular coal layered is bigger (Fig.4b), which reaches above seventy degrees (Tab 3). It provides the main sliding surface for the coal dump. The comprehension action of the three factors provides favorable condition for the coal dump. It leads to the dump accident easy to occur in the structural deformation area of press-in type.

Table 3: Substance of dump and deformed coal features

Dump position	Substance of dump		Deposit slope of the dumped coal (°)	Dip angle of granular coal layer (°)
	Gas (m^3)	Coal (t)		
12011 tansport tunnel	151	15.9	43°	72°
12011 returen airway	1000	20	39°	67°

4.3 Structure deformation of superposed type controls the outburst

In the structure deformation area of the superposed type, the outburst distributes intensively in the thickening position of the coal seam (Fig.4c). The statistical analysis on the outburst accidents shows that in the outburst of this area, the gas emission is the largest, the gas emission of one ton coal can reaches up to 150m^3/t (Table 4). The research shows that the coal seam gas and the gas pressure are the major dynamic factors to control outburst, and the large amount of gas emission increases the dangerousness of the outburst.

The coal seam gas content is mainly related with the gas generation quantity and the preservation condition of the coal seam gas (Hao et al., 2012). For the generation quantity of the coal seam gas, the metamorphism degree is the primary control factor. The generation quantity increases with the increase of the metamorphism degree. The metamorphism degree of the coal is usually measured by the volatile matter. The lower volatile matter shows the higher metamorphism degree and the larger generation quantity of the gas. The research of the superposition structure deformation characteristics and the formation mechanism show that the area experienced the tectonic compression movement in Indosinian and Yanshanian. The strong tectonic dynamic metamorphism action results in the increase of the metamorphism degree of the coal seam, the volatile matter decreases is as low as 9.46 percent (Table 5). It caused the increase of the coal seam gas generation quantity. For the coal seam gas preservation, the mylonitic coal is a dense gas insulation layer. When the thickness of the mylonitic coal is large, the upper coal seam obstructs the loss of the coal seam gas of the lower coal seam. It's beneficial for the coal seam gas preservation (Hao et al., 2012). In the structural deformation area of the superposed type, the coal seam usually develops mylonitic coal of full-thickness. The thickness often reaches more than five meters, the gas permeability is poor, and it's adverse to the gas emission. On the other hand, the mylonitic coal has extremely strong absorbability to the coal seam gas, and the adsorption constant reaches up to 56.9 (Table 5). It's highly beneficial to the gas preservation, and the coal seam gas content is much bigger than general regions (Guo et al., 2016). Moreover, the coal seam gas content increases with the increase of the thickness of the mylonitic coal. The measured value reaches up to 16.3m^3/t, and the gas pressure reaches up to 3.1MP (Table 5). The research shows that the full-thickness mylonitic coal results in the sharp increase of the coal seam gas content. It's the major reason for the outburst accident easy to occur in this area, and the outburst dangerousness increases with the increase of the thickness of the mylonitic coal.

Table 4: Gas occurrence and its control factors in region of superposed type

Region	Volatiles (%)	Adsorption constant ($cm^3/g \cdot r$)	Gas content ($m^3 \cdot t^{-1}$)	Gas pressure (MPa)
General region	14.67~17.73	28.6~46.7	7.97~11.63	0.32~0.96
Superposed region	9.46~13.89	42.5~56.9	11.49~16.37	1.10~3.13

5. Conclusions

In conclusion, the coal and gas outburst type is different in areas of different structural deformation type. According to its geometry characteristics and formation mechanism, the structural deformation of the coal seam can be divided into three types: press-in, press-out and superposed type. Thereinto, coal extrusion tends to occur in the structural deformation area of press-out type; coal dump tends to occur in the structural deformation area of press-in type; outburst tends to occur in the structural deformation area of superposed type, moreover, the outburst dangerousness increases with the increase of the thickness of the mylonitic coal.

Acknowledgments

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Reference

An F.H., Cheng Y.P., 2014, The effect of a tectonic stress field on coal and gas outbursts, The Scientific World Journal, 2014(1), 1-10. Doi: 10.1155/2014/813063.

Guo H.J., Cheng Y.P., Ren T., 2016, Pulverization characteristics of coal from a strong outburst-prone coal seam and their impact on gas desorption and diffusion properties, Journal of Natural Gas Science and Engineering, 33, 867-878.

Han J., Zhang H.W., Song W.H., Li S., Lan T.W., 2011, Coal and gas outburst mechanism and risk analysis of tectonic concave, Journal of China Coal Society, 36(S1), 108-113.

Hao F.C., Liu M.J., Wei J.P., Fu Y.Q., 2012, The controlling role of gravitational slide structure to coal and gas outburst, Journal of China Coal Society, 37(5), 825-829.

Jia T.R., Wang W., Zhang Z.M., Tan Z.H., Zang Y.G., 2013, Influence of fault strike on gas outburst under modern tectonic stress field, Journal of Mining & Safety Engineering, 30(6), 930-934.

Li H.Y., 2001, Major and minor structural features of a bedding shear zone along a coal seam and related gas outburst, Pingdingshan coalfield, northern China, International Journal of Coal Geology, 47, 101-113.

Peng L.S., Yuan C.F., 2009, Gas Geology and Gas Outburst Prediction, China Science and Technology, Beijing, China.

Wang G.L., 1999, Discussion on superposed folds in coal mines of China, Earth Science Frontiers, 6(S1), 175-182.

Wei G.Y., Wang B.J., Yan J.W., Wang W., Jia T.R., 2015, Gas geological control characteristics of outbursts coal seam in Pingdingshan, No. 8 Mine, Journal of China Coal Society, 40(3), 555-561.

Yu B.F., 2005, Prevention and Utilization Technology of Coal Gas Calamity Manual, China Coal Industry, Beijing, China.

Yuan Z.D., 2010, Yuxi area tectonic characteristics and evolution, Coal Technology, 29(3), 167-170.