

# Guiding Effect of Soft Tectonic Coal on Coal and Gas Outburst and its Experimental Study

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## Research

**Keywords:** coal and gas outburst, soft tectonic coal, tectonic movement, outburst energy, simulation experiment

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# Guiding effect of soft tectonic coal on coal and gas outburst and its experimental study

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**Abstract:** Soft tectonic coal commonly exists in coal and gas outburst zones. The physical simulation experiment was carried out to reproduce the influences of soft coal area on the outburst, and the guiding action mechanism of soft tectonic coal on the outburst was investigated. This study concludes that the amount of outburst coal in the experiments of group with local existence of soft coal area are relatively lower. The outburst coal amount (3.8035 kg) and relative outburst intensity (21.02%) in the GR5# experiment were both lower than that in the GN6# experiment of control group. However, the outburst coal in the experiments of group with local existence of soft coal area could be commonly migrated to a long distance, the maximum throwing distances in the three experiments were all over 16.73 m, reaching as high as 20.10 m. Under the gas pressure of 0.30 MPa in the group with local existence of soft coal area, the outburst coal amount (2.7355 kg) was smaller than the amount (2.803 kg) of pulverized coal filled, and the 2.0 cm coal pillar experiences failure only nearby the outburst mouth. As the gas pressure increases, the failure degree of the coal pillar becomes higher and higher until complete failure. The outburst development sequence is changed due to the existence of the soft tectonic soft area. Once the sealing conditions are destructed, the outburst firstly develops in the soft tectonic coal area. Nevertheless, sufficient energy is supplied to transport the coal mass in the soft tectonic coal area to a farther distance, while the residual outburst energy can just result in the outburst of a small quantity of coal masses in the normal area. This research will be of great scientific significance for explaining the soft tectonic coal-induced change of outburst starting and development

sequence.

**Keywords:** coal and gas outburst; soft tectonic coal; tectonic movement; outburst energy; simulation experiment

## 1 Introduction

As a type of non-renewable energy, coal plays an important role in the world energy structure, which is one of the main energy sources in China, the United States, Australia and other countries (Jiang et al., 2021). However, a variety of disasters and accidents become more serious as the mining depth increasing, and they have great influence on the safety of coal mining (Liu et al., 2020). Among them, coal and gas outburst (hereinafter referred to as outburst) attracts worldwide attention toward mine safety (Wang et al., 2020). Outburst is the rapid release of a large quantity of gas in conjunction with ejection of coal into the mine working areas (Yang et al., 2021), which is usually accompanied by enormous destruction effect (Xue et al., 2020). Due to the complexity and non-repeatability of outburst, it is difficult to explain the outburst mechanism under different geological conditions with unified theories (Liu et al., 2019). According to literatures (Dennis and Black, 2019; Zhao et al., 2015), the outburst is generalized into the characteristic comprehensive action of stress, gas, and coal.

However, the outburst is strongly associated with geological structure, and most outburst accidents take place in geological tectonic zones (fault, fold, thrust, etc.) (Tu et al., 2019). Gray (2015) made statistics of 105 outburst cases in the main coal production countries across the globe, where it was pointed out clearly that fault, fold, complex tectonic zone, etc. existed nearby the outburst points in 87 cases. Cao et al. (2001) deemed that the coal seam on the thrust fault footwall bore greater tectonic deformation than that on the hanging wall, the extension distance of tectonic reworking zone on the thrust fault footwall was larger than that on the hanging wall, and these factors decided the controlling effect of thrust fault on outburst. For the association between outburst and geological structure as indicated in the related literatures (An and Cheng, 2013; Black, 2019), these geological structures not only change the coal seam stress and gas environment, but more importantly, they change the coal microstructure (matrix, pore, crack, etc.), and further change the coal characteristics. Influenced by the

geological structures, soft tectonic coals with high crushing degree are found on many outburst accident scenes (Lu et al., 2017).

Soft tectonic coal is generated when the original coal measure strata undergo geological tectonic movements (Ju et al., 2005). The microstructure of tectonic coal decides its characteristics, so when the external factors are changed, tectonic coal's mechanical behaviors, response to gas flow, etc. play critical roles in the occurrence and development of outburst (Wang et al., 2019). However, the research emphasis is mostly laid on the roles played by stress and gas in outburst coal instability, continuous development of coal instability (Skoczylas et al., 2014; Xue et al., 2015), and migration of thrown-out coal (Jin et al., 2018). Few attention is paid to the role played by the characteristics of soft tectonic coals in the outburst process, not to mention their controlling effect on the occurrence of outburst, and guiding effect on the development of outburst.

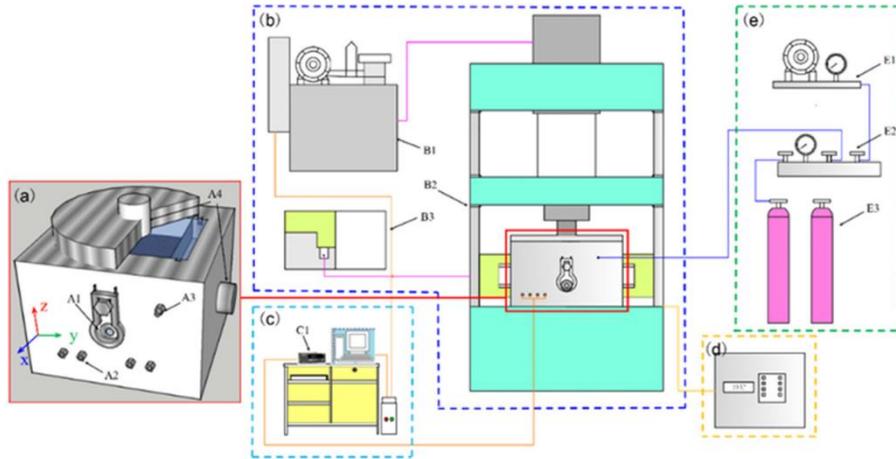
In this paper, the physical simulation experiment was carried out to reproduce the influences of soft coal area on the outburst intensity, holes, and coal spalling. Then, the geological genesis of soft tectonic coal was discussed. Finally, the guiding action mechanism of soft tectonic coal on the outburst was investigated from a view of the density distributions for outburst potential energy and energy consumption in coal mass before the outburst. This research will be of great scientific significance for explaining the soft tectonic coal-induced change of outburst starting and development sequence.

## **2 Experimental study of guiding effect of soft tectonic coal on outburst**

The coal and gas outburst simulation experiment is a direct and effective method of reproducing the outburst process (Tu et al., 2018; Yin et al., 2016). The guiding effect of soft tectonic coal on the outburst will be further explored via the simulation experiment in this paper.

### **2.1 Experimental equipment and scheme**

The true triaxial coal and gas outburst simulation experiment system was used in the simulation experiment, as shown in Fig. 1. This system is mainly composed of triaxial outburst simulation experiment cavity (a), stress loading system (b), data acquisition system (c), constant temperature system (d), and gas injection/vacuum system (e).



A1: Outburst mouth, A2: Monitoring hole, A3: Gas inlet/outlet, A4: Piston;  
 B1: Axial pressure pump station, B2: Horizontal loading pump station,  
 B3: Axial compression experimenting machine; C1: Data acquisition instrument;  
 E1: Vacuum pump, E2: Three-way valve, E3: Gas cylinder

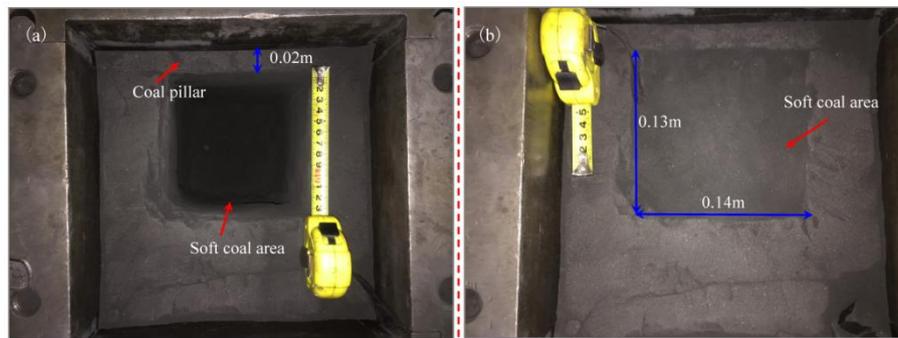
**Fig. 1 Schematic diagram of experiment system** (Tu et al., 2016)

According to the experimental scheme, two groups of outburst simulation experiments (control group GN and experiment group GR) were designed, where the specimen in the control group GN was loaded under 48 MPa moulding pressure, with dimensions of about 250 mm × 250 mm × 250 mm. As for the experiment group GR, the soft coal area was designed based on the moulding specimen in the control group GN, the soft coal area (dimensions: 0.14 m × 0.13 m × 0.2 m) was located in the middle of the experiment cavity, and a 2 cm coal pillar was reserved between the soft coal area and front wall of the experiment cavity.

The preparation steps of the moulding specimen in the experiment group GR were as follows. First, 6% moisture was added into the pulverized coal (below 0.25 mm) to realize compression moulding of the specimen under moulding pressure of 48 MPa, which was kept for 40 min. Secondly, a hole was drilled in the specimen with an electric drill according to the soft coal area design as shown in Fig. 2 (a). In the end, loose pulverized coal sample (additive amount of moisture: 6%) was filled inside the hole to complete the specimen preparation as shown in Fig. 2 (b). The gas pressure was changed to carry out the outburst simulation experiment on the control group GN and experiment group GR for 6 times and 5 times, respectively. The experimenting scheme is seen in Tab. 1, and the nonexplosive gas CO<sub>2</sub> was used to replace CH<sub>4</sub> to conduct the outburst simulation experiment. In addition, the quantity of coal pulled out and quantity

of pulverized coal filled in the soft coal area in each experiment of the experiment group GR were recorded in Tab. 1, and the backfill rate of coal sample in each experiment ranged from 55.53% to 58.33%. Therefore, the coal density in the soft coal area was lower than the surrounding coal density after the filling, and as a result, the coal strength in the soft coal area was lower than the surrounding coal mass.

The outburst simulation experimental process can be described as follows: after the preparation of the specimens, each specimen was outgassed into a vacuum for 48 h; then, CO<sub>2</sub> was injected to reach the desired gas pressure; finally, the specimen was loaded, and the outburst port was opened.



**Fig.2 Location of soft coal area**

**(a) Before filling loose coal; (b) After filling loose coal**

**Tab. 1 Coal and gas outburst simulation experimental scheme**

Experiment group	Moulding pressure (MPa)	Experiment No.	Gas pressure (MPa)	Coal pulled out (kg)	Pulverized coal filled (kg)	Triaxial stress (MPa)		
						$\sigma_z$	$\sigma_x$	$\sigma_y$
GN	48	GN1#	0.20	-	-	2.0	2.0	2.0
		GN2#	0.25	-	-	2.0	2.0	2.0
		GN3#	0.30	-	-	2.0	2.0	2.0
		GN4#	0.35	-	-	2.0	2.0	2.0
		GN5#	0.40	-	-	2.0	2.0	2.0
		GN6#	0.50	-	-	2.0	2.0	2.0
G2	48	GR1#	0.20	4.857	2.791	2.0	2.0	2.0
		GR2#	0.25	4.874	2.758	2.0	2.0	2.0
		GR3#	0.30	4.915	2.803	2.0	2.0	2.0
		GR4#	0.40	4.824	2.814	2.0	2.0	2.0
		GR5#	0.60	4.945	2.746	2.0	2.0	2.0

## 2.2 Experimental results analysis

### 2.2.1 Outburst intensity characteristics

The experiment results showed that the experimental phenomena in the control group GN and experiment group GR included: no outburst, stripping, and outburst, as

shown in Tab. 2. The GN group experienced stripping phenomenon under gas pressure of 0.30 MPa. The coal mass mainly experienced stripping, the formed outburst hole was small, and its depth (direction x) was less than 2.4 cm. The outburst occurred in the GN group in the three experiments under the gas pressure of 0.35 MPa or above, and the relative outburst intensity was increased with the gas pressure.

For the GR group, 14.5 g of crushed coal was found inside the outburst mouth after the GR2# experiment was completed, and the depth of the outburst hole (direction x) was 1.7 cm. The outburst took place in the GR group in the 3 experiments under gas pressure of 0.30 MPa or above. The threshold value of critical gas pressure in the GR group was lower than that in the GN group; the outburst coal amount and relative outburst intensity in all outburst experiments of the GR group were both lower than those in the GN group under the same gas pressure. Especially, the outburst coal amount (3.8035 kg) and relative outburst intensity (21.02%) in the GR5# experiment were both lower than that in the GN6# experiment under gas pressure of 0.5 MPa. However, the outburst coal in the outburst experiments of the GR group could be commonly migrated to a long distance, the maximum throwing distances in the three experiments were all over 16.73 m, reaching as high as 20.10 m.

**Tab. 2 Outburst Simulation Experiment Results**

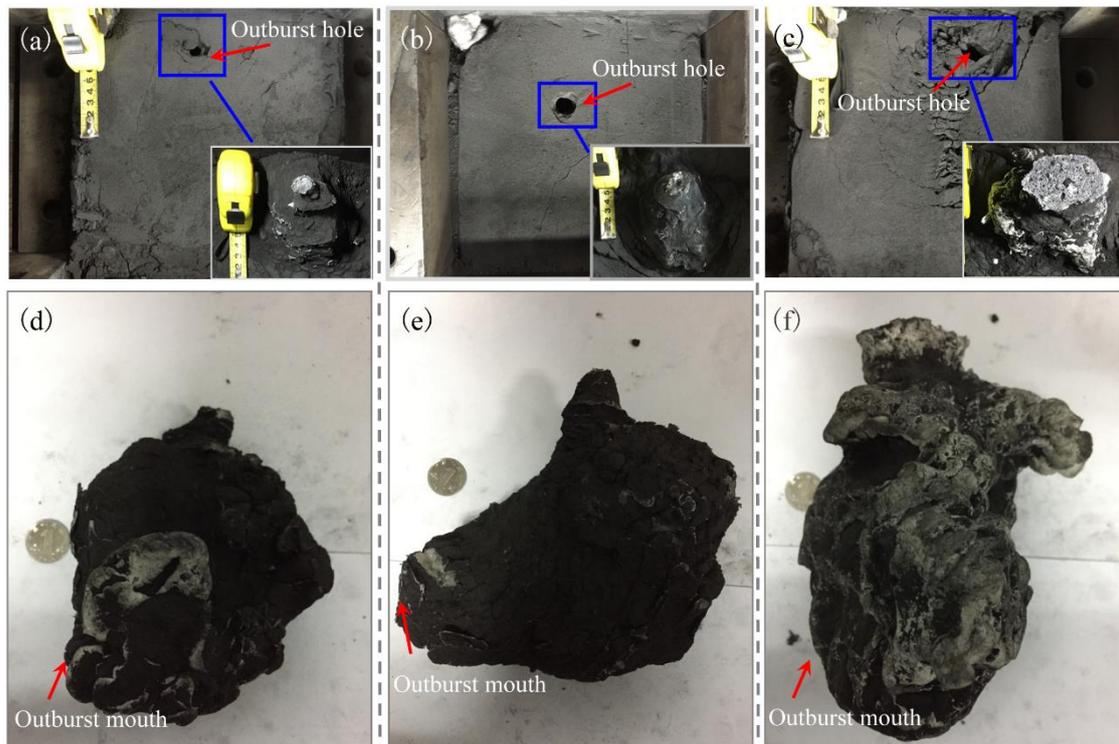
Experiment group	Experiment No.	Outburst phenomenon	Total amount of coal filled (kg)	Outburst coal amount (kg)	Relative outburst intensity (%)	Maximum throwing distance (m)	$V_1$ (cm <sup>3</sup> )
GN	GN1#	No outburst	20.187	0	0	0	0
	GN2#	No outburst	20.254	0	0	0	0
	GN3#	Stripping	20.017	0.0265	0.13	0.31	0
	GN4#	Outburst	19.923	2.9965	15.04	10.65	712
	GN5#	Outburst	20.297	3.8625	19.03	12.81	1128
	GN6#	Outburst	20.462	5.0765	24.81	15.9	1354
GR	GR1#	No outburst	18.123	0	0	0	0
	GR2#	No outburst	18.118	0	0	0	0
	GR3#	Outburst	17.975	2.7355	15.22	16.91	1582
	GR4#	Outburst	17.943	3.2555	18.14	16.73	2464
	GR5#	Outburst	18.091	3.8035	21.02	20.10	1794

Note: Relative outburst intensity was defined as the ratio of outburst coal amount to total amount of

coal filled.

### 2.2.2 Outburst hole characteristics

After the outburst occurred to the GN group, only a small circular hole could be observed above the residual coal mass, but there was a very large space beneath the circular hole. The model of each outburst hole was acquired after filling with polyurethane, as shown in Fig. 3. Most of the outburst hole models were cylindrical or semi-spherical, and the side face of each model was approximate to a spherical shell. According to the positions of outburst mouths marked in the models, the outburst mouth was at the bottom of outburst hole in each experiment, and the hole started continuously inward development from the outburst mouth. Outburst hole development above the outburst mouth was much more obvious than that beneath the outburst mouth, indicating that the outburst hole started from the outburst mouth and gradually developed towards the inclined top. The volume ( $V_1$ ) of outburst hole model shown that the outburst hole model presented an enlarging trend with the increase of gas pressure, as seen in Tab. 2.

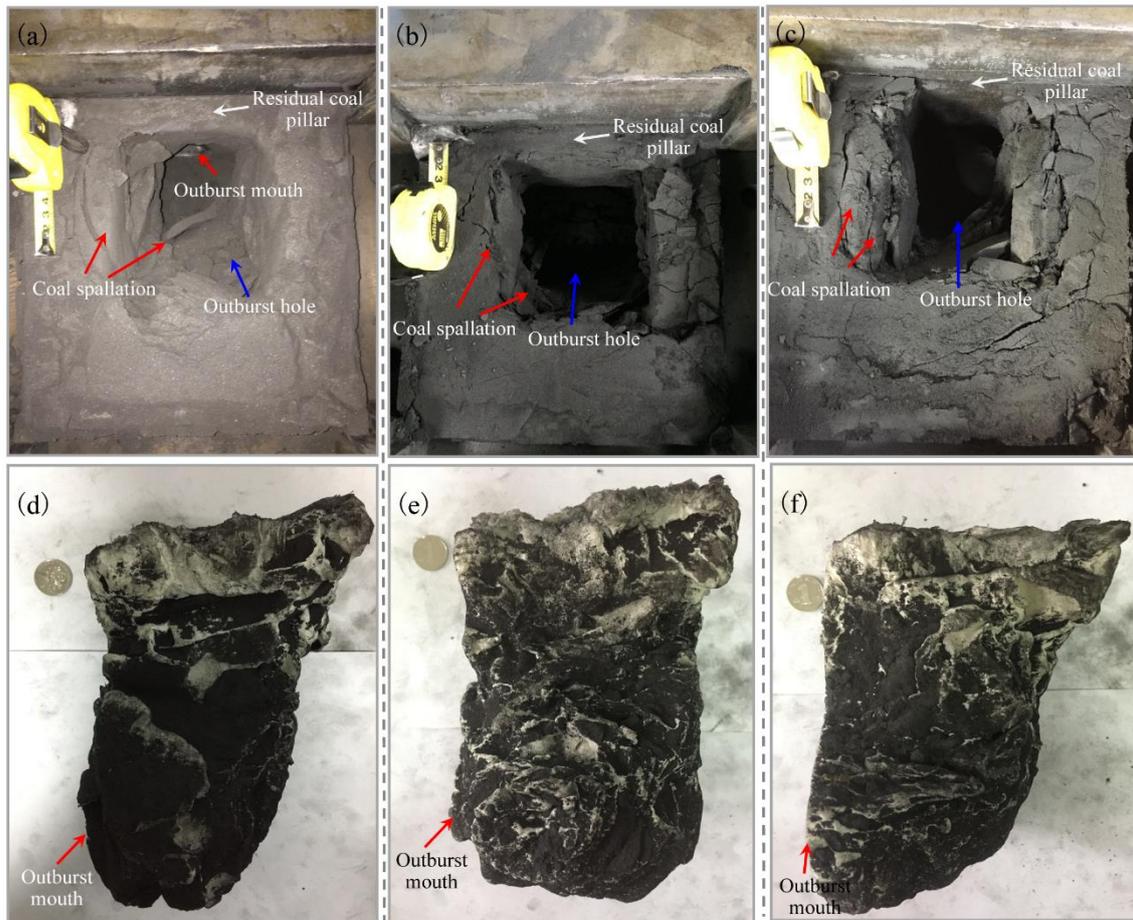


**Fig. 3 Outburst holes and models in GN group**

**(a)-(c) holes in GN4#- GN6# experiments; (d)-(f) hole models in GN4#- GN6# experiments**

The outburst holes and hole models in the GR experiment group are shown in Fig.

4.



**Fig. 4 Outburst holes and models in GR group**

**(a)-(c) holes in GR3#- GR5# experiments; (d)-(f) hole models in GR3#- GR5# experiments**

When the gas pressure was 0.30 MPa, the outburst mainly took place in the soft coal area, and the thrown coal was mainly loose pulverized coal in the soft coal area. The outburst coal amount (2.7355 kg) was smaller than the amount (2.803) of pulverized coal filled, indicating that a part of loose pulverized coal did not participate in the outburst process under this gas pressure. The outburst influenced the normal coal mass around the soft coal area, and the normal coal mass experienced spallation within a small range around, but they kept a high integrity. Furthermore, the coal pillar (thickness: 2.0 cm) between the soft coal area and front wall of experiment cavity underwent a failure only nearby the outburst mouth, and it basically kept the status quo above the specimen.

Under the gas pressure of 0.40 MPa, the outburst hole was mainly located in the soft coal area, but the size of outburst hole model under this pressure was obviously

larger than that under 0.30 MPa. Comparison of outburst coal amount (3.2555 kg) with amount (2.814 kg) of pulverized coal filled in the experiment, the coal mass around the soft coal area also took a part in the outburst under this gas pressure. Observing the failure of coal mass around the soft coal area, the surrounding coal mass suffered obvious failure under this gas pressure, spallation structures were formed, but most of them were fractured. The coal pillar 2 cm in thickness was not completely damaged, and the coal pillar above the specimen basically stayed the same.

However, the outburst phenomenon became more violent under gas pressure of 0.60 MPa, and more coal masses around the soft coal area suffered the outburst. The coal mass around the hole was seriously damaged, and the formed spallation structures were fragmented with high degree of damage; the outburst hole experienced evident shrinkage due to loosening and forward movement of surrounding coal mass. The coal pillar 2 cm in thickness was totally damaged, and there was no residual coal pillar in front of the outburst hole. According to the outburst hole models in 3 experiments recorded in Fig. 5 (d)-(f) and the hole volumes listed in Tab. 2, the outburst hole ( $V_1 = 2464\text{cm}^3$ ) under gas pressure of 0.40 MPa was larger than that ( $V_1 = 1582\text{cm}^3$ ) under 0.30 MPa, indicating that the outburst range was enlarged with the increase of gas pressure, and more coal masses suffered outburst. The outburst hole ( $V_1 = 1794\text{cm}^3$ ) under 0.60 MPa was smaller than that under 0.40 MPa, which was mainly ascribed to the hole shrinkage under the loosening and forward movement of surrounding coal masses.

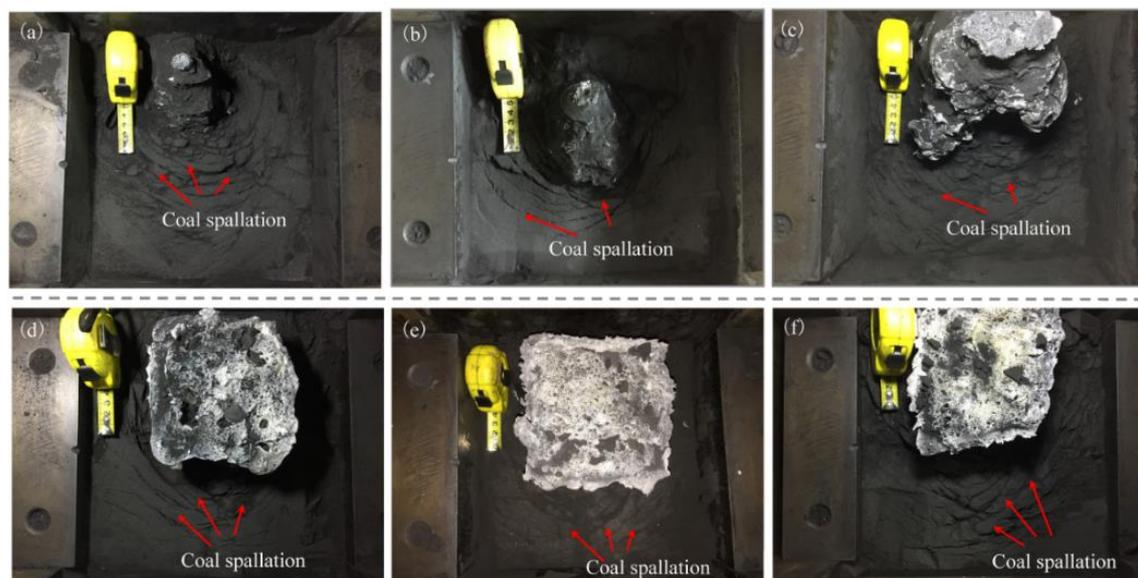
### 2.2.3 Spallation characteristics of outburst coal

Spallation was one of the most obvious characteristics of the coal mass behind the outburst hole (Tu et al., 2017). In the experiments with occurrence of outburst, the upper coal mass was cleared for 6-8 cm, and clear spallation structures could be acquired as shown in Fig. 5. In the experiments of GN group, a great number of arc-shaped cracks approximately parallel to the outburst hole were distributed in the coal mass behind the outburst hole. These cracks segmented the coal mass into spherical shell-like coal flakes with a certain thickness. Multi-layer spallation structures existed in the coal mass behind the hole, and the spallation layers were successively arrayed. In addition, some short cracks, which presented oblique crossing in the spallation structures and cut them

into several segments of coal briquettes, existed in the coal mass.

In the experiments of GR group, the outburst of soft coal led to the spallation of surrounding coal mass. In the GR3# experiment, the spallation structures were concentrated around the outburst hole, and mainly located at the middle of the specimen but not extended to the left and right sides of the experiment cavity. The spallation area was narrow. The formed spallation structures were featured by high integrity and large spallation thickness.

The number of spallation layers and the scope of spallation area were obviously enlarged in the GR4# experiment. The spallation thickness was reduced, and meanwhile, the integrity was relatively high. The spallation phenomenon was more apparent in the G5# experiment, the number of spallation layers was large, and the spallation area was already extended to the rear wall of the experiment cavity. These spallation structures were of small thickness and poor integrity, some were even crushed into several segments, and this crushing phenomenon was especially serious at the right side of the experiment cavity.



**Fig. 5 Spallation characteristics of local soft coal area in outburst experiment**  
(a) GN4# experiment; (b) GN5# experiment; (c) GN6# experiment (d) GR3# experiment;  
(e) GR4# experiment; (f) GR5# experiment

When clearing the coal samples, the experimenter recorded the detailed information, e.g. depth ( $l_x$ ) of outburst hole along direction x, thickness ( $d_1, d_2, d_3, \dots$ ) of each spallation layer, number of spallation layers ( $n$ ), and width ( $l_d$ ) of spallation

area, and acquired the average spallation thickness ( $\bar{d}$ ) by calculating the thickness of each spallation layer. The recorded information and calculation results are seen in Tab. 3. There is a series of quantitative processing to obtain the spallation characteristics. After each outburst experiment, the polyurethane was used to obtain the outburst holes model and fix the coal mass behind the hole at same time. Then, the coal samples were cleaned by layers, and the spallation of each layer was described by using the scale paper. Finally, the scale paper of each layer was used to measure the spallation thicknesses and numbers.

**Tab. 3 The thickness of coal spallation for experiment groups GR and GN**

No.	Spallation thickness													$\bar{d}$
	$d_1$	$d_2$	$d_3$	$d_4$	$d_5$	$d_6$	$d_7$	$d_8$	$d_9$	$d_{10}$	$d_{11}$	$d_{12}$	$d_{13}$	
GN4#	0.5	0.6	0.6	1.3	1.3	1.3	1.1	1.6	1.5	2.6	-	-	-	1.24
GN5#	0.7	0.9	0.9	1.1	1.3	1.5	-	-	-	-	-	-	-	1.07
GN6#	0.5	0.7	0.9	1.0	1.0	0.9	1.2	1.4	1.5	1.8	-	-	-	1.09
GR3#	1.2	1	0.9	1.5	0.8	1.4	1.9	-	-	-	-	-	-	1.24
GR4#	1.3	1.1	0.9	1.1	1.1	0.9	0.8	1.0	1.1	1.6	-	-	-	1.09
GR5#	0.6	0.6	0.7	0.8	1.2	1.2	1.2	1.3	0.9	0.7	1.9	1.0	1.2	1.02

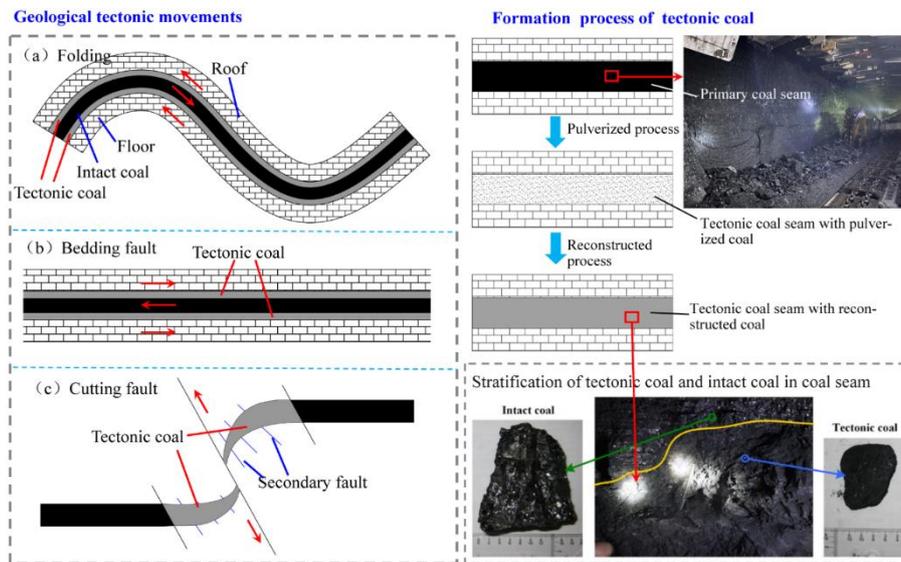
As shown in Tab. 3, the thickness of each spallation layer in the coal mass behind the outburst hole was not constant, but instead, it varied from layer to layer very obviously. The minimum spallation thickness was 0.5 cm, and the maximum spallation thickness could reach 2.6 cm. However, the spallation thickness data could still reflect some laws, namely the spallation thickness close to the outburst hole in each experiment was thin, and those with the maximum thickness were mostly the last layers. For example, the thicknesses of the first 3 spallation layers in the 6 outbursts of GN group and GR group were basically smaller than 1.0 cm. The number of experiments where the spallation layer with the maximum thickness was the last layer was 5, and the layer with the maximum spallation thickness in the rest 1 experiment was located at the 3<sup>rd</sup> layer. In addition, the average spallation thicknesses in different experiments of the same group presented a declining trend with the increase of gas pressure.

### 3 Discussion

#### 3.1 Geological genesis of soft tectonic coal

The soft tectonic coal is the product generated when the original coal measure strata undergo geological tectonic movements (Ju et al., 2005). Soft tectonic coals are

distributed at the coal seams in many typical mining areas (Lei et al., 2010). However, the tectonic coal has more complicated physical structure than primary coal due to different tectonic geneses and degrees (Ju et al., 2004). Wang et al. (2009) divided tectonic coal into 8 subtypes according to its morphological structural characteristics. As a whole, the tectonic coal is reconstructed coal cemented by bulk coal. Tectonic cracks are densely developed in this type of coal, with an increasing number of microcracks, while large-scale tensile cracks and shear cracks are sparsely developed (Cheng and Pan, 2020).



**Fig. 6 Physical structural transformation of primary coal seam by tectonic movement**  
(Cheng and Pan, 2020)

The distribution form of tectonic coal in the coal seam is related to the type of tectonic movements it experiences as shown in Fig. 6. The coal mass can be repeatedly rubbed due to folding and bedding fault, and as a result, tectonic coals are extensively distributed in the coal seam in the form of regional distribution or layered distribution (Li et al., 2011). During the formation process of normal and thrust faults, the hanging wall and footwall repeatedly rub each other under the action of tectonic stress. With the derivation of secondary faults around the faults, the coal mass nearby the fault planes will be crushed to form a local soft tectonic coal area.

E.g. on November 21, 2009, an especially serious outburst accident took place in Xinxing Coal Mine in Heilongjiang Province. This outburst was a typical outburst accident controlled by tectonic movements, as shown in Fig. 7. Influenced by the

densely distributed large, medium, and small faults in the area, the coal seam in the area and rock strata on roof and floor underwent the occurrence change, the rock strata on roof and floor were crushed, and the coal seam was highly crushed and even pulverized.

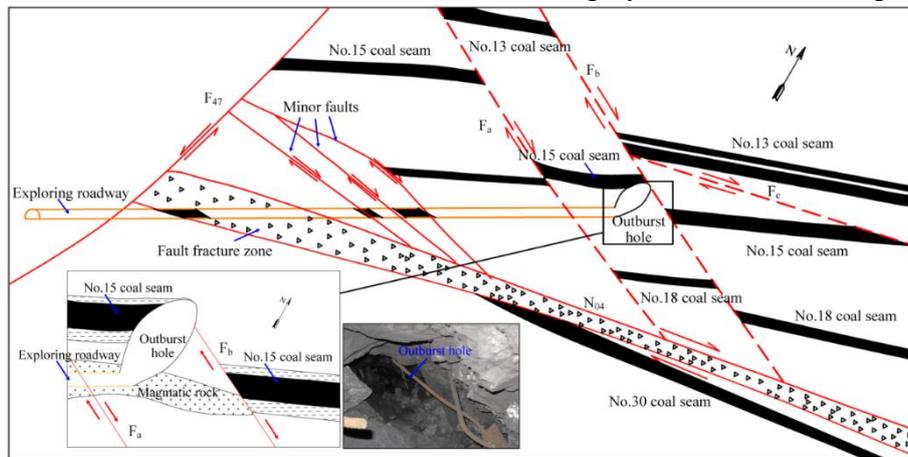


Fig. 7 Geological structural distribution in No. 15 coal seam exploring roadway

### 3.2 Guiding action mechanism of tectonic coal on outburst

#### 3.2.1 Influence of local soft coal area on outburst

The density distributions of outburst potential energy and energy consumption in coal mass before the exposure were analyzed to investigate the guiding effect of local tectonic coal area on outburst. In view that the difference of the coal in the soft coal area from that in the surrounding normal area mainly lies in the coal strength, followed by the differences in stress and gas. The change of coal stress energy and gas energy is neglected in the analysis of outburst potential of coal mass, while the emphasis is laid on the reduction of outburst energy consumption due to reduction of coal strength. According to the experiment results of control group (GN group) and experiment group (GR group), the density distributions of outburst potential energy and energy consumption in coal mass are presented in the form of Fig. 8, where A represents coal mass in normal area, and C is coal mass in the soft coal area.

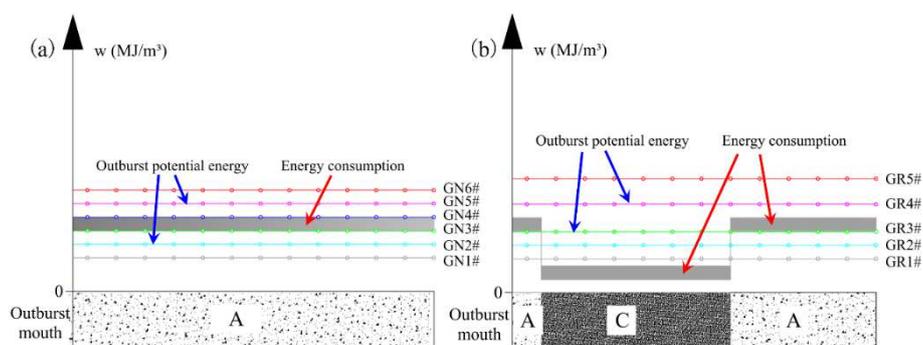


Fig. 8 Schematic diagram of the density distributions of outburst potential energy and

**energy consumption of coal before outburst**  
**(a) GN1#- GN6# experiments; (b) GR1#- GR5# experiments**

As shown in Fig. 8, comparison with the experiments in the control group (GN group), the existence of soft coal area changed the density distribution of outburst energy consumption before the outburst. The outburst energy consumption in the coal mass in the soft coal area was much lower than that in the coal mass in the surrounding normal area. Therefore, an area with low outburst energy consumption was formed in the soft coal area as shown in Fig. 8 (b).

The experiment results showed that when the gas pressure was 0.25 MPa, a small quantity of crushed coal was found in the outburst experiment (GR2#) containing the soft coal area, the depth of the formed hole was 1.7 cm, and the coal pillar 2.0 cm in thickness was not exposed yet. Under the gas pressure of 0.30 MPa, the outburst took place in the outburst experiment (GR3#), it mainly happened in the soft coal area. Part of loose pulverized coal was left over, and the 2.0 cm coal pillar reserved at front of the soft coal area underwent a failure only nearby the outburst mouth. While, only a small quantity of coal mass was stripped off in the GN3# experiment, and the depth  $l_x$  of formed hole was 2.4 cm.

Furthermore, the outburst happened in the experiments containing soft coal area (GR4#~GR5#) or the control experiment (GN5#~GN6#) when the gas pressure was greater than or equal to 0.40 MPa. The coal mass in the surrounding normal area also experienced the outburst, where the reserved coal pillar was completely damaged in the GR5# experiment. It could be found that the coal pillar needed to be reserved to cope with the coal outburst in the soft coal area; when the coal pillar was exposed, the sealing effect of the coal pillar disappeared, and outburst in the soft coal area occurred.

### 3.2.2 Guiding effect of tectonic coal on outburst

During the formation process, the soft tectonic coal was already completely crushed or pulverized under the effect of tectonic stress, and the energy consumed by secondary coal failure in the outburst process was very low. The soft tectonic coal area changed the distribution of outburst energy consumption in the coal mass, and the outburst energy consumption in the area was reduced to a great extent.

The outburst development sequence is changed due to the existence of the soft tectonic soft area. Once the sealing condition before the soft tectonic coal area was

damaged, the area would be suddenly exposed, the outburst would happen in the coal mass in this area even under low outburst energy, and it firstly took place in this area.

When it developed to the edge of the area, if the residual outburst energy was enough to overcome the outburst energy consumption of surrounding coal mass, the outburst would continue to develop towards the surrounding coal mass. However, the great outburst energy contained in the coal mass would be released during the outburst process of the soft tectonic coal area. Consequently, with enough energy, the coal mass in the soft tectonic coal area could be transported to a longer distance, and the residual outburst energy could only contribute to the outburst of a small quantity of coal masses in the normal area.

In a word, the physical structure characteristics of soft tectonic coal determine that the energy consumed by secondary coal failure in the outburst process is very low. The soft tectonic coal area changed the distribution of outburst energy consumption in the coal mass, and the outburst energy consumption in the area was reduced to a great extent. Therefore, the outburst development sequence is changed due to the existence of the soft tectonic soft area.

#### **4 Conclusions**

Soft tectonic coal commonly exists in outburst zones. The soft tectonic coal changes the outburst starting and development sequence are studied in this paper, and the main conclusions are summarized as follows:

1) Comparison with the experiments in the GN group, the amount of outburst coal and relative outburst intensity in the experiments of GR group are relatively lower. The outburst coal amount (3.8035 kg) and relative outburst intensity (21.02%) in the GR5# experiment were both lower than that in the GN6# experiment. However, the outburst coal in the experiments of GR group could be commonly migrated to a long distance, the maximum throwing distances in the three experiments were all over 16.73 m, reaching as high as 20.10 m.

2) Under the gas pressure of 0.30 MPa in the experiments of GR group, the outburst coal amount (2.7355 kg) was smaller than the amount (2.803 kg) of pulverized coal filled. The 2.0 cm coal pillar experiences failure only nearby the outburst mouth, and intact spallation appears in the small-range coal mass around the soft coal area. As

the gas pressure increases, more and more surrounding coal masses undergo the outburst phenomenon, the failure degree of the coal pillar becomes higher and higher until complete failure, and the spallation phenomenon of surrounding coal masses becomes more obvious.

3) Influenced by the tectonic stress in the formation process, the soft tectonic coal is already completely crushed, and the energy consumed by the secondary failure of this coal in the outburst process is very low. The soft tectonic coal area changes the distribution of outburst energy consumption in the coal seam, and the outburst energy consumption in the area is reduced by a large margin. Once the sealing conditions before the soft tectonic coal area are destructed, the outburst can be triggered to the coal mass in the area even under low outburst energy.

4) The soft tectonic coal induce the change of outburst starting and development sequence. The outburst firstly develops in the soft tectonic coal area, and when it develops to the edge of the area, if the residual energy is sufficient to overcome the outburst energy consumption of surrounding coal mass, the outburst will continue to develop towards the surrounding coal mass. With enough energy, the coal mass in the soft tectonic coal area could be transported to a longer distance, and the residual outburst energy could only contribute to the outburst of a small quantity of coal masses in the normal area.

Obviously, extensive research attentions shall be paid to geological factors of outburst, and it is necessary to carry out further systematic studies.

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