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EFFECT OF MAGMA INTRUSION ON COAL GAS OUTBURST INDEXES IN CHINA

Liang Wang, Yuanping Cheng, Jingyu Jiang, Shengli Kong, Haina Jiang, Xiaolei Zhang

ABSTRACT: Numerous coal and gas outburst disasters in China were caused by magma intrusion. Several outburst accidents show that the affected region of magma intrusion is the key area with abnormal gas occurrence and gas outburst disasters. The intrusive igneous rock's occurrence, lithology and distribution form have an important impact on outburst indexes. Laboratory tests and field experimental research, analysed coal reservoirs adsorption characteristics under the function of high temperature pyrolysis and metamorphism caused by layered magma intrusion, and revealed internal relations between coal seam adsorption characteristics and outburst indexes, which were verified in the field. The results showed that under the additive effects of pyrolysis and metamorphism, the metamorphic degree of the coal seam got higher the closer the distance to the igneous rock, the adsorption characteristics of the metamorphic coal were positively correlated with gas outburst indexes. When the magma layer eroded the coal seam, along with the distance from the igneous rock, gas outburst indexes increased first, then decreased. When the layered magma intruded into the coal seam roof, coal seam gas was trapped by igneous rock, and gas outburst indexes were commonly higher, which decreased with the distance away from the igneous rock. When the layered magma intruded into the coal seam floor, the effect of high temperature pyrolysis was the strongest, and the gas outburst indexes were determined by the lithological characters of the roof.

INTRODUCTION

During the lengthy geologic history, magma action is quite frequent in China. Especially since the Yanshan movement in Mesozoic, crustal movement in eastern China became more intense, and magma action got more widespread. The magma intrusion provides a high temperature and high pressure environment for coal seams, which promotes the thermal evolution of coal seams, making low rank bitumite change to katogene metamorphism under the baking of magma, and speeding up the formation of gas, and bringing huge changes in metamorphism of coal, pore structure, adsorption-desorption characteristics, and coal structure.

Numerous coal and gas outburst disasters in China were caused by magma intrusion, in such mining areas as Hebi, Zhengzhou, Yaojie, Huaibei, Huainan, Hegang. Several outburst accidents show that the affected region of magma intrusion is the key area for abnormal gas emission and outburst accidents. There are two main types of occurrence of magma in China: dyke and sill. The dyke, formed by magma penetrated coal-rock mass through faults or fissures as flowing channels, is the vertical or skew intrusion with coal-rock bedding. The sill, formed by magma intruded into the roof, or the floor, even the coal seam through the bedding planes, are widely distributed in China, which can cause heavy damages to the coal seam in different shapes (Zhang, 2008). The size of magma, the intrusion place, the shape of magma, the structure of coal and coalfield, and such other factors could control the physical properties and characteristics of coal, gas occurrence and gas outbursts.

Scholars at home and abroad have done a lot research on the coal quality change, in the metamorphic aureole zone intruded by magma, Qin and Xu (1984); Yuan (2000); Wang and Zhang (2006); Liu *et al.* (2007); Shen (2008); Fredericks *et al.* (1985); Stewart *et al.* (2005); Dai and Ren (2007); Saghafi *et al.* (2008); Susan *et al.* (2009). They analysed the degree of coal metamorphism by using proximate analysis, elemental analysis, microscopic coal petrology characteristics and some other chemical process indexes, and considered that large quantities of volatile components and pressure caused by the coal thermal decomposition process would deteriorate the coal quantity. Golab and Carr (2004) compared the inorganic components of normal coal and the coal near the magma dyke in Australia's Dartbrook Coal Mine. They found that metamorphic coal was rich in inorganic elements, mainly silicon aluminates, which could be used as a guidance to evaluate the affection scope of magma metamorphic

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aureole. Raymond and Murchison (1988) found that during the coal-forming, the degree of coal compaction and the water capacity of pore had a great impact on the metamorphic grade of coal intruded by magma. The lower the maturity and compaction, the less metamorphism action on humid coal. Wang *et al.* (2008) simulated the baking effect on coal seam produced by the tectonic-heat events by using a pyrolysis analyser, the results showed that the number and dimensions of pore in coal rock increased obviously after thermal baking. Gurba and Weber (2001), Saghafi *et al.* (2008) found that, gas adsorption capacity, porosity, gas content and gas diffusion rates would correspondingly increased with the enhanced metamorphic degree of coal caused by magma intrusion, and the generating gas was stored in coal seams which were trapped by the igneous rock.

Based on geology research on gas emission sites recently, magma intrusion always caused gas outburst indexes to exceed critical values, such as the initial gas releasing rate Δp and the coal sturdiness coefficient f , and to produce gas and CO_2, all of which increased the possibility of coal spontaneous combustion and gas outburst accidents (Golab and Carr, 2004). Gas emission intensity near intrusive igneous rock usually greatly increased, especially when the permeability of igneous rock was low, which made a large quantity of the generating gas trapped, and greatly increased gas pressure and gas content (Saghafi, *et al.*, 2008; Golab and Carr, 2004).

Nowadays, it could be found that the magma intrusion researches were mainly focusing on coal quality change, porosity evolution, and so on. The adsorption characteristics, variation of gas outburst indexes and the relation among the gas parameters were not discussed in detail, and the gas outburst index data measured in field and laboratory with pertinence were short, which result ed in that we were unable to master gas occurrence law in magma intrusion area.

The distribution of sills is widespread in China, and the sill intrusion contributes to the damage to coal seams. By laboratory tests and field experimental research, coal reservoirs adsorption characteristics under the function of high temperature pyrolysis and metamorphism caused by layered magma intrusion were analysed.

REGIONAL STRUCTURE EVOLUTION AND MAGMA INTRUSION CHARACTERISTICS IN HUAIBEI COALFIELD

There is an affinity between magma action and geological structure, especially the fracture structure that plays a controlling role in the distribution of a magma intrusion. Magma is a viscous lava, and it always moves to the direction of least pressure in the tectonic stress field. Tensional and wrench fractures with a good opening and small lateral pressure are beneficial to magma intrusion (Zhang, 2008). Coal is a macromolecular compound mainly consisted of carbon, hydrogen, oxygen and nitrogen. It has a low melting point and poor chemical stability, and is easily dissolved when heated, while the magma always intrudes along coal seams. Generally, magma intrudes along faults, and diffuses uphill into the coal seam.

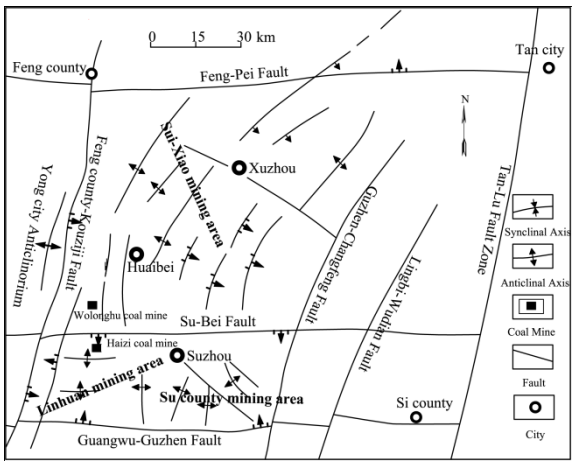
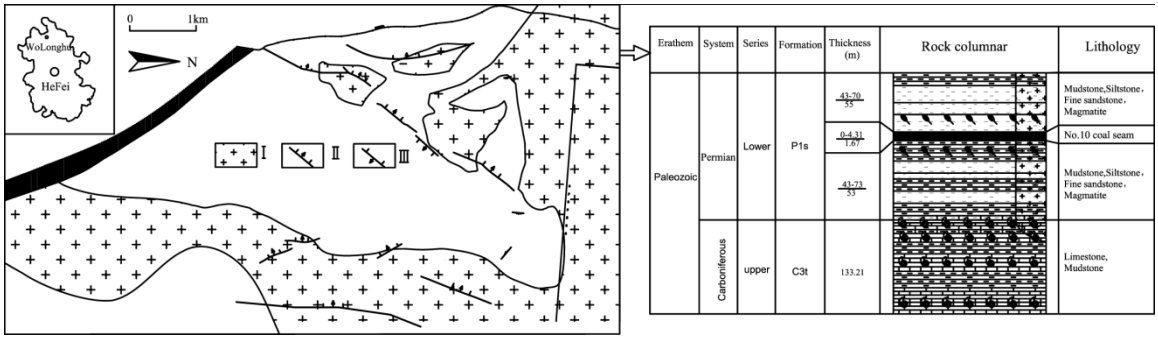


Figure 1 - Regional structure outline of Huaibei coalfield (Modified according to Shi *et al.*, 2007)

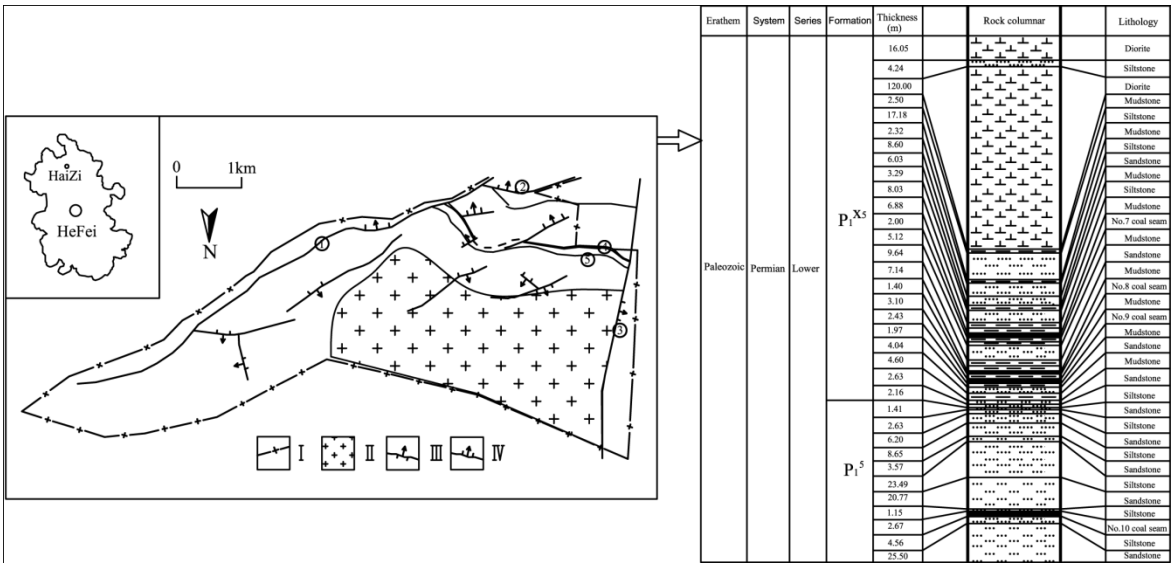
Test sites are in the central and south of Huaibei coalfield, which is located in the Xu-Huai sag in the southeast of the north China plate, and is adjacent to the east side Tan-Lu fault zone, clamping in

Feng-Pei and Bengbu apophysis with a nearly east-west trend. The place is at the end of the large region relating to the Subei fault in neighboring area, to the north of the Taihe-Wuhe fault, to the east of Feng-Wo fault and to the west of Guzhen-Changfeng fault, which is covered by Quaternary strata, which was shown in Figure 1 (Wu *et al*., 2009). Under the influence of Indosinian Movement and Yanshan Movement, the Paleozoic deposition of Huaibei was wrinkled, uplifted, broken and denuded (Yang, 1996), the Permian coal seam formation in the zone had experienced a complex tectonic evolution, and had received a second strong metamorphism by magma action since the Dabie-Sulu mountain building.



I —Intrusion area; II —Reverse fault; III —Normal fault

Figure 2 - Magma distribution and rock profile of No.10 coal seam in Wolonghu Coal Mine



I —Mine border; II —Intrusion area; III —Reverse fault; IV —Normal fault

Figure 3 - Magma distribution and rock profile in Haizi Coal Mine

The Huaibei mining area formed a series of drapes and fractures along NNE trend in the Yanshan Period, and extrusion was the main form, meanwhile a large-scale magma intrusion action happened. In this period, the magma, which intruded along the Subei fault up into the hanging wall and footwall, intruded the Linhuan mining area southward and the Suixiao mining area northward (Xu,1986). The Wolonghu Coal Mine is located in the west edge of Xusu arcuate structure, on the east side of the Kouziji fault in Feng county, on the north side of the Zhaozhuang anticline, and on the south side close to the Subei fault. Magma action is very universal from the No.2 coal seam to No.C3, and much intrusion is layered along the coal-rock bedding. The intrusion case of the No.10 coal seam is shown in Figure 2. Haizi Coal Mine is located between the NW trend fault (Subei fault and Guangwu-Guzheng fault) and the NE trend fault (Taihe-Wuhe fault and Guzhen-Changfeng fault), and in the northwest of the Tongting anticline. The magmatic rock is distributed as a sill which intrudes along the No.5 coal seam in the middle and western part of the mine, which is called the extremely thick igneous rock (Wang, *et al*., 2008; Wang, 2009; Wang, *et al*., 2010). The length of its strike is 6.5 km and the trend length is about 140 km. The distance in height between the No.10 and 9 coal seams is 84 m on average, and the No.7 coal seam is 115 m above the No.10 coal seam, which in turn, is 55 m above a 120 m extremely thick igneous rock. The extremely thick

igneous rock is distributed in a stable condition in the II102 mining area above the No.7 coal roof; its thickness is usually more than 120 m. The magma distribution and rock profile is shown in Figure 3.

EXPERIMENTAL METHODS AND SAMPLING

Test parameters

The adsorption capability testing of coal is based on gas adsorption theory, usually the gas adsorption constants (*a, b*) are used to measure the gas adsorption capacity. Adsorption constant (*a*) is the extreme gas adsorption quantity, and its value reflects the maximum gas adsorption capacity. The adsorption constants (*a, b*) of the coal sample are measured by using the HCA (High Capacity Method).

Gas outburst indexes are significant indicators of coal and gas outburst tendency, such as the initial gas releasing rate Δp and coal sturdiness coefficient *f*. The initial gas releasing rate Δp indicates the speed of gas emission, which is related to gas content, porous structure and pore surface properties, and is measured by velocity of gas diffusion in the WT-1 type measuring instrument. Its critical value is 10mmHg in China. The coal sturdiness coefficient *f* reflects the physical and mechanical properties of coal seams. The greater the coefficient, the more likelihood outbursts occurring. In China, the dropping hammer method is adopted to measure the sturdiness coefficient, and its critical value is 0.5.

Coal industrial analysis includes the measurement of moisture, ash content, volatile content and carbon. It is measured by using the 5E-MAG6600 type automatic industry analyser. Coal industrial analysis could master the industrial quality and component of coal seams, which can also reflect the degree of coal seam metamorphism by volatile content.

Distribution of sampling locations

In order to research the metamorphism, adsorption characteristics and variation law of gas outburst indexes of the coal under the action of magma intrusion, continuous samples from the magma intrusion region are needed. The samples of Wolonghu Coal Mine were taken from 102 working face in the No.10 coal seam, where 6 samples were taken from the magma intrusion region to the normal region along 102 intake airflow roadway, which was shown in Figure 4. As magma intruded along the No.5 coal seam in Haizi Coal Mine, the samples were continuously taken from No.7, 8, 9 and 10 coal seams under the extremely thick igneous rock. Two samples were taken respectively from the No.7, 8 and 10 coal seams, and only one sample was taken from the No.9 coal seam, as it was near from the No.8 coal seam and they intercepted. Meanwhile, one sample was taken from the normal region in the No.10 coal seam in order to carrying on the comparative experiment.

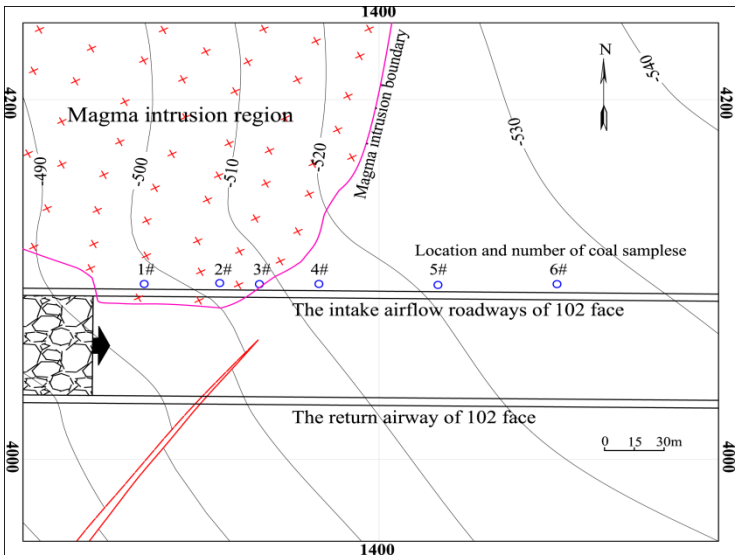


Figure 4 - Magma intrusion border and the distribution of sampling locations in No.10 coal seam of Wolonghu

TESTING RESULTS

Related parameters were determined in the laboratory of National Engineering Research Center of Coal Gas Control, China University of Mining and Technology, and the results were shown in Tables 1 and 2. In order to analyse the relationship of the coal metamorphism characteristics, gas adsorption characteristics and gas outburst indexes at different distance away from the magma intrusion area analysis contrast charts were established. In the charts the distance away from magma intrusion region was the abscissa and the coal volatile content (V_{daf}), the adsorption constant (a), initial gas releasing rate (Δp), and the coal sturdiness coefficient (f) were y-coordinates. The testing results of Wolonghu Coal Mine are shown in Figure 5 and results of Haizi Coal Mine are shown in Figure 6. The samples of Wolonghu were taken along 102 intake airflow roadway, and the elevation did not largely change and its influence wasn't considered. Two samples were taken from each coal seam under the extremely thick igneous rock in Haizi Coal Mine. Because the action of the igneous rock occupied the dominant position, during processing the date in Table 2, we took the average value of the two samples in the same coal seam for analyzing. At the same time, we tested the sample from the non-igneous rock covered region at the same elevation in the No.10 coal seam for comparison purposes.

Table 1 - Continuous coal samples testing results of No.10 Coal Seam from 102 intake airflow roadway

Sample number	Coal seam	Distance away from magma intrusion	Elevation /m	Adsorption constant (a) /m^3/t	Adsorption constant (b) /MPa^{-1}	Δp /mmHg	f	Industrial analysis			
								M_{ad}/%	A_{ad}/%	V_{daf}%	Fc_{ad}/%
1#	10	60m in the intrusion region	-497	16.0627	0.1958	1.6	0.76	2.49	42.42	4.20	50.89
2#		20m in the intrusion region	-503	35.9952	0.9339	3.0	0.80	4.98	34.17	7.11	53.74
3#		boundary of magma intrusion	-506	26.2635	0.0939	11.0	0.57	1.89	40.32	8.42	49.37
4#		30m from the boundary	-510	56.5327	1.6021	30.8	3.00	3.62	36.89	7.82	51.67
5#		90m from the boundary	-520	59.0229	1.5674	40.0	2.40	4.25	32.63	8.23	54.89
6#		150m from the boundary	-530	47.0921	1.3671	30.0	2.80	3.86	21.50	7.74	66.90

Table 2 - Testing results of the samples taken from the No.7, 8, 9 and No.10 coal seam in Haizi Coal Mine

Sample number	Coal seam	Distance away from magma intrusion	Elevation /m	Adsorption constant (a) /m^3/t	Adsorption constant (b) /MPa^{-1}	Δp /mmHg	f	Industrial analysis			
								M_{ad}/%	A_{ad}/%	V_{daf}%	Fc_{ad}/%
9#	7	55	-530	40.6800	1.0560	40	0.38	2.68	38.75	7.32	51.25
10#			-280	46.8459	1.0313	48	0.235	2.54	19.82	10.63	67.01
11#	8	79	-554	35.7932	1.3657	32	0.22	2.57	20.46	8.65	68.32
12#			-422	33.8680	1.1746	29	0.29	0.96	21.83	9.36	67.85
13#	9	84	-560	35.0500	1.0100	27	0.41	1.60	21.05	9.45	67.90
14#	10	170	-633	26.8075	1.1497	19	0.20	1.96	11.36	13.74	72.94
15#			-643.3	31.6753	1.0432	26	0.17	0.83	11.58	15.49	72.10
16#		Non-igneous rock covering	-630.0	19.3298	0.8713	9	0.41	0.79	9.07	19.67	70.47

ANALYSIS OF TESTING RESULTS

The affect on coal rank of magma intrusion

When magma intrudes into the coal seam, the coal seam lies in a high temperature and high pressure environment, under the effects of contact and regional thermal metamorphism, the coal molecular composition will change, and the condensation degree of aromatic thickening rings increases rapidly. The side chain of alkyl and oxygen containing functional groups exfoliates and decomposes, the volatile content of coal is reduced, vitrinite reflectance increases, and the metamorphic grade of coal improves. Metamorphic grade of coal is related to the distance with the intrusion region. When magma intrudes along coal seam bedding, contact and regional thermal metamorphism make the coal seam change to be natural coke, natural char and super anthracite coal. Over a distance, it could divide into several zones

according to the metamorphic grade, from near to far away from the intrusion region. These zones were described as natural coke zone - anthracite coal and other contact metamorphism coal zone-normal coal zone (Guo, *et al.*, 2007). Coal quality depends on the size of the igneous rock and the rock layer thickness between the coal seam and the igneous rock, which determines the degree of coal metamorphism and the distribution area. The relationship between the size of igneous intrusion and the volatile content variation is shown in Figure 7 (Zhao,1978), which showed that for the thicker igneous rock and the smaller thickness of rock layer between the igneous rock and the coal seam, the volatile content got lower, and, the coal metamorphic grade became higher.

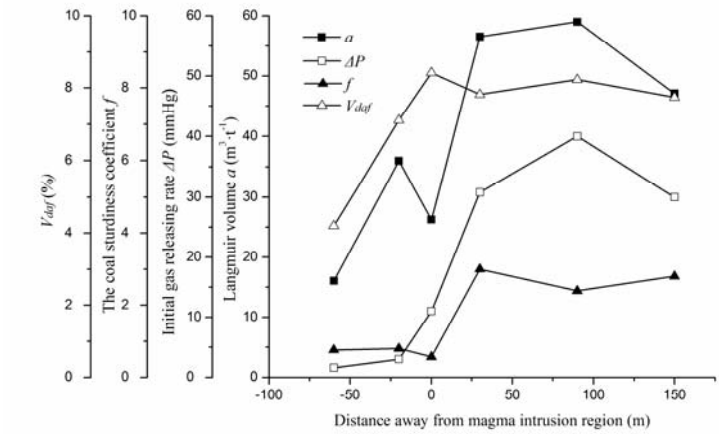


Figure 5 - Variation relation among the coal volatile content, the gas adsorption constant and outburst indexes of the samples taken from Wolonghu Coal Mine

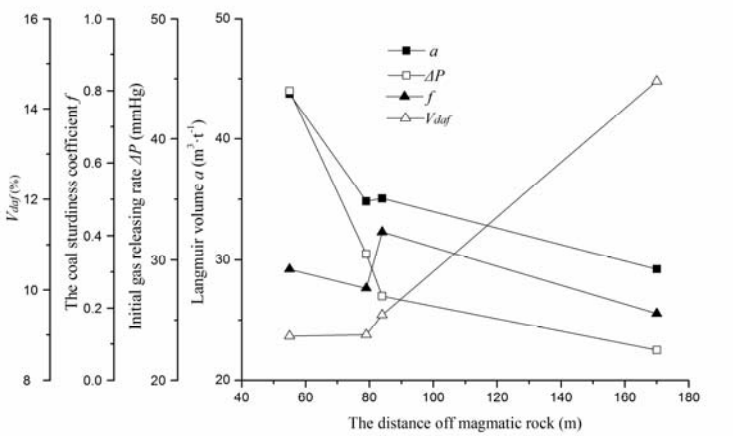


Figure 6 - Variation relation among the coal volatile content, the gas adsorption constant and outburst indexes of the samples taken from Haizi Coal Mine

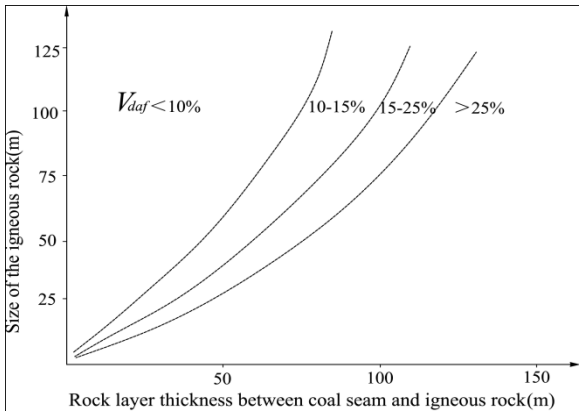


Figure 7 - Variation curves of V_{daf} with rock bed thickness and distance between rock bed and coal seam in certain coal mine

As shown in Figure 5, it was found that at the position of 60 m inside intrusion region, the coal volatile content was only 4.2%, and the coal was anthracite coal. From contact metamorphic zone to normal zone, the volatile content increased, but was less than 10% on the whole, which indicated that the coal was still in the anthracite stage. The metamorphic region was broad, which surpassed the boundary of 150 m in plane.

As shown in Figure 6, it can be seen that the volatile content of the No.7, 8, 9 and 10 coal seams gradually increased with the distance away from the igneous rock, the metamorphic grade of middle coal seam groups were deeper than the No.10 coal seam. The No.10 coal seam was lean coal while the corresponding middle coal seam groups were almost anthracite coal. From the testing results of the No.10 coal seam in Table 2, it was found that the No.10 coal seam with non-igneous rock covering was coking coal with a lower metamorphic grade, which proved that the high-temperature thermal baking effect of extremely thick igneous played a dominant role on coal quantity in the Haizi Coal Mine.

Affection on coal adsorption characteristics of magma intrusion

From a large accumulation of adsorption experimental data, it was found that there was no single value relationship between coal adsorption and metamorphic grade. But there was a general trend that the coal adsorption quantity of gas increased with the improving of coal metamorphic grade under the same gas pressure. It can be seen from Figure 5 that the adsorption constant (*a*) of super anthracite coal in the contact metamorphic aureole of Wolonghu Coal Mine was small, and the adsorption capacity of coal samples were the biggest in the transitional zone, and with increasing distance away from the intrusion boundary, the adsorption constant (*a*) declined on the whole. In Figure 6, the relation of the adsorption constant (*a*) and metamorphic grade changed correspondingly, namely the shorter the distance between the coal seam and the igneous rock, the higher the metamorphic grade of coal, and the stronger the adsorption capacity. Meanwhile, it was found that the adsorption capacity of the No.10 coal seam with non-igneous rock covering was far smaller than the coal under the extremely thick igneous rock in Tab.2. The high baking temperature increased the coal metamorphic grade and the number of micro-pores, and gas absorption capacity of the coal seam was enhanced which improved the capacity for gas storage.

Affection on coal gas outburst indexes of magma intrusion

Generally, the coal and gas outburst disasters happen in the soft coal seam which is called "tectonic coal" (Yu, 1992). The outburst coal seam has the following features: the mechanical strength is low and changes quickly, the permeability and humidity are low, the initial gas releasing rate is high, and the coal bedding is disturbed and broken by geological tectonic force. According to Figure 5, when magma intruded into the coal seam, the total coal seam would become natural coke, and the coal was broken in the metamorphic aureole, fractures developed and the coal sturdiness coefficient (*f*) was lower than the normal one. According to Figure 6, the coal sturdiness coefficients (*f*) caused by the high temperature baking under the extremely thick igneous rock were all lower than outburst critical value (0.5). The soft coal seams were often broken and presented the typical characteristics of "tectonic coal". Meanwhile, from Figure 5 and Figure 6, it was found that the initial gas releasing rate (Δp) obeyed the same variation law with the adsorption constant (*a*). Generally, the coal seam with a large adsorption capacity always had a high initial releasing rate. However, the coal sturdiness coefficient (*f*) did not match the initial gas releasing rate (Δp). Gas outburst accidents in hard coal seams have happened at home and abroad at present, so the combination effect of the gas outburst indexes should be considered to judge the outburst tendency.

Besides, when layered magma intrudes into the coal seam floor, the pyrolysis action is the strongest. The distance away from the igneous rock decides the metamorphic degree. The covering lithology and thickness of overlying strata decides the gas occurrence and outburst index value.

CONCLUSIONS

The geological history of magma intrusion in the central and southern parts of Huaibei coalfield, were analysed by using Wolonghu Coal Mine and Haizi Coal Mine as testing sites. By laboratory tests and field experimental research, coal reservoirs adsorption characteristics and gas outburst index variations under the function of high temperature pyrolysis and metamorphism caused by layered magma intrusion were analysed. The results showed that under the additive effects of pyrolysis and metamorphism, the metamorphic degree of a coal seam increased the closer it was to the igneous rock. The adsorption

characteristics of the metamorphic coal were positively correlated with gas outburst indexes. When the magma layer eroded the coal seam, along with the distance from the igneous rock, gas outburst indexes increased first, then decreased. When the layered magma intruded into the coal seam roof, coal seam gas was trapped by the igneous rock, and gas outburst indexes were commonly higher, which decreased with the distance away from the igneous rock. When the layered magma intruded into the coal seam floor, the effect of high temperature pyrolysis was the strongest, and the gas outburst indexes were determined by the covered strata above the coal seam.

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