Effect and mechanism of geological structures on coal seam gas occurrence in Changping minefield

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Abstract
The main factor affecting the gas content in a coal seam is the geological structure, and different types of geological structure have different effects on the gas content in a coal seam. To explore the main controlling factors of gas content in coal seam No. 3 in the Changping minefield, and the effect of different geological structures on gas control in a coal seam, this study analyzes the types and quantities of geological structures in the Changping minefield. Further, geological boreholes are used to sample and analyze coal seams near different geological structures and at different burial depths. The results show that the main controlling factor of gas content in a coal seam is the burial depth of the coal seam, and the gas content tends to increase with the increasing depth. A geological structure has an effect on the occurrence of coal seam gas in a local area, and the gas content in the coal seam near a fault is 1.6 times that in the normal areas at the same depth. The gas content in the upper wall of a normal fault is 21.6% higher than that in the lower wall. The syncline and anticline axes are prone to form gas accumulation areas, where the gas content is 30%-60% higher than the normal level. Gas accumulation is prone to occur around a collapse column, and the gas content there is 2.47 times higher than that in a normal area at the same burial depth. Combining the formation mechanism and structural characteristics of different geological structures, this study analyzes the effect of geological structures on coal seam gas quantitatively and provides a theoretical basis for the prevention and control of gas disasters in the Changping minefield.

Keywords
Changping minefield, control mechanism, gas content, geological structure

1 | INTRODUCTION
Coal is the most important energy source and chemical raw material in China. Statistics from the National Bureau of Statistics show that in 2018, 59% of China’s primary energy structure was based on coal. The coal mining process is threatened by a variety of disasters, and gas disasters have particularly plagued mine production worldwide for a century. According to statistics, there were 2826 gas accidents in China between 2001 and 2017. Among them, the proportion of gas explosion accidents was approximately 44%, and that of coal and gas outburst accidents was approximately 19%. The casualties from these two disasters were much higher than those caused by other types of mine disasters, and...
they seriously threatened the safety of underground workers and production equipment.\textsuperscript{4,5}

Gas is one of the main products of the coal-forming process. The main geological factors affecting gas content and its distribution are the geological structure and depth, thickness, and surrounding rock of the coal seam. The formation, preservation, migration, and enrichment of gas are closely related to geological conditions.\textsuperscript{6,7} Within the same geological unit, there is a main geological control factor that determines the gas content in the geological unit, whereas other factors lead to the uneven distribution of gas in the unit.\textsuperscript{8,9} The occurrence of coal and gas outburst accidents is closely related to the geostress, gas pressure, and physical and mechanical properties of the coal.\textsuperscript{10} The stress concentration and internal energy of the gas are the energy sources of coal and gas outbursts, and small size, low strength structural coal is the material basis for these outbursts. Near a geological structure, stress concentration and gas accumulation mostly exist, and there is tectonic coal development.\textsuperscript{11-13} When these conditions are available at the same time, coal and gas outburst accidents are easily induced under the strong disturbance of mining activities. Therefore, it is important to study the effect and mechanism of geological structures on coal seam gas occurrence for safe and efficient mining.\textsuperscript{14,15}

Geological structures play an important role in controlling the occurrence and distribution of gas in minefields. Researchers from the major mining countries in the world have studied the relationship between the occurrence and distribution of gas and the geological structures, and they have achieved useful research results. Through a field geological investigation and experimental study, Yidong Cai\textsuperscript{16} analyzed the difference of gas content in coal around different geological structures in the Qinshui basin and concluded that the gas content in coal seams is positively correlated with the groundwater content in the basin. Based on laboratory research and a large amount of data collection and analysis, Yan Song et al.\textsuperscript{17} considered that there are favorable conditions for gas accumulation and storage near a syncline structure, and this rule has been verified in practice. Guowei Dong and Qianting Hu\textsuperscript{18} defined and classified the concept of “main controlling geological body” to control gas disasters. They pointed out that geological tectonics controlled the regional distribution, content, and pressure of gas and then controlled the regional distribution and disaster degree of coal-rock gas dynamic disasters. Based on experiments and field verification, Liang Wang\textsuperscript{19} analyzed the change rule of the coal seam physical properties and gas adsorption and desorption characteristics caused by magma intrusion. The results show that under the action of magma, the coal metamorphism degree, gas adsorption capacity, initial desorption velocity, and desorption capacity all increase, and the coal seam gas content and gas pressure also increase substantially. Thus, the possibility of coal-rock dynamic disasters increases, which was confirmed by the research of Longpao Cheng.\textsuperscript{20} Zhiguo Yang\textsuperscript{21} analyzed the control effect of faults on local gas content in a coal seam using the gas geology analysis method. It was concluded that the influence of faults on gas occurrence characteristics depended on the mechanical properties of the faults, lithology of two walls of faults, buried depth and scale of faults, and other factors. It was also indicated that open faults were conducive to gas escape. Lang Zhang\textsuperscript{22} established the stress model of a fault plane to judge the sealing and stability of the fault and analyzed the gas pressure and fault characteristics of gas dynamic disasters near the fault. The results show that there are extreme conditions for gas pressure to induce outbursts near the fault plane, which can only occur in this pressure range.

In summary, although several scholars have performed a significant amount of research in the field of gas geology and achieved useful results, most of them only elaborated the influence trend of the geological structure on gas content in coal seams. Further, they conducted a qualitative analysis of the control effect of a geological structure on gas occurrence, without specific quantification.

The Changping minefield is located in the south of Qinshui Basin, and its geological structure is complex. The aim of this study is to explore the main controlling factors of gas in No. 3 coal seam of Changping minefield and quantitatively analyze the influence of the geological structures in the minefield on gas occurrence. Based on the analysis of the distribution of geological structures in the Changping minefield, the main controlling factors of gas occurrence in the minefield are determined, and the mathematical model of the main factors controlling gas occurrence is established in combination with the laboratory test of coal seam gas content and the field measured data. On this basis, the influence of different geological structures on gas occurrence is quantitatively analyzed by measuring the gas content in coal seams near folds, faults, and collapse columns. Combined with the formation process of the geological structure, its mechanism of influence on gas occurrence is analyzed, which provides a theoretical basis for the prevention and control of gas disasters.

2 \hspace{1em} GENERAL SITUATION OF MINE GEOLOGY

2.1 \hspace{1em} Distribution characteristics of geological evolution in mining area

The area of the minefield is located in the secondary tectonic unit of the Sino-Korean quasi-platform, which is in the central and southern part of the middle uplift area of Shanxi province. The southeastern Shanxi is controlled by the Yanshanian tectonic movement, which shows different tectonic forms in different periods of the Yanshanian movement. In the early Yanshanian movement, due to the action
of EW-trending principal compressive stress, the structural changes were mainly large-scale open folds, such as the Taihang Mountain compound anticline uplift, Huoshan north-south anticline, and Qinshui compound anticline. The middle Yanshanian movement was the main period of formation of the NE-trending structures. Under the combined action of south-north torsional force and east-west compressive force, tectonic changes occurred in the block, and the direction of the principal compressive stress changed from the early east-west direction to NWW-SEE direction. Thus, NE-trending linear compressive belts were formed, such as the Jincheng-Huolu fold belt and Wuxiang-Yangcheng concave fold belt. During the late Yanshanian-Himalayan period, the regional tectonic stress pattern changed. The direction of the principal tensile stress was NW-SE. The corresponding tectonic change was dominated by pretransformation deformation, and the tectonic type was dominated by faults, followed by folds. The main faults are the Qinshui normal fault, Nanjiazhuang reverse fault, Shangwoquan-Yangquan normal fault, Sitou normal fault, and Tuwo normal fault. The regional geological tectonic map is shown in Figure 1.

2.2 | Minefield geological structure and distribution characteristics

The Changping minefield is located in Gaoping County, Jincheng City, Shanxi Province. It is located in the east of the middle section of the Qinshui coal field, the west side of the south of the Jinhuo fold belt, the north east of the EW-NW
trending fault zone in the south margin of the Qinshui basin, and the south margin of the Qinshui basin. The area of the coalfield is 54.9127 km², and the overall trend of the formation is NNE, inclining to NW and W, and the dip angle of the formation is 5°-12°. The geographic location and geological outline of the Changping minefield are shown in Figure 2.

According to the results of the geological exploration, there are 8 folds, 53 faults, and 118 collapse columns in the Changping minefield without magmatic intrusion. Locally affected by tectonic stress, secondary undulations are developed, which are characterized by gentle medium-small anticlines and synclines, accompanied by many small and medium-sized faults and collapse columns. Unstable structural soft coal is found near the geological structure in the minefield, far from the geological structure area, and there is basically no structural soft coal.

3 | INFLUENCE OF GEOLOGICAL STRUCTURE ON GAS OCCURRENCE IN COAL SEAM

The theory of stepwise control of gas geological structures states that the regional structure controls the overall gas content level in the minefield, and the structure in the coalfield controls the gas distribution in the minefield. In each level of control, there are many factors affecting the occurrence of coal seam gas at the same time. Therefore, although the content and distribution of coal seam gas in the minefield are controlled by many factors, there is a main factor controlling the overall content of gas in the area, while other factors cause differences of gas content in the local area. Through the theory of progressive structure, the scope can be reduced continuously, and the gas enrichment area and the dangerous outburst area in a coal seam can be accurately determined.

The measured value of gas content in No. 3 coal seam of the Changping minefield is presented in Table 1.

3.1 | Influence of burial depth on gas occurrence and determination of main controlling factors

The burial depth of a coal seam is one of the main factors affecting gas content in the coal seam.

In general, without considering the influence of the geological structure on gas content, the gas content in a coal seam is proportional to the burial depth of the coal seam. With the increase in burial depth, the crustal stress increases sharply, the coal and surrounding rock are compacted under great pressure, the macroscopic fracture in the coal seam disappears, and the permeability decreases greatly. At the same time, the increase in burial depth leads to the increase in gas migration distance to the surface, which further increases the difficulty of gas escaping to the surface. According to the results of borehole sampling, with the increase in burial depth, the proportion of methane components in the gas shows an overall upward trend. Through sampling and analysis of gas content, the gas content of No. 3 coal seam in the Changping minefield is positively correlated with the burial depth of the coal seam, and the trend diagrams of both are shown in
Figure 3. Through data fitting, the relationship between gas content and burial depth of the coal seam can be expressed by the following formula:

\[ W = 0.0186H - 2.7283, \]

where \( W \) is gas content in the coal seam, in m³/t; \( H \) is the depth of coal seam burial, m.

According to the geological outline map of the Changping minefield, its geological structure is relatively simple. The results of the borehole gas content measurement show that the geological structure in the area is not enough to control the overall gas distribution in the minefield. The main controlling factor of gas occurrence in coal seam No. 3 in the Changping minefield is the depth of the coal seam. The gas content in the coal seam shows an increasing trend with increasing burial depth. According to the relationship between the depth of measuring points and the gas content in coal seam No. 3 in Figure 3, the gas content in some measuring points appears to have a relatively large oscillation phenomenon. According to the depth of the survey point and the distribution of the surrounding geological structure, it is considered that the abnormal gas content in some of the survey points is caused by the influence of the geological structure.

### 3.2 Effect of fault on gas occurrence

The fault movement occurs along with tectonic movement, which can be divided into open and closed faults. The type of fault has an important influence on gas preservation. The types of faults mainly depend on their nature and mechanical properties, the connection between the faults and surface or alluvium, the lithology of the coal seam and fault contact surface, and the

| Number | Sample depth/m | Gas content/m³/t | Number | Sample depth/m | Gas content/m³/t |
|--------|----------------|-----------------|--------|----------------|-----------------|
| 1      | 360            | 2.98            | 12     | 746            | 10.97           |
| 2      | 384            | 2.56            | 13     | 556            | 11.51           |
| 3      | 322            | 3.03            | 14     | 525            | 13.41           |
| 4      | 420            | 5.53            | 15     | 684            | 9.44            |
| 5      | 403            | 5.23            | 16     | 759            | 11.21           |
| 6      | 486            | 5.95            | 17     | 576            | 4.89            |
| 7      | 663            | 11.86           | 18     | 655            | 11.48           |
| 8      | 478            | 11.62           | 19     | 778            | 7.48            |
| 9      | 454            | 7.9             | 20     | 320            | 2.97            |
| 10     | 535            | 9.45            | 21     | 322            | 3.02            |
| 11     | 501            | 9.08            | 22     | 310            | 2.4             |
| 12     | 746            | 10.97           | 23     | 308            | 2.6             |
| 13     | 556            | 11.51           | 24     | 307            | 3.94            |
| 14     | 525            | 13.41           | 25     | 311            | 3.86            |
| 15     | 684            | 9.44            | 26     | 208            | 2.36            |
| 16     | 759            | 11.21           | 27     | 210            | 3.19            |
| 17     | 576            | 4.89            | 28     | 210            | 1.85            |
| 18     | 655            | 11.48           | 29     | 300            | 1.79            |
| 19     | 778            | 7.48            | 30     | 290            | 1.1             |
| 20     | 320            | 2.97            | 31     | 208            | 2.36            |
| 21     | 322            | 3.02            | 32     | 208            | 5.83            |
characteristics of the fault zone. Different types of faults form different tectonic boundary conditions of blocks, which have different effects on gas preservation and emission.

According to the field measured data analysis, the influence of faults on gas occurrence in the Changping minefield is as follows:

(1) The gas content near faults is generally higher than that in normal areas. For example, the measured gas content of the 4305 working face near the Lijiahe normal fault is as high as 9.92 m$^3$/t, whereas the gas content of the coal seam at the same depth far from the fault is only 6.12 and 6.22 m$^3$/t, which is 1.6 times lower. (2) The gas content in the upper wall of a normal fault is higher than that in the lower wall. As shown in Figure 4, borehole 15 is located in the lower wall of the Lijiahe normal fault, with a depth of 684 m, and the measured gas content is 9.44 m$^3$/t. Borehole 18 is located in the upper wall of the Lijiahe normal fault, with a depth of 655 m, and the measured gas content is 11.48 m$^3$/t. The depth of the two boreholes is approximately the same. The gas content in the upper wall of the fault is 21.6% higher than that in the lower wall. In conclusion, the gas content in the upper wall of the normal fault is greater than that in the lower wall.

3.3 | Effect of fold on gas occurrence

The distribution law of the gas content in coal seam No. 3 in the Changping coal mine is closely related to the fold structure, and the gas content in these structural affected areas increases obviously.

The compressive stress field is above the neutral plane of both wings and axes of the syncline structure, which shows an obvious stress concentration and high pressure area. The tensile stress field is below the neutral plane of the axle, and the burial depth of the coal seam is often large, where only a small number of open cracks are produced, some stress is released, and a relatively low pressure area is formed. Therefore, the areas above the neutral plane of the two wings and axes of the syncline are favorable for gas storage and accumulation. In particular, the axes of the syncline are abnormal areas with high gas content. When the roof and floor are thick mudstone, gas accumulation will also occur in the neutral surface. The underground syncline in the Changping coal mine is mostly a gentle syncline with a small dip angle of both wings, of no more than 15°. It is not easy for gas to escape to both wings, and the roof and floor are thick mudstone, which is conducive to gas storage. In addition, the folds in the minefield were compressed during the Yanshan period, and the coal seam is compacted under stress and poor permeability; thus, a gas accumulation area is formed at the axis of the syncline. For example, the gas content in borehole 9 located at the axis of the Pangou South syncline is 7.90 m$^3$/t, the predicted gas content is 5-6 m$^3$/t, the measured gas content is 32%-58% higher than the predicted value, and the gas content in borehole 12 is 10.97 m$^3$/t higher than the predicted value.

The compressive stress field is below the neutral plane of both wings and axes of the anticline structure, which shows obvious stress concentration and a high pressure area. The neutral plane and the above axes are in a tension stress field, and the burial depth of the coal seam is often large, where only a small number of open cracks are produced, some stress is released, and a relatively low pressure area is formed. When the roof and floor of coal seam are thick mudstone or shale with poor permeability and when the burial depth is large, the upper rock of the axle neutral plane of the anticline will show plastic deformation and will not produce cracks. Therefore, the roof and floor still maintain good coverage performance, and the gas on both wings will also migrate to the axle, resulting in high gas content of the coal seam.

In the Changping coal mine, the area affected by the anticlinal inclination generally increases. For example, when the rubber-tire roadway encounters an anticlinal structure, with a driving distance of 647 m from the 4206 roadway, the gas emission increases from 0.20 m$^3$/min to 3.64 m$^3$/min, increasing 18 times. Figure 5 displays the gas emission variation curve of the rubber-tire roadway driving face. From the measured gas content, the gas content outside the anticlinal affected area is 6.08 m$^3$/t, and it increases to 8.75 m$^3$/t after entering the anticlinal axis. After the anticlinal, the gas content decreases to 6.74 m$^3$/t, and the increase range of gas content in the anticlinal axis is 30%-40%. In an anticline near the 1222 roadway, the measured gas content in the axis is 2.39 m$^3$/t outside the anticlinal affected area. In the axis of the anticline, the measured gas content is as high as 5.78 m$^3$/t, which is 2.42 times that outside the affected area.

3.4 | Effect of collapse column on gas occurrence

Three-dimensional seismic survey results show that there are 118 collapse columns in the minefield, including 2 collapsed
to the surface and 20 collapsed in the underground roadway. The influence of the collapse column on gas occurrence mainly depends on the development of cracks and the connection between the collapse column and surface. The collapse column is well developed in the Changping minefield. The borehole observation shows that the fracture contact surface of the collapse column in the Changping minefield is squeezed tightly. The roof and floor of the coal seam are mudstone and fine-grained sandstone with poor permeability, which has a good sealing property and is conducive to gas accumulation. The formation of the collapse column releases the original stress of the coal seam. A large amount of gas in the coal seam is desorbed and transported to the surrounding column and the column body, and a high gas area is formed around the collapse column.

For example, borehole 13 is located near the 130\# collapse column, and gas content is 11.51 m\(^3\)/t; borehole 14 is located near the 70\# collapse column, and gas content is 11.41 m\(^3\)/t. The gas content of the two boreholes is higher than the predicted value. There are 32\#, 33\#, and 34\# boreholes near the 53\# collapse column. The gas content of 33\# boreholes that are nearest to the collapse column is as high as 5.83 m\(^3\)/t, which is 2.47 times higher than that of 32\# boreholes (2.36 m\(^3\)/t) that are far from the collapse column. The relative positions of boreholes and collapse columns are shown in Figure 6.

### 3.5 Effect of surrounding rock lithology on coal seam gas occurrence

The surrounding rock of a coal seam includes the main roof, direct roof, floor, and surrounding coal seam with certain thickness. The porosity, pore structure, and permeability of the surrounding rock directly determine the characteristics of gas occurrence in the coal seam area. Generally, the roof and floor rocks have large porosity and good permeability, which are conducive to gas emission in coal seams, such as in conglomerate and sandstone with pore or brittle fracture development. On the contrary, if the roof and floor are composed of dense, complete shale, oil shale, and other poor-permeability rocks, the gas content in coal seam is relatively high. The roof of the 3# coal seam near borehole 19 is fine-grained sandstone with gas content of 7.83 m\(^3\)/t, whereas roof 3# coal seam near borehole 15 (gas content of 9.44 m\(^3\)/t), borehole 16 (11.21 m\(^3\)/t), and borehole 18 (11.48 m\(^3\)/t) is mudstone. Therefore, in the same coal seam, the mudstone with poor permeability has a sealing effect on gas, which is not conducive to gas migration and escape.

### 4 ANALYSIS OF THE MECHANISM OF INFLUENCE OF STRUCTURE ON THE OCCURRENCE OF COAL SEAM GAS

The results show that the geological structure has a certain effect of control on the occurrence of coal seam gas, including the influence on the overall level of regional coal seam gas and the local uneven distribution of gas. Different geological structures have different effects and degrees of coal seam gas occurrence owing to their different formation processes and structural characteristics. The geological structure mainly affects gas occurrence in a coal seam through two ways: One is to change the form of occurrence and coal body structure of the coal seam through compression and shearing; the other is to change the permeability and fracture development of surrounding and overlying strata of the coal seam, which affects gas migration and escape.
4.1 Effect of burial depth and roof and floor lithology on coal seam gas occurrence

The burial depth of a coal seam and the lithology of the rock surrounding the roof and floor are some of the main factors affecting the gas content in a coal seam. With the increase in burial depth, the self-weight overburden leads to the increase in static pressure. The horizontal principal stress is calculated according to the following formula:

$$\sigma_H = \frac{\mu}{1-\mu} \rho g Z.$$

In the formula, $\sigma_H$ is the maximum horizontal principal stress, MPa; $\mu$ is Poisson’s ratio; $\rho$ is rock density, kg/m$^3$; $g$ is gravity acceleration, m/s$^2$; and $Z$ is burial depth, m.

The horizontal stress is usually several times the static pressure of the overburden. According to the measurement, when the depth is 800 m, the static pressure caused by the weight of the overlying strata has reached 20 MPa. Because of the anisotropy of rock, the maximum horizontal principal stress $\sigma_{H_{max}}$ is 1.5-3.3 times larger than the minimum horizontal principal stress $\sigma_{H_{min}}$. Under the strong stress, the crushed rock produced by geological movements in the stratum is gradually compacted and the cracks are closed, resulting in a significant reduction in the permeability of the overburden rock, thus blocking the gas escape channel. At the same time, the increase in burial depth makes the distance of gas escape longer, which makes it difficult for the coal seam gas to escape to the surface. The lithology of the coal seam overburden also has a great influence on gas storage. If the surrounding rock is a poor-permeability rock, such as mudstone and siltstone, the gas in the coal seam does not easily diffuse outward, and the gas content in the coal seam is relatively high. If the surrounding rock is coarse sandstone and a conglomerate with good permeability, the gas can easily escape to other coal seams through the surrounding rock. If the direct roof of the coal seam is a rock with strong permeability, the main roof is a rock with poor compactness and permeability, and even the gas content in the direct roof is higher than that in the coal seam. Therefore, the effect of the surrounding rock on coal seam gas occurrence depends entirely on the physical properties of this surrounding rock.

In summary, the geological structure has limited influence on the overall gas occurrence law in the minefield, but it has a greater impact on local areas and often leads to the increase in gas content. This makes gas disasters prone to occur near geological structures, which has been proved in engineering practice. Therefore, it is of great significance to detect geological structures accurately and adopt a reasonable gas control technology for preventing gas disasters.

4.2 Influencing mechanism of fault on coal seam gas occurrence

Faults are common structural types in geological tectonic movements. The occurrence of faults destroys the continuity of coal seams and plays an important role in controlling local gas occurrence. Coal and gas outburst accidents can easily occur near faults. The controlling effect of faults on gas occurrence in coal seams depends on the comprehensive effect of many factors, such as the mechanical properties of faults, lithology of two walls of faults, size of faults, and tectonic stress field. Different mechanical properties of faults lead to different effects on gas occurrence. Figure 7 is a schematic diagram of normal and reverse faults.

Faults are formed under horizontal compression. Normal faults are generally tensional and open. The upper wall of the fault slides downward along the fault plane, whereas the lower wall moves upward along the fault plane. Pores and fissures develop in the two walls of the open
Fault, which provides a channel for gas desorption and escape. Regardless of whether the fault is connected with the surface or not, it will cause the gas to escape through the fissures within a certain range of the two walls of fault, and the gas content will be reduced. The buried depth of the coal seam on the upper wall of the Lijiahe normal fault increases, and the path of gas migration increases. The fault strikes close to the coal seam and further prevents the gas migration from inclining to the coal seam, thus preserving the coal seam gas to a certain extent.

Reverse faults are generally compressive-torsional and closed faults, which play a role in sealing the local gas. The lithology of the two walls of a fault controls the occurrence of gas. If the two walls are brittle rocks, a large number of pores and fissures appear, and gas permeability is easily generated in the course of the geological movement. If the two walls are composed of strongly plastic rocks, the fault plane will be relatively closed, the two plates produce fewer fissures, and the fissures are easy to be recompacted, blocking the gas escape channel. The compressive strength, tensile strength, and shear strength of coal are only approximately 1/10 of those of sandstone. Compared with the roof and floor strata, coal is more sensitive to a stress and strain environment. Therefore, under the action of a strong stress field, tectonic coal develops near faults. The reserve of tectonic coal is proportional to the size of the faults. In the early stage of fault formation, the original gas adsorption is large, but the larger the size of the faults, the two sides of faults tend to develop faults, which is not conducive to gas enrichment.

Faults have many influential factors on gas occurrence. It is impossible to judge the control effect of faults on gas occurrence only from a single feature. It is necessary to consider many factors comprehensively to determine the effect and degree of effect of the faults on gas occurrence.

4.3 Influencing mechanism of fold on gas occurrence in coal seam

Folds are usually scattered in the plate collision area and intracontinental deformation area of coal measured strata. During the formation of folds, strong rocks form a fold nappe or a slip nappe, which plays the role of energy level layer. Coal and rocks with weak strength are prone to deformation under stress and form a slip layer. Under the action of stress extrusion, a slip phenomenon occurs between the weaker coal seam and the surrounding rock. Coal migrates from the high stress area to the low stress area, and plastic deformation occurs, which makes the thickness of the coal seam different in the fold axis and wings. Influenced by the slip and shear deformation during the folding process, the primary structure of the coal body is seriously damaged, and a large amount of fine-grained structural soft coal is formed. The structural soft coal has the characteristics of high gas content, cleavage development, and low permeability, and its internal cracks and micropores are more developed. Therefore, a large amount of gas can be stored in the tectonic coal, and the formation process and mechanical properties of the folds determine the development of tectonic coal around these folds. The extrusion stress environment produces a large amount of gas trapped in the tectonic coal, forming a high gas area near the folds. Figure 8 displays a rheological diagram of a coal seam in the process of folding formation.

In addition, the types of fold also play a controlling role in the occurrence of local coal seam gas. According to the relationship between the deformation of folds and the degree of gas accumulation in coal seams, folds can be divided into four types: the upper escaping type of anticline, the lower accumulating type of anticline, the upper accumulating type of syncline, and the lower escaping type of syncline. With regard to the anticline, when the coal seam is above the neutral plane, the coal seam and rock seam are tensioned. Under the action of the huge stress, the thickness of the coal seam at the axis of the anticline becomes thinner, and both coal and rock are fractured. The increase in pores and fissures leads to a great improvement in gas permeability, which provides conditions for upward gas migration. When the neutral surface is above the coal seam, the stress upon it is pressure. Under this pressure, the coal seam presents the condition of thick axes and thin wings. The coal body is crumpled and broken while displacement occurs, and the gas gathers along the antclinal axis. If the open fissures in the upper part of the neutral surface do not affect the coal seam, a closed gas area will be formed at the axis of the anticline. For the syncline, when the neutral surface is located at the lower part of the coal seam, the coal seam is in tension state. If the open fissures in the upper part of the neutral surface do not affect the coal seam, a closed high gas area will be formed at the axis of the syncline. For the syncline, when the neutral surface is located at the lower part of the coal seam, the coal seam is in tension state, the coal body moves from two wings to the axle, and gas is desorbed in large quantities. Although the surrounding rock is deformed and destroyed under stress, it is compacted quickly under pressure, creating a closed environment for a large amount of gas gathered in the axle. When the neutral surface is above the coal seam, the coal seam is in tension state, the coal body moves from the axis to the wings, and the rock seam at the lower part of the coal seam produces cracks under tension. When the gas moves with the coal body, part

**FIGURE 8** Rheological diagram of coal seam in the process of folding formation.
of the gas escapes from the cracks, and the gas content in the shaft decreases. The fold in the Changping coal mine is mostly a gentle syncline with a small dip angle of both wings, and the roof and floor are thick mudstone, which is conducive to gas storage. Therefore, gas accumulation is easy to occur near the fold.

### 4.4 Effect of collapse column on coal seam gas occurrence

The collapse column is a common geological structure in northern China. Generally, it is irregularly conical and most of the contact interfaces between the collapse column and the surrounding rock are irregularly serrated. The angle of contact of the surface between the collapse column and the surrounding rock is between 50° and 80°. Coal and rock fissures are developed in the range of 3-5 m around the collapse column and are fractured, and sometimes, normal faults with a small drop can be seen. The formation of a collapse column is closely related to the flow of groundwater. The soluble strata are gradually hollowed out under the erosion effect of groundwater. The overlying nonsoluble strata collapse downward under the action of gravity and ground stress to form a collapse column. The formation process of a collapse column is shown in Figure 9. The influence of the collapse column on gas occurrence mainly depends on the lithology of the upper caprock, the development of fissures, and whether or not the collapse column is connected with the surface and a flow of groundwater. A large number of joints, fissures, and small faults will occur during the formation of collapse column, which will easily become the channel of gas migration between coal seams. At the same time, the area usually has a certain role in promoting gas release. The stress of the coal seam and the surrounding rock is released by the collapse column, and a large amount of gas is desorbed as free state and moves upward with the cracks around the collapse column. Therefore, the body of the collapse column and its surroundings often lead to gas enrichment. If the overlying strata are well sealed and there are no fissures to develop with the surface, a high gas area is easily formed around the collapse column. In addition, if the associated fissures of the collapse column are connected with aquifers and water-conducting faults, the gas is easily transported to other areas with the flow of groundwater.

The fracture contact surface of the collapse column in the Changping minefield is squeezed tightly, and the coal seam has no contact with the permeable rocks, which provide good conditions for gas accumulation. Therefore, it is easy to form high gas area near collapse column.

### 5 CONCLUSION

1. In the Changping minefield, the main controlling factor of the coal seam gas content is burial depth, which is positively correlated with burial depth, while other geological structures control the local coal seam gas content. Different geological structures have different effects on the gas content of coal seams.

2. Gas enrichment occurs near faults in the Changping minefield, forming a large gas area. The coal seam gas content near faults is 1.6 times that of the normal area, and the gas content in the upper wall is 21.6% higher than that in the lower wall. Syncline and anticline structures are conducive to gas storage and enrichment in the axes, where the gas content is 32%-58% higher than the predicted value. The gas content near the collapse column is 2.47 times higher than that in the normal area.

3. The influence of geological structures on the gas content in a coal seam is mainly controlled by the change in the occurrence state of the coal seam and the permeability of the overlying strata. If the pressure of the coal and rock mass around the geological structure is relieved, it is beneficial to gas desorption in the coal seam and gas escaping through the pores and fissures generated by the structure. If stress concentration occurs in the formation process of the geological structure, the gas is not easy to desorb, and the fissures generated in the process of geological movement are rapidly compacted, forming a sealed caprock, resulting in a gas enrichment phenomenon in the local area and forming a large gas area.
4. A geological structure in a minefield can only control the gas content in the local area, and most of the structures lead to the increase in gas content in the controlled area. Therefore, when mining near a geological structure, reasonable measures should be taken to reduce the gas content in the coal seam and prevent the occurrence of gas disasters.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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