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Mechanism of stepwise tectonic control on gas occurrence: A study in North China

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ABSTRACT

To gain an understanding of gas occurrence, distribution is the fundamental basis for preventing gas disasters. Presently, how tectonic structures control gas occurrence remains problematic. This study proposes the theory and elucidates the mechanism of stepwise tectonic control on gas occurrence according to the characteristics of gas occurrence and the patterns of gas distribution in coal mines in North China. On the one hand, tectonic compression and shearing lead to stress concentration and thus deform the coal and reduce the coal seam permeability, further contributing to gas preservation. On the other hand, tectonic extension and rifting lead to stress release and thus improve the coal seam permeability, further contributing to gas emission. Therefore, the distribution zones of tectonic compression, ubiquitous coal deformation, and gas accumulation have been step-wisely revealed, and the coal-gas outburst proneness zones are finally identified. The proposed theory of step-wise tectonic control on gas occurrence is of practical significance for gas prediction and control.
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1. Introduction

By the end of 2011, there were 1044 outburst mines with 16,740 events of coal and gas outburst in China. Associated gas disasters have seriously constrained China's energy security, yet it remains difficult to prevent and control such events. A root cause is that the mechanism of gas occurrence has not been fully elucidated. The characteristics of gas occurrence and distribution refer to gas content, gas pressure, and coal seam permeability. Therefore, it is a great necessity to clarify the occurrence and distribution of coal-seam gas for better understanding of coal-gas outburst mechanisms, thorough control of gas disasters, and effective gas drainage.

Gas occurrence is generally thought to be controlled by tectonic structures. Farmer and Pooley [1] found that outbursts only occurred in the districts subjected to severe tectonic activity, which are in association in many places with anthracite, including deformation and depositional structures (e.g., folds, faults, rolls, and slips), especially those with rapid fluctuations of seam thickness. Shepherd et al. [2] found that probably over 90% of significant outbursts have occurred in strongly deformed narrow zones along the axes of structures such as asymmetrical anticlines, hinge zones of recumbent folds, and intensely deformed zones of strike-slip, thrust, reverse, and normal faults.

A number of studies have investigated the geological characteristics of gas in coal mines in China. Zhang and co-workers [3,4] proposed that plate margin belts, intraplate orogenic belts, deep thrust belts, deep active fault belts, and nappe tectonic belts are sensitive zones of coal and gas outbursts. These authors further divided gas occurrence under regional tectonic control in China's coal mines into 30 districts of 10 types [5]. Other scholars studied the control effect of tectonic stress field evolution, tectonic type, and deformed coal on gas outburst [6–19]. However, the above studies have mainly been focused on the impacts of specific tectonic structures on gas occurrence and outburst, but detailed analysis of the mechanism of tectonic control on gas occurrence is less. Thus, great difficulties are encountered when applying those studies in practice.

In the present study, we propose the theory of stepwise tectonic control on gas occurrence in accordance with the characteristics of gas occurrence in coal seams and the patterns of gas distribution in coal mines in North China. The stepwise tectonic control mechanism is elucidated by applying the theory to two representative tectonic structures associated with compression-shearing and extension-rifting, respectively.

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2. Theory of stepwise tectonic control on gas occurrence

In the theory of stepwise tectonic control on gas occurrence, the occurrence and distribution of coal seam gas are results of multiple tectonic events in tectonic evolution as controlled by a variety of geological factors. During each tectonic event, tectonic plate collision and regional compressional shearing or extensional rifting lead to the formation of uplifts or depressions with a series of faults, folds, or magmatic activities at different levels. Associated geological factors play a role in controlling the occurrence state and distribution pattern of coal seam gas, including gas content, gas pressure, and permeability.

Tectonic compressional shearing causes stress concentration and thus easily deforms the coal, leading to ubiquitous occurrence of deformed coal with low permeability. As a result, gas migration and escape are prevented. These conditions are conducive to gas preservation, thereby resulting in the development of gas accumulation zones. By contrast, tectonic extensional rifting leads to stress release and thus improves seam permeability, further contributing to gas emission (Fig. 1).

Orogenic belts, thrust-nappe belts, compressional uplifts, depressions, and high stress belts formed by tectonic plate collision and regional tectonic compression constitute the base zones of ubiquitous coal deformation and gas accumulation, which play important roles in controlling the distribution of outburst proneness zones (Fig. 2). The extensional forces of tectonic plate and regional structures control the tensile stress fields of coal mining areas, mines, and working faces as well as the formation of tectonic extensions and rifts, which are associated with gas escape and thus mainly form low-gas coal seams.

Tectonic plate movements control the formation of regional structures, while the latter control the structures of mining areas and mines. That is, high-level tectonic structures control low-level tectonic structures. The distribution zones of tectonic compression, gas accumulation, and ubiquitous coal deformation are step-wisely revealed, and the proneness zones of coal and gas outburst are finally identified (Fig. 3).

3. Control of tectonic compression on gas occurrence

Taking the example of orogenic belts, the control of tectonic compression on gas occurrence and associated characteristics of gas distribution are analyzed. Due to extrusion of the Siberian Plate, Pacific Plate, Philippine Sea Plate, and Indian Plate, a number of orogenic belts were developed in the plate and on the plate margin of Mainland China, such as the Qinling mountain-Dabieshan mountain on the southern margin and the Yinshan mountain-Yanshan mountain and Taihang mountains on the northern margin of the North China Plate. Uplifting and extrusion of the above orogenic belts formed a series of compressional shear zones in adjacent coalfields. Layer slip of coal rocks led to the destruction of coal formation and the ubiquity of deformed coal. The low coal seam permeability and excellent gas preservation conditions were conducive to gas accumulation, leading to the formation of seven high-gas outburst zones with 220 gas outburst mines across the southern and northern margins of the North China Plate, including the eastern foot of Taihang Mountains, Zhuozishan-Helanshan, Longmenshan-Kangdian, Huayingshan, and Zigui of Dabashan.

3.1. High-gas outburst zone on southern margin of the North China Plate

On the southern margin of the North China Plate, the high gas outburst zone is primarily controlled by thrust-nappe structures on the northern margin of the Qinling-Dabie mountains orogenic belt (Fig. 4). Along the northern boundary of Qinling orogenic belt, i.e., Tianshui-Baoji-Tongguan-Mianchi-Lushan-Wuyang-Zhoukou Basin-southern margin of Tanzhuang Depression-Huainan-Dingyuan, there exist 10 more high-gas outburst mining areas, i.e., Shanmian, Yima, Xin'an, Yiluo, Dengfeng, Xinmi, Yinggong, Linru, Yuzhou, Pingdingshan, and Huainan (incl. Panxie). Presently, there are a total of 51 coal and gas outburst mines and 13 high gas mines with 796 events of coal and gas outburst. The initial outburst depth is 155 m in the mine Xie No. 1 in Huainan. The largest outburst occurs in the mine No. 10 in Pingdingshan, whose outburst strength is 2243 t, 47,509 m^3. The largest gas pressure occurs in the mine No. 1 in Pingdingshan, i.e., 6.61 MPa, while the largest gas content occurs in the mine No. 12 in Pingdingshan, i.e., 25.6 m^3/t.

After deposition of the Carboniferous-Permian coal-bearing strata, the high-gas outburst zone on the southern margin of the North China Plate experienced a long period of tectonic plate collision followed by uplifting and extrusion of the Qinling-Dabie orogenic belt. Especially in the mid-Yanshanian, the orogenic belt was controlled by intracontinental orogenic thrust-nappe and granitic magmatism post the main orogenic period. An extrusion force from the SW side led to the formation of a series of NW- and NWW-trending structures such as thrusts, nappes, faults, and folds, which contributed to the formation of deformed coal and gas preservation.

Nearly in the same period, the high-gas outburst zone was influenced by NNW-trending subduction of the Pacific Plate. The original NW- and NWW-trending structures were superimposed by NNE- and NE-trending structures followed by recombination (see Fig. 5). The NNE- and NE-trending structures were associated with sinistral compressional shearing, which could easily form deformed coal and contribute to gas preservation.

During the Late Yanshanian to Himalayan period, the whole orogenic belt experienced tectonic extension and uplifting under the compressive regime. The high-gas outburst zone was controlled by significant intracontinental subduction of faults along the northern boundary of the orogenic belt. Almost contemporaneously, the Pacific Plate underwent NWW-trending subduction toward the North China Plate, while the NE- and NNE-trending faults were associated with dextral compressional shearing. In this stage, the extensional rifting activities were conducive to gas and stress release.

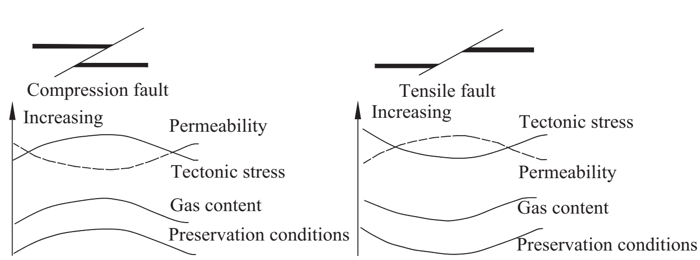

Fig. 1. Relation between stress of fault and gas occurrence.

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