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Research on disaster mechanism and correlation of natural earthquake and coal and gas outburst

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In recent years, with the increasing of mining depth and mining intensity, coal and gas outburst has become one of the most destructive and harmful dynamic disasters in coal mines. Natural earthquakes are the most destructive natural disasters in the earth's crust. Both of coal and gas outbursts and natural earthquakes are caused by geo-dynamic processes. In order to research the correlation between coal and gas outburst and natural earthquake, in this manuscript, we took Pingdingshan eastern mining area as the research object. The principles of disaster prevention, seismology, statistics and geophysics were taken as the research basis, both the characteristics and laws of natural earthquakes, and the occurrence laws and characteristics of coal and gas outburst were systematically analyzed by geo-dynamic division method. At the same time, the relationship between the two disasters were established. The research results show that natural earthquake is the accumulation and release process of elastic properties in rock mass, which can induce the abnormal emission of gas in coal mines under specific conditions. Especially the "weak plane structure" in geological structure, which is more likely to lead to the occurrence of coal and gas outburst accidents. Tectonic activities and stress field changes have a unified mechanism for the occurrence of natural earthquake and coal and gas outburst, there are correlations between space and intensity. The research results can also provide new ideas for the prediction work of these two kinds of disasters.

KEYWORDS

coal and gas outburst, natural earthquake, geological structure zone, disaster causing mechanism, geo-dynamic division

1 Introduction

With the increasing of mining depth in coal mines and the increasing complexity of geological conditions in China, the number of coal and gas outburst coal mines in China has also increased year by year. The violent dynamic effect of coal and gas outburst has caused serious personnel and property losses to society and enterprises (Yu, 1979; Hu et al., 2008; Li and Lin, 2010; Shu et al., 2017; Luo et al., 2018). As the most serious disaster in nature, natural earthquake is also a problem that the scientific community has always been unable to solve (Li et al., 2014; Mao et al., 2019). However, after years of research by scholars all around the world, it has been found that the occurrence of the two disasters are affected by geo-dynamic environmental factors such as tectonic activities and stress field changes (Chen et al., 2005; Zhu et al., 2018). If the influence law between the two disasters could be determined, it will have a far-reaching impact on the prediction and early warning of earthquakes and coal and gas outbursts.

The classic M8.1 earthquake in Mountain Kunlun was taken as an example. After the earthquake, gas accidents occurred in five adjacent coal mines (Chen et al., 2009). Since then, the corresponding relationship between coal and gas outburst accidents and natural earthquakes has been found in time and space. For example, the gas explosion in Fushun, Liaoning on 30 March 2003, and the gas explosion in Fuxin, Liaoning on 14 February 2005, which have attracted the attention of many researchers.

Chen et al. (2005) analyzed the change of gas emission in mining space from three aspects, which are rock stress concentration, stress release and seismic activity (rock burst) before and after the earthquake, and they concluded that gas accidents in coal mines may caused by seismic activity.

Li and Cai (2008) explored the possibility and mechanism of gas disaster nucleation caused in coal mines by seismic energy based on the field geophysical observation. The abnormal gas emission in coal mines boosted by earthquake, and the response mechanism of groundwater to far-field earthquake were taken as an analogy, which combined with the geophysical evidence of large-scale simultaneous crustal movement. The analysis results showed that the possibility of coal mine gas disaster could be increased by seismic energy.

He et al. (2018) established the corresponding index evaluation system based on the theory of realizing regional monitoring with microseismic monitoring technology, and conducted application tests in outburst coal mines. The results showed that to monitor coal mining disturbance and geological anomaly was of good effect by taking microseismic frequency index and energy index.

In order to research the microseismic precursor characteristics of coal and gas outburst, based on the optimized outburst physical model and with the help of COMSOL multiphysics, Zhu et al. (2018) constructed a three-dimensional model of spatial gradual change of mechanical properties of coal, and he analyzed the distribution and evolution law of original rock stress and mining stress before and after roadway excavation. The results show that the sharp change of mechanical properties of coal is accompanied by local high stress area, low stress area and large gradient stress distribution. Before the coal outburst caused by regional structure in the process of roadway excavation in coal mines, the evolution of microseismic signal will go through three stages, which are safety period, foreshock period and quiet period. The microseismic signal will gradually decrease with the gradual gradient of soft coal.

According to the principle that mine earthquakes and natural earthquakes are jointly affected by the regional stress field, Pan et al. (2003) put the mine into the regional stress field and the whole Chinese plate for research, and they discussed the correlation between mine earthquakes and the natural earthquakes in the nearby region.

Zhang (2003) believe that tectonic activities and stress field changes have a unified mechanism for the occurrence of natural earthquakes, coal and gas outbursts, mine earthquakes, rock burst and other dynamic disasters in coal mines. Dynamic disasters in coal mines are an accompanying phenomenon in the process of geological fault activities and development of different scales, which are the result of the breeding and formation of secondary faults and fissures.

Zhu et al. (2019) researched the temporal and spatial distribution and evolution law of microseisms during tunneling. They analyzed and obtained the microseismic response law of geological anomaly areas within the mining range. The results show that microseismic events are generally distributed around the roadway during the tunneling of the working face, and the dislocation of the hanging and footwall of the fault caused by mining causes the release of energy in the rock mass, which is the main reason for the fault activation type microseismic activity.

In order to solve the problem of lack of regional online detection and early warning technology in coal and gas outburst mines, Song et al. (2021) applied the microseismic technology, which could reflect the dynamic load and static load of the mine to coal and gas outburst mines. They studied the spatio-temporal evolution characteristics of microseismic signals induced by tunneling. Based on the seismic wave computed tomography technology, the distribution characteristics of regional stress field in heading face are inversed.

In this paper, Pingdingshan eastern mining area was taken as the research object, we divided the No. 8 coal mine, the No. 10 coal mine and the No. 12 coal mine area into grade Ⅰ to Ⅴ fault structures, and determined the distribution characteristics and interaction relationship of fault structures in this area. After that, we integrated many disciplines to connect coal and gas outburst and natural earthquake through the geo-dynamic environment, combined with the mechanism and characteristics of coal and gas outburst and natural earthquake, and analyzed the relationship between them in time and space. The research results can provide guidance for the prediction and control of coal and gas dynamic disasters in coal mines.

2 Analysis of occurrence mechanism of natural earthquake and coal and gas outburst

2.1 Type and occurrence mechanism of earthquake

Natural earthquakes can be divided into three types, which are tectonic earthquakes, volcanic earthquakes and subsided earthquakes. Tectonic earthquake is an earthquake caused by the rupture and dislocation of rock strata deep underground, which is also known as “fault earthquake” (Jiang et al., 2022; Li et al., 2022). The earthquakes usually mentioned by us are tectonic earthquakes, which account for more than 90% of the total number of earthquakes in the world, and tectonic earthquakes pose the greatest threat to mankind. In this paper, we will focus on the occurrence mechanism of tectonic earthquakes and the correlation between coal and gas outburst and tectonic earthquake.

The movement of geological structure will destroy and deform the rock, redistribute the original rock stress, produce high stress areas, and form accumulation and concentration of stress. When the continuously accumulated stress in the rock mass exceeds its ultimate strength, the rock mass will be sheared or tensioned.

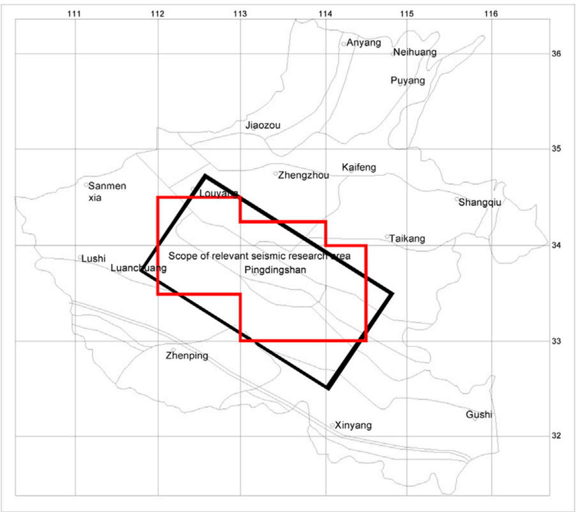

FIGURE 1
Scope of the research area.

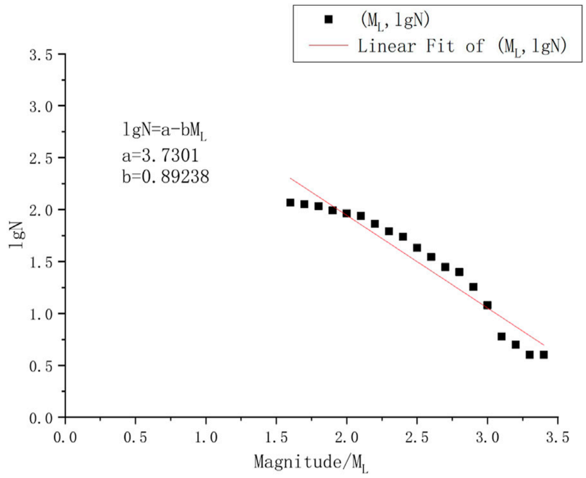

FIGURE 2
Fitting diagram of seismic b value in the research area.

The continuously increasing stress will force the rock mass to vibrate elastically and return to its original shape with its own elastic vibration. The energy released by the elastic vibration will cause earthquakes (Shang and Shi, 2022). This elastic recovery vibration mechanism is used to explain shallow earthquakes with focal depth less than 10 km. When the rock mass is dislocated and deformed, due to the uneven frictional resistance on the damaged structural surface and the stick-slip mechanism of viscosity and sliding during the dislocation process, a series of earthquakes are formed, and the focal depth of these earthquakes is within 20 km. During the tectonic movement, due to the difference in the stiffness of the upper and lower strata, pressure-induced tension fracture and roof breaking and empty lifting phenomenon were formed in the folding process. The deep old strata under high pressure moved up along the fault, igneous rock like dikes and rock discs invaded, and the extrusion mass invaded the surrounding rock, which led to the expansion and development of the fault and triggered the earthquakes. This is the diapiric tectonic development mechanism, but its focal depth is about the level of Conrad surface (About 20 km below the crust) and above the Conrad surface (Wu et al., 2021).

2.2 Mechanism of coal and gas outburst

Coal and gas outburst is a complex dynamic phenomenon and disaster in coal mines. After many scholars' long-term observation and research on a large number of coal and gas outburst phenomena in coal mines, we have basically mastered the causes, conditions and processes of coal and gas outburst, and made it clear that the coal, rock, gas and stress field involved in the outburst are a unified system. The elastic strain energy and gas internal energy accumulated in coal and rock mass are the energy sources of coal and gas outburst. The sudden change of ground stress and the disturbance of mining activities are the excitation factors of coal and gas outburst. If there are weak structural planes, external disturbances, and sudden brittle failure of coal and rock, it may lead to the instability of coal mass in the energy limit equilibrium zone. The elastic potential energy, gas internal energy accumulated in coal and rock mass and the gravity potential energy of unstable coal mass will be unstable, the coal mass will be broken and thrown out (or extruded), and the coal and gas outburst will occur (Gao et al., 2019).

To sum up, when the tectonic stress in the crust gradually accumulates beyond the ultimate bearing capacity of the weak surface of the geological structure, the stress and strain energy will be released in the form of earthquake to obtain a new balance. In the coal mines, the original tectonic stress and mining influence stress and gas pressure formed by mining activities are superimposed. When the stress of coal and rock mass exceeds its ultimate bearing capacity, the stress and energy will be released through coal and gas outburst to obtain a new balance.

2.3 Characteristics of seismicity in Pingdingshan eastern mining area

Pingdingshan eastern mining area is located in the Jiaxian—Pingdingshan fault depression area, and the generation and development of seismic activity in this area are controlled by fault activity. According to the requirements of relevant seismic research area, including the tectonic blocks and active faults that control the seismic activity in Jiaxian—Pingdingshan fault depression area where Pingdingshan eastern mining area is located. In order to analyze the correlation between coal and gas outburst and natural earthquake, the area shown in Figure 1 is selected as the scope of relevant seismic research area. In order to facilitate the selection of seismic data, the scope of relevant seismic research area is approximately a combination of three areas, which are (112°–113°E, 33.5°to 34.5°N), (113°–114°E, 33°to 34.25°N), and (114°–114.5°E, 33°to 34°N). In Figure 1, the area is indicated by the red and thick lines.

The seismicity parameter "b" has a clear physical meaning. High "b" value represents a large proportion of small earthquakes in the

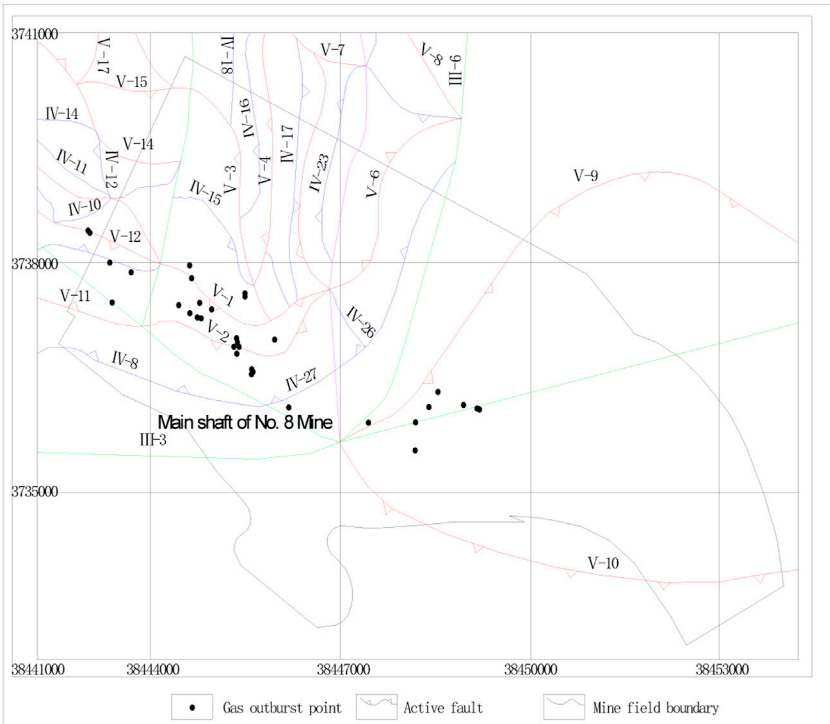

FIGURE 3
Grade VI fault map and spatial distribution map of coal and gas outburst in Pingdingshan No. 8 coal mine.

seismic sample, while low "b" value represents a large proportion of large earthquakes in the seismic sample (Guo et al., 2021). The "b" value is inversely proportional to the shear stress, and the low "b" value region has higher stress accumulation. Therefore, the magnitude of natural earthquake "b" value can be used as an index to measure the stress level of coal and rock mass in the region, thus to evaluate the type and risk of regional dynamic disasters in coal mines.

In order to ensure the reliability of "b" value, the minimum magnitude M_C=1.6 in the natural earthquake catalog is taken as the lower limit of the statistical sample, and the maximum magnitude M_C=3.4 with frequency>1 is taken as the upper limit of the statistical sample. The magnitude frequency relationship of the earthquake catalog is fitted by the least square method, so as to obtain the natural earthquake "b" value in the research area.

According to the calculation, the "b" value of natural earthquakes in the research area is 0.89238, which is higher than the "b" value of natural earthquakes in the whole North China region (0.798), which belonging to the region with relatively high "b" value distribution in North China region. The higher "b" value reflects that the crustal stress level in the research area in recent 30 years is lower than that in the whole North China region, so there are fewer rock burst and mine earthquakes that are more affected by the crustal stress. It is determined that coal and gas outburst are the main mine dynamic disasters in the research area, and the seismic "b" value fitting diagram of the research area is shown in Figure 2.

According to the above analysis results, the coal and gas outburst in the mining area and the occurrence of natural earthquake have internal correlation in terms of geo-dynamic conditions. Therefore, we use the geo-dynamic division method to divide the fault structures in Pingdingshan eastern mining area into grade I to V, and determine the high stress area, stress gradient area and low stress area, so as to build the relationship between the two disasters.

3 Geo-dynamic division of Pingdingshan eastern mining area

3.1 Geological structure characteristics of Pingdingshan eastern mining area

The geological structure of the mining area in the east of Pingdingshan is mainly distributed in NW direction and NE direction. In the NW direction, the geological structure is mainly subjected to compression and shear, while in the NE direction, the geological structure is mainly subjected to tension and shear. No. 8 coal mine, No. 10 coal mine and No. 12 coal mine in Pingdingshan eastern mining area are located in the structural complex area controlled by NW trending faults and folds. Coal and gas outbursts mainly occur near the structure.

The occurrence of dynamic disasters in Pingdingshan eastern mining area is controlled by the thrust nappe tectonic belt, which has a strong extrusion effect. Under the extrusion pressure, the porosity of the coal seam is reduced, and the ability of the coal seam to store gas is enhanced. Under the extrusion stress, the stress concentration and energy accumulation appear in the coal and rock mass. Pingdingshan mining area is located in the northeast edge of the thrust nappe structural belt, which is in the energy accumulation

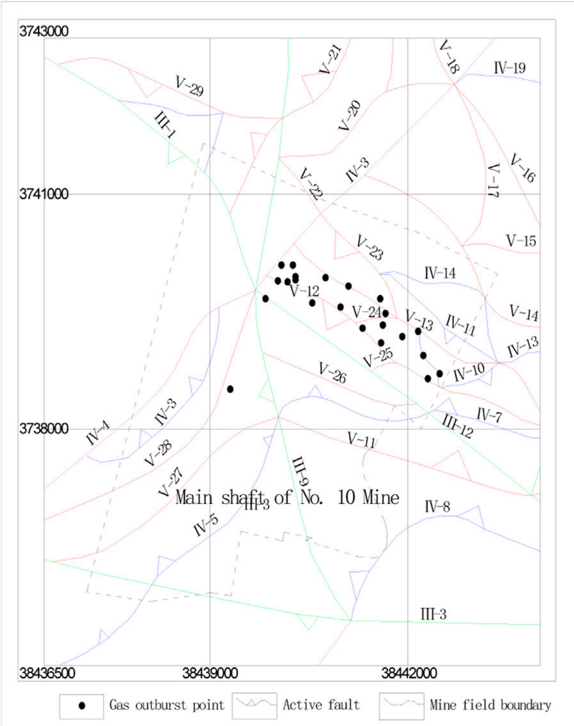

FIGURE 4
Grade VI fault map and spatial distribution map of coal and gas outburst in Pingdingshan No. 10 coal mine.

area. When the energy accumulated by coal and rock volume reaches the critical condition, under the disturbance of mining, the accumulated elastic energy will release in the weak surface of coal and rock mass, and coal and gas outburst will be formed.

3.2 Classification of grade IV and grade V fault structures in the mining area

Geo-dynamic division is an interdisciplinary subject, which is involved mining, geology, surveying mechanics, and computer technology. It is mainly based on the principle that the basic form and main characteristics of landform which are determined by the form of geological structure. Through the analysis of landform, the formation and development of regional faults could be found out, the stress state of rock mass could be determined, geological environment information for human engineering activities could be provided and the possible geological effects of engineering activities could be predicted (Zhang et al., 1998; Zhang et al., 2019).

In this paper, we use geo-dynamic division method to divide the research area into faults. On the basis of the division of grade I to grade III faults, we narrow the division scope to the research area with a larger scale. After that, we divide the grade IV and grade V faults. The division of regional geological structure is more specific than the actual fault, which can reflect the formation and development of the fault and reflect a trend. It is a structural model map of the research area based on the actual geological structure fault, mainly by drawing method, combined with the interpretation of aerial and satellite photos, trend surface analysis, earthquake and regional tectonic activity survey methods, so as to observe the relationship between fault structure and coal and gas outburst in location. No. 8 coal mine and No. 10 coal mine were taken as examples, the spatial distribution of active faults and coal and gas outbursts are shown in Figures 3, 4.

As shown in Figure 3, the coal and gas outburst in the western area of No. 8 coal mine is mainly controlled by active faults III-6, III-12, V-1, V-2, V-11, and V-12. Among the 24 coal and gas outbursts in Wu-9-10th coal seam, 19 were located between active faults III-12 and V-1, and active fault V-2 passed through the middle. 2 were located at the intersection of V-3 fault and VI-15 fault. 3 were located between III-12 and V-12 active faults, and 2 were distributed along VI-7 fault. 3 of the 18 coal and gas outbursts occurred near the intersection of III-6, III-12, and V-11 in Ji-15th coal seam. 1 was located at the intersection of III-12 fault and VI-27 fault, which was mainly affected by the active III-12 fault. In general, the western area of Pingdingshan No. 8 coal mine is affected by the III-12 large-scale active fault, and under the influence of the active faults V-1, V-2, and V-12, resulting in the frequent occurrence of coal and gas outbursts near the fault zone, and in the intersection area.

The coal and gas outburst events in No. 10 coal mine are mainly distributed near the north side of the III-12 fault. Among the 25 coal and gas outbursts in the Wu-9-10th coal seam, 14 occurred near the V-12 active fault. 4 were located near the V-13 fault zone, two times near the V-24 fault zone, and 3 near the VI-9 fault zone. It can be seen that the area is generally affected by active fault III-12. In this area, due to the strong activity of grade III active faults and the large distribution density of grade V active faults, the rock mass is highly fractured and the tectonic stress concentration is strong, resulting in the high frequency and intensity of coal and gas outburst. It shows that the geological fault structure is the energy source of coal and gas outburst.

3.3 Geo-dynamic division and seismic structure of mining area

The fault structure will form a local tectonic stress concentration area, and the concentration of tectonic stress will lead to the accumulation of elastic deformation potential of coal and rock mass. When underground engineering activities enter this area, due to the superposition of mining stress, the stress balance of coal and rock mass is destroyed, and the elastic potential accumulated in coal and rock strata is suddenly released. When the released elastic energy is greater than the consumed energy, it will lead to coal and gas outburst, rock burst and other mine dynamic disasters. Therefore, based on the view of geo-dynamic division, it is considered that tectonic activity and tectonic stress are the dynamic sources of mine geo-dynamic disasters, and engineering activity is the direct inducement of coal and gas outburst and rock burst. In order to analyze the specific relationship between earthquakes and fault structures in the mining area, earthquakes with magnitudes greater than 1.1 that have occurred near the mining area are linked to the grade III fault division map. The relationship between grade III

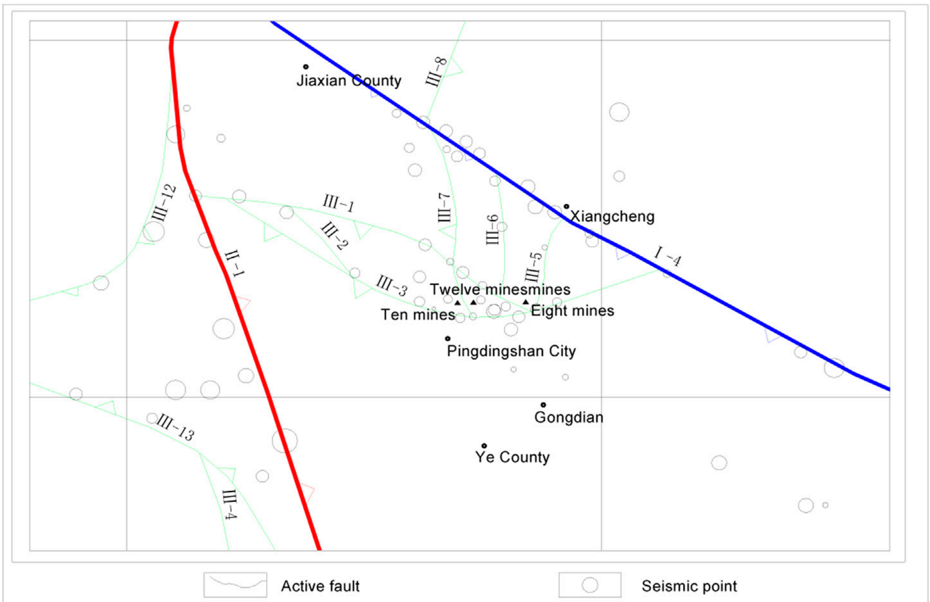

FIGURE 5
Grade III division and seismic distribution in the mining area.

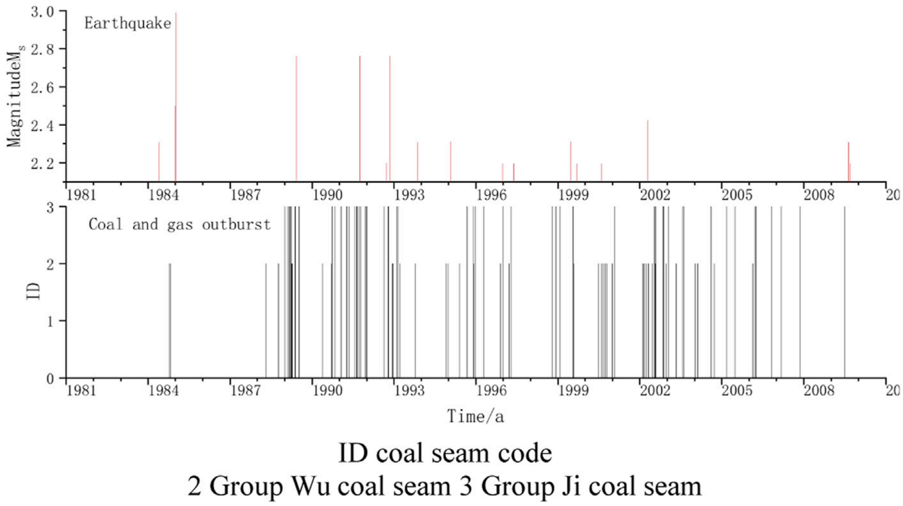

FIGURE 6
Time sequence comparison diagram of coal and gas outburst and natural earthquake (M_S>2.1) in Pingdingshan eastern mining area.

division and seismic distribution in the mining area is shown in Figure 5.

Among them, the major faults are I-4 and II-1, and the III-3 fault crosses between the two major faults. Earthquakes are also mostly distributed near this fault, so the above three fault zones play a leading role in the occurrence of earthquakes controlling, and the existence of the fault is easy to cause stress concentration and earthquake. The earthquake caused by the fault structure activity releases the energy of the fault structure, which is easy to cause mine geodynamic disasters such as coal and gas outburst.

4 Study on the correlation between natural earthquake and coal and gas outburst in Pingdingshan eastern mining area

4.1 Temporal correlation

Synchronicity specifically refers to that when Ms>2.1 earthquakes occur or are more frequent in the research area, coal and gas outbursts occur more or intensively in

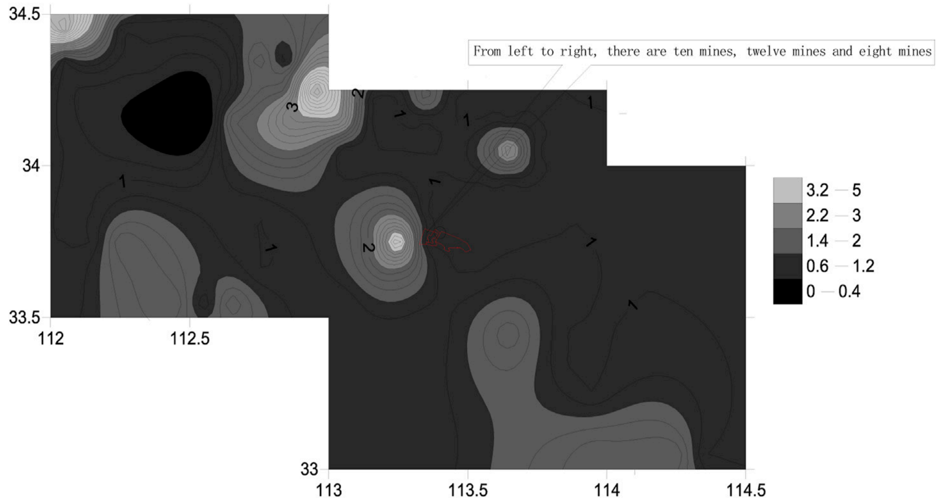

FIGURE 7
Isoline of seismic frequency in the research area.

Pingdingshan eastern mining area, and *vice versa*. The time sequence comparison of coal and gas outburst in Pingdingshan eastern mining area and natural earthquake (Ms≥2.1) in the research area is shown in Figure 6.

On 6 January 1985, an earthquake with M_S=3.0 occurred in Yichuan, Henan Province. There were also three earthquakes with Ms>2.1 in about half a year before the earthquake. These four earthquakes were the only earthquakes with Ms>2.1 from 1981 to 1987. During the four earthquakes, two coal and gas outbursts occurred in Pingdingshan eastern mining area for the first time since production, while no coal and gas outbursts occurred in the eastern mining area of Pingdingshan in 3 years after the four earthquakes. Coal and gas outburst and natural earthquake are close to synchronization in time. In addition, two coal and gas outbursts occurred before the Yichuan earthquake with M_S=3.0, and the other three earthquakes with M_S>2.1 appeared as "precursors" of larger earthquakes. There were three earthquakes with larger magnitudes from 1988 to 1993, all of which were magnitude, corresponding to three intensive coal and gas outbursts in Pingdingshan eastern mining area in 1989, 1991 and the end of 1992 (early 1993), At the same time, the M_S = 2.75 earthquake on 5 June 1989 also lagged behind that in 1988, and coal and gas outbursts also appeared as "precursors".

After 2008, the synchronization of coal and gas outburst and natural earthquake in Pingdingshan eastern mining area was highlighted again. On August 25th and 12 September 2009, earthquakes with M_S = 2.3 and M_S = 2.2 occurred in Yicheng and Yiyang, Henan, respectively. This was the first earthquake with M_S>2.1 since 2003. The mining area was highlighted in 2009, but not in the adjacent years.

As shown in Figure 6, although the coal and gas outburst in Pingdingshan eastern mining area and the natural earthquake in the research area have a certain degree of synchronization in the dense sparse time process, the synchronization is poor in some years (1994–2008), which reflecting that although the tectonic activity and stress field changes have a unified mechanism for the occurrence of natural earthquakes and coal and gas outbursts, and the two disasters are correlated, the occurrence of coal and gas outbursts is also affected by gas occurrence due to the influence of coal seam mining, outburst prevention and control activities and other factors, the degree of correlation varies from time to place.

4.2 Spatial distribution relevance

The research area is divided into evenly spaced grids with grid cell size of 0.1°×0.1°, count the frequency of seismic records in the grid unit, and using this as the frequency of seismic activity at the center of the unit to draw the seismic frequency contour. The natural earthquake frequency contour in the research area is shown in Figure 7.

According to the frequency contour, the spatial distribution characteristics of earthquake frequency in the research area are basically consistent with the spatial distribution characteristics of earthquake magnitude, showing the pattern of natural seismicity in the region. The mining area in Pingdingshan eastern mining area is located near the light colored area of the seismic frequency contour map, which is near the seismic high frequency area of the research area.

In terms of magnitude and frequency, the mining area in Pingdingshan eastern mining area belongs to the concentrated area of crustal energy release, and the stress field is relatively unstable. The spatial distribution characteristics of natural seismicity reveal that Pingdingshan eastern mining area is prone to dynamic disasters. The change of stress field of seismic response conforms to the characteristics of dynamic source of coal and gas outburst in the research area, and the two disasters are spatially correlated. In such a dynamic environment, coal and gas outbursts and other mine dynamic disasters will occur frequently in Pingdingshan eastern mining area.

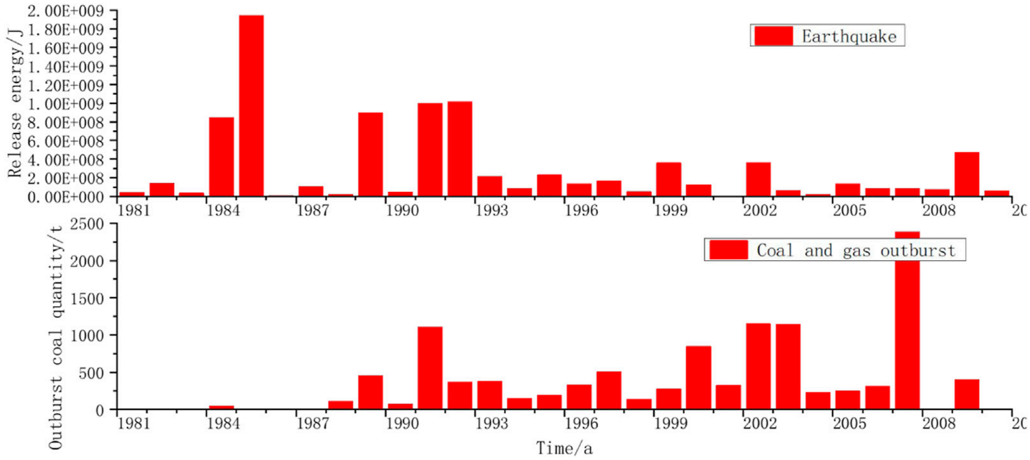

FIGURE 8
Comparison histogram of annual coal and gas outburst and annual energy released by natural earthquake in Pingdingshan eastern mining area.

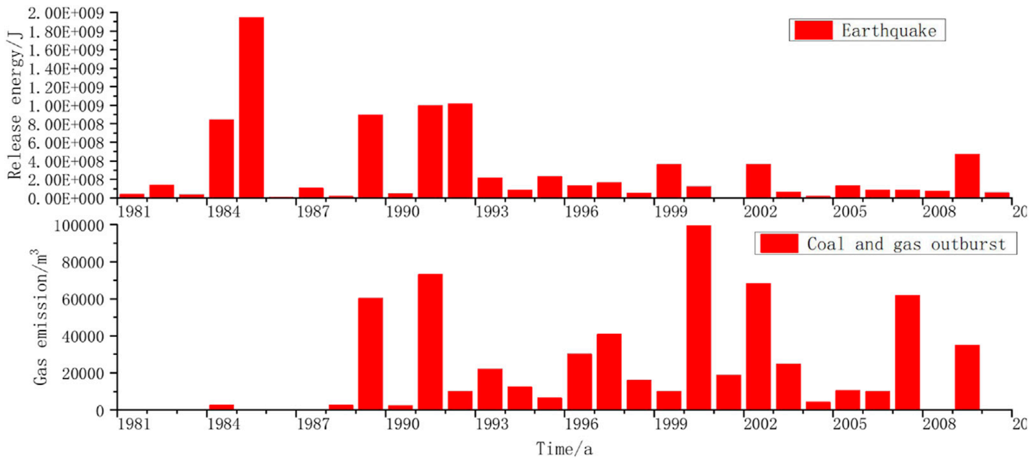

FIGURE 9
Histogram of annual outburst gas volume and annual release energy of natural earthquake of coal and gas outburst in Pingdingshan eastern mining area.

4.3 Strength relevance

The energy released by earthquakes depends on magnitude and frequency, and the annual energy released by earthquakes that combine magnitude and frequency reflects the intensity of seismic activity (Wangi et al., 2021). The intensity of coal and gas outburst is represented by the volume of outburst coal and the amount of gas emitted (Wang et al., 2022). According to the annual released energy of natural earthquakes in the research area and the annual coal and gas outburst volume and annual gas emission data of coal and gas outburst in Pingdingshan eastern mining area, Figures 8, 9 are drawn.

It can be seen from Figures 8, 9 that the annual activity intensity of coal and gas outburst and natural earthquake basically maintained the same trend before 1993, that is, in the year when the energy released by natural earthquake was large, the annual intensity of coal and gas outburst was also in the peak year. It shows that the natural earthquake and coal and gas outburst are affected by the tectonic activity and the change of stress field. The external manifestation of the effect is the natural earthquake or coal and gas outburst and other mine dynamic disasters. It also shows that the tectonic activity and the change of stress field before 1993 are the dominant factors inducing coal and gas outburst.

From 1994 to 2008, the annual energy released by natural earthquakes in the mining area generally showed a downward trend, while the coal and gas outburst generally showed an upward trend according to the judgment of the amount of outburst coal and gas emission. To analysis of the reasons, first, with the deepening of mining, mining disturbance plays a major role

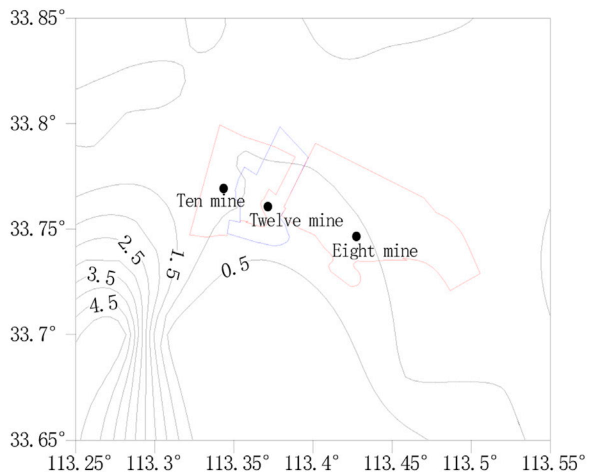

FIGURE 10
Comparison of mine dynamic disasters and natural earthquake frequency such as coal and gas outburst (M_S>2.1).

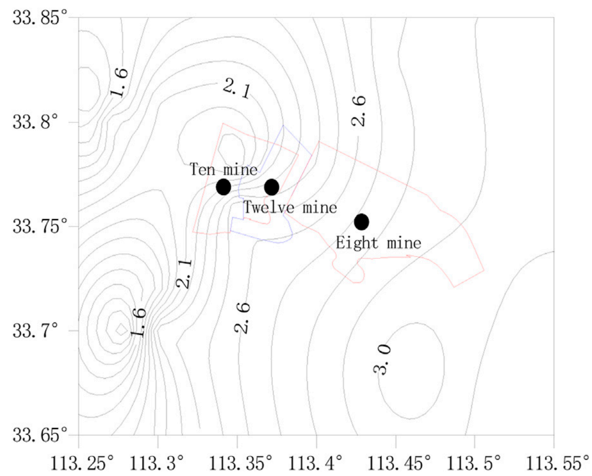

FIGURE 11
Comparison results of coal and gas outburst and other mine dynamic disasters with natural earthquake magnitude (M_S>2.1).

in the change of local stress field in a small range, and its influence ability has exceeded the self-regulation of regional tectonic stress field in a large range to a certain extent. Second, the gas content in the coal seam below 900 m is increasing with the increase of buried depth (according to the actual measurement), and the impact of high gas is greater. The intensity of energy released by natural earthquakes in 2007 is not large, which belongs to the medium level in the 30 years from 1981 to 2010, reflecting that the adjustment of regional tectonic stress field is not strong, and the tectonic activity is relatively calm. However, the amount of coal and gas outburst in 2007 reached the highest level in the history of outburst in the eastern mining area, indicating that the participation of tectonic stress in outburst was not high in 2007, and high gas and mining stress were the main factors of causing outburst.

The annual energy released by natural earthquakes showed an upward trend in 2009 and later. The annual energy released by earthquakes in 2009 reached the maximum value in the past 17 years, and the corresponding coal and gas outburst volume and gas emission volume were large. It shows that with the strengthening of regional tectonic activity and stress field, the influence of tectonic activity and stress field change on coal and gas outburst has begun to dominate.

It can be seen from the above analysis that the earthquake activity corresponding to the gas accident is generally at the magnitude of 2.5–4.5, rather than the magnitude of more than 5, which is specifically manifested in the destruction of gas reservoirs and coal seams caused by the earthquake. During the earthquake, the coal seam containing gas is loosened, the permeability of the coal seam is increased, the stress is released, and a large amount of gas is emitted.

4.4 Impact of natural earthquake on coal and gas outburst

In order to better reflect the impact of natural earthquakes on coal and gas outburst in the mining area, the comparison diagram between the frequency and magnitude of coal and gas outburst events and natural earthquakes in Pingdingshan eastern mining area is drawn, and the comparison results are shown in Figures 10, 11.

In Figures 10, 11, the spatial distribution of magnitude and frequency of natural earthquakes in Pingdingshan eastern mining area are reflected. The historical magnitudes of natural earthquakes in No. 8 coal mine, No. 10 coal mine and No. 12 coal mine are concentrated between 2.0 and 2.9, reflecting that the magnitude of natural earthquakes in Pingdingshan eastern mining area is relatively large and concentrated near the high value area.

The above analysis results show that the natural earthquake and coal and gas outburst in Pingdingshan eastern mining area have a certain correlation in time, space and intensity, and both of them are affected by the geological structure, with the same energy base and dynamic source. The seismic activity directly causes the physical damage of the gas reservoir, providing the conditions for the analysis and migration of the gas overflow in the coal mass. On the correlation between seismic activity and coal and gas outburst, tectonic movement plays a leading role, and coal and gas outburst is in a passive position. Tectonic movement causes coal and gas outburst and other mine dynamic disasters through stress disturbance.

5 Conclusions and suggestions

(1) The occurrence mechanism of coal and gas outburst and natural earthquake have been analyzed. Both of them are affected by tectonic activities and stress field changes. Tectonic activities and stress field changes have a unified mechanism for the occurrence of coal and gas outburst and natural earthquake.
(2) Pingdingshan eastern mining area and its surrounding areas are relatively high in North China (b value), and the tectonic stress level is lower than the average level of the whole North China region. The dynamic disasters in Pingdingshan eastern mining area are mainly coal and gas outbursts.
(3) Pingdingshan eastern mining area has been divided into I to V fault structures by geo-dynamic division method. The results

show that most of the earthquakes in the mining area are distributed near the fault structures, and the fault structures control the small earthquakes and microseismic events in the mining area.

(4) Natural earthquake and coal and gas outburst have certain relevance in time, space and intensity. The specific performance is that natural seismic activity affects the occurrence of coal and gas outburst events, the disturbance amplitude of *in situ* stress is the key role, tectonic movement is the leading role, and coal and gas outburst is in a passive position.

(5) According to the geological structure form and fault strike of the mining area, we should understand the influence of tectonic stress disturbance and mining pressure relief on the roof and gas release, find out the stress concentration area, and establish a standard ground pressure and gas monitoring system.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HR and SY wrote the main manuscript text. WS and GT were responsible for geo-dynamic division in Pingdingshan mining area. YW, DS, and BH were responsible for figure making and data analysis. All authors reviewed the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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