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Paleo-tectonic Stress Field and Tectonic Evolution since the Mesozoic in the Eastern Mining Area of Pingdingshan

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ABSTRACT

By observing a large number of conjugate shear joint data in the field and underground of the study area, the conjugate shear joint data is analyzed by the stereographic projection method, and the paleo-tectonic stress field experienced in the mining area since the Mesozoic is inferred. Based on the above research, the tectonic evolution process of the eastern mining area of Pingdingshan is discussed from the aspect of dynamic mechanism. The results show that: (1) The eastern mining area of Pingdingshan experienced the Indosinian, Yanshan early-middle, Yanshanian, and Xishanian tectonic stress fields, with the directions of NS, NW, NE, and NNE, respectively. (2) The tectonic evolution of the mining area can be divided into four stages: (a) The Indosinian tectonic stress field has the weakest effect on the study area, the coal-bearing strata are gradually uplifted by the stress field in this period, and some small structures are formed in the coal-bearing strata; (b) The early-middle Yanshanian tectonic stress field has a certain transformation effect on the coal-bearing strata in the eastern part of Pingdingshan. It mainly forms the secondary structure of the mining area such as Huoyan normal fault and small fault-fracture structure; (c) The late Yanshanian tectonic stress field has the strongest effect, and the control complex fold structure with the axis near NW direction is formed under the tectonic stress field of this period, such as Likou syncline, Baishishan anticline, Lingwushan syncline, Guozhuang anticline, Niuzhuang syncline, etc. The near-NW direction of the control fault structure is also formed under the action of the late Yanshanian tectonic stress field, such as the Niuzhuang reverse fault, the original No.11 mine reverse fault, etc.; (d) The Himalayan tectonic stress field mainly forms some secondary and small structures in the mining area and has a certain transformation effect on the structure formed by the early tectonic stress field. The tectonic pattern of the eastern mining area of Pingdingshan is the result of the above-mentioned tectonic stress field acting in sequence with the coal-bearing strata, causing structural deformation of the coal seam.

Keywords: paleo-tectonic stress field; gas occurrence; fault; fold; the eastern mining area of Pingdingshan.

Campo de estrés paleotectónico y evolución tectónica desde el mesozoico en el área minera oriental de Pingdingshan

RESUMEN

Tras recopilar una gran cantidad de datos de cizallamiento en campo y bajo tierra del área de estudio, se analizó esta información con el método de proyección estereográfica, y el campo de esfuerzo paleo-tectónico experimentado en el área minera desde que se infiere el Mesozoico. Luego de este análisis de información se discutió el proceso de evolución tectónica de la zona minera oriental de Pingdingshan con enfoque en el mecanismo dinámico. Los resultados muestran que: (1) El área minera oriental de Pingdingshan experimentó los campos de estrés tectónico Indosiniano, Yanshan temprano-medio, Yanshaniano y Xishaniano, con las direcciones de NS, NW, NE y NNE, respectivamente. (2) La evolución tectónica del área minera se puede dividir en cuatro etapas: (a) El campo de tensión tectónica Indosiniana tiene el efecto más débil en el área de estudio, los estratos portadores de carbón se elevan gradualmente por el campo de tensión en este período, y se forman algunas estructuras pequeñas en los estratos portadores de carbón; (b) El campo de tensión tectónica Yanshaniana de principios y medios tiene un cierto efecto de transformación en los estratos portadores de carbón en la parte oriental de Pingdingshan. Esto forma principalmente la estructura secundaria del área minera, como la falla normal de Huoyan y la estructura de fractura de fallas pequeñas; (c) El campo de estrés tectónico de Yanshanian tardío tiene el efecto más fuerte, y la compleja estructura de control de plegado con el eje cerca de la dirección NW se forma bajo el campo de estrés tectónico de este período, como la sinclinal de Likou, la anticlinal de Baishishan, la sinclinal de Lingwushan, la anticlinal de Guozhuang, la línea de sincronización de Niuzhuang, etc. La dirección cerca-NW de la estructura de falla de control también se forma bajo la acción del campo de tensión tectónica de Yanshanian tardío, como la falla inversa de Niuzhuang, la falla inversa original de mina No.11, etc.; (d) El campo de tensión tectónica del Himalaya forma principalmente algunas estructuras secundarias y pequeñas en el área minera, y tiene un cierto efecto de transformación en la estructura formada por el campo de tensión tectónica temprana. El patrón tectónico del área minera oriental de Pingdingshan es el resultado del campo de tensión tectónica mencionado anteriormente que actúa en secuencia con los estratos portadores de carbón, causando deformación estructural de la capa de carbón.

Palabras clave: campo de estrés paleo-tectónico; ocurrencia de gas; falla; doblez; la zona minera oriental de Pingdingshan.

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Introduction

China is the world's largest coal-producing country with abundant coal resources. The country's proven coal geological reserves are 114 billion tons, and its associated coalbed methane (mainly gas) is rich in resources, reaching 36.8 trillion m^3, ranking third in the world. Although coal's share of energy consumption has been declining in recent years, coal accounts for nearly 60% of China's primary energy consumption in 2018. Pingdingshan Mining Area is one of the 14 large coal bases planned by China (Wang, 2017). However, the mining area, especially in the eastern mining area, is generally deep, with a depth of up to 1200 m. The risk of geological disasters such as coal and gas outbursts and rock outbursts is high. How to prevent and control the above geological disasters has been a hot topic. Nearly 80% of coal and gas outburst accidents in the eastern mining area of Pingdingshan occur in geological structure areas (Gong & Guo, 2018). Therefore, studying the geological structure characteristics and its formation and evolution process can provide a geological guarantee for safe and efficient mining of coal mines. Due to the lack of corresponding magmatic activity in the mining area, it is difficult to determine the tectonic deformation period by the traditional isotope dating method, which makes the formation order and evolution law of the fault-fold structure always unclear. In this case, it is a more effective way to demonstrate the tectonic evolution process through the inversion of the tectonic stress field. The eastern mining area of Pingdingshan is located in the southern margin of the North China Plate and in the central part of Henan Province. The coal accumulation period of the mining area is mainly in the Carboniferous and Permian. The tectonic stress field evolution of the coalfield in this mining area is mainly studied after the coal formation, that is, the tectonic stress field after the Mesozoic. There are many pieces of research on the regional paleo-tectonic stress field in the Qinling-Dabie tectonic belt of the southern margin of the North China Plate and the Henan Province. However, there are few studies on the evolution of the paleo-tectonic stress field in the eastern part of the Pingdingshan, and the predecessors have carried out the inferential analysis, which is difficult to provide an effective basis for the tectonic evolution law of the mining area. Li (1987) believes that the evolution of the North China plate can be divided into six stages: craton, hyperplasia, initial cleavage, shear translation, fault depression, and equilibrium. Zhou and Wang (1999), and Jia, He and Lu (2004) believed that the Neogene Proterozoic in the southern margin of the North China Plate can be divided into four stages: volcanic activity, depression filling, differential lifting, and continental proliferation. Nie (1985) conducted a detailed study on the Yanshanian tectonic stress field in the North China Plate, and clarified the role of the five-curve tectonic movement in the Yanshanian period, and discussed the tectonic activity laws and mechanisms of the North China Plate in the Yanshanian period. Zhang, Dong, Zhao, and Zhang (2007) divided the tectonic evolution of the North China Plate during the Jurassic period into three stages. In the early Jurassic, the plate stratigraphy was uplifted, and the Early Middle Jurassic plate was in a weakly extended state. The Middle and Late Jurassic plate was at Squeeze the deformation state. Wu, Zhang, and Zhao (2000) studied the layered landforms of the plateau mountains in North China Plate and concluded that the first scene of the Xishan movement occurred in the Eocene to the Oligocene, and the second scene occurred in the Miocene to the Pliocene, the third scene began in the Quaternary and continues to this day. Liu and Zhang (2008) analyzed the formation of the basin-mountain system in the eastern Qinling-Dabie structural belt and considered that it was controlled by the tectonic stress field generated by the collision between different plates. Wang (2009) studied the tectonic evolution of the Henan region and believed that the Henan strata experienced the tectonic stress field of the Indosinian, the early Yanshanian, the late Yanshanian, the early Xishan, and the late Xishan in the Late Triassic to the Quaternary. The five-stage tectonic stress field determines the state and occurrence of coal seams and the distribution of structural coal in the coal-producing area. Pei, Ba, and Wang (2007)believed that the Pingdingshan area experienced the three tectonic stress fields of the Indosinian, Yanshanian and Himalayan periods during the Mesozoic Era, and the strong squeezing action of the Yanshanian tectonic stress field formed a large number of fault-reducing structures in the area, which basically laid the structural pattern. Zhang and Zhang (2003) believed that the compressive stress field from the southwestern side of the Yanshanian period caused the thrusting nappe action in the Pingdingshan mining area and formed the main structure of the mining area. Yan, Zhang, and Wang (2015) inferred from the regional tectonic evolution that the Pingdingshan mining area mainly experienced the three tectonic stress fields of the Indosinian, Yanshanian and Himalayan periods; Cui and Cai (2000) based on the interaction and movement process between the continental plate and the surrounding plate, it is believed that the Pingdingshan mining area experienced the Indosinian, Yanshan early-middle, Yanshanian, and Xishanian tectonic stress fields. In short, regarding the evolution of the tectonic stress field in the eastern mining area of Pingdingshan, the research that has been carried out is very limited, and the understanding of its evolution law is very limited. It is necessary to carry out systematic research work and provide key information for the tectonic evolution of the area. Based on the above situation, this paper carried out extensive field and underground observations on the joint structure of the eastern Pingdingshan mining area, obtained a large number of conjugate shear joint data. Through the stereonet stress field inversion software operation, the 4th paleo-tectonic stress field in the mining area since the Mesozoic was studied. On this basis, the tectonic evolution of the study mining area is analyzed, which provides important information for the tectonic evolution process and laws of the mining area, and provides a geological guarantee for safe mining in geological structure areas.

Regional geological background

The eastern mining area is located in the eastern part of the Pingdingshan Coalfield, which includes the No. 8 mine, No. 10 mine, No. 12 mine, and Shoushan mine. The main geologic structure of the mining area is the Likou syncline; the axial direction is roughly NW50°, and the axial surface is nearly upright. The northwest limb is relatively gently dipping, the southeast limb is relatively tight, and the two limbs are basically symmetrical; the stratigraphic inclination of this structure is generally 5-15°. There are many secondary folds that were developed by the two limbs of the Likou syncline, which are mostly NW-oriented, including the Niuzhuang syncline, the Guozhuang anticline, the Baishishan anticline, and the Lingwushan syncline. The fault structure is very developed in the mining area and mainly includes normal faults and strike-slip faults. The fault directions are divided into two groups: one is NW, including the Baishigou fault, the Huoyan fault, the F1 fault, and the Niuzhuang reverse fault; the other is NE, including the Goulifeng normal faults and some small faults (Figs. 1-3).

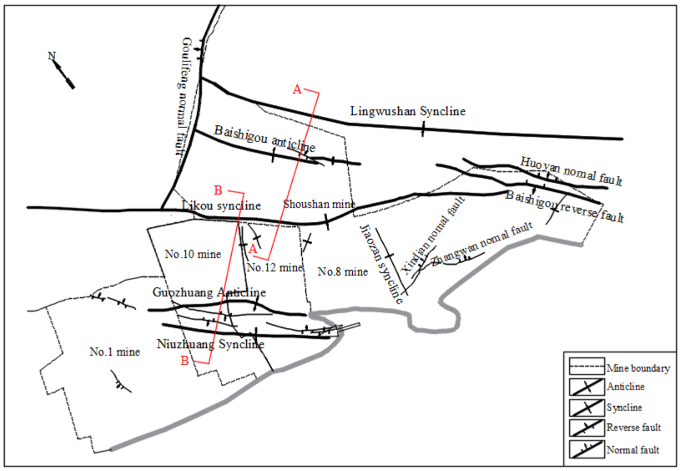

Figure 1. Geological structure outline and geostress measuring point distribution map of the Pingdingshan eastern mining area

Study on paleo-tectonic stress field in the eastern mining area of Pingdingshan

Principle of Inversion of Paleotectonic Stress Field by Conjugate shear joint

Joints are microfractures which are formed by the tectonic stress field acting on the rock stratum (Eyal, Gross, Engelder, & Becker, 2001; Bai & Pollard, 2000; De Guidi, Caputo, & Scudero, 2013). According to the type of tectonic stress field formed by joints, they are divided into tension joints and shear joints (De Guidi et al., 2013; Mandl, 2005). The relationship between shear joint and principal stress is similar to that of fault, but the accuracy of

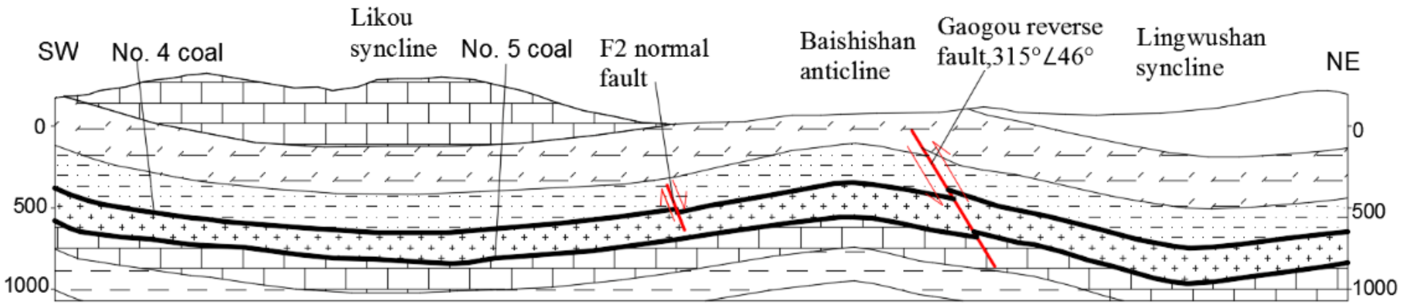

Figure 2. Likou syncline-Baishishan anticline-Lingwushan syncline profile map (A-A)

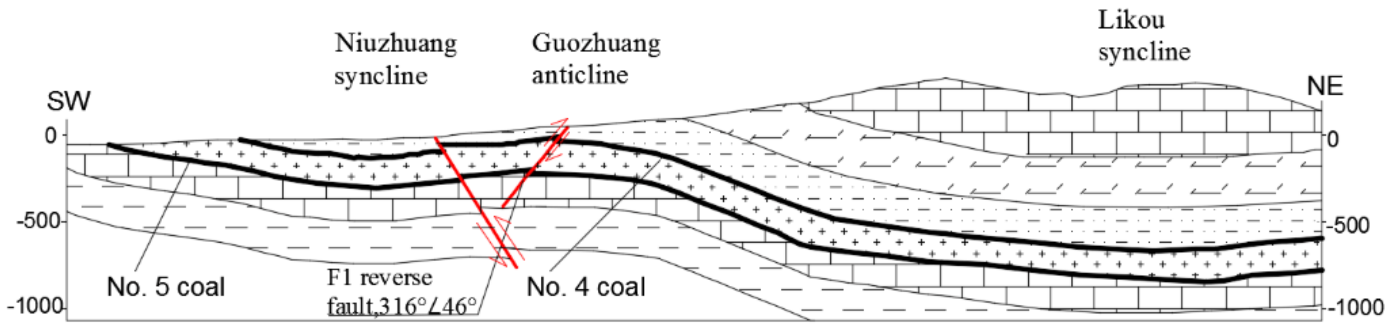

Figure 3. Niuzhuang syncline-Guozhuang anticline-Likou syncline profile map (B-B)

a shear joint inversion tectonic stress field is insufficient, and the reliability of conjugate shear joint inversion is greatly improved. Therefore, conjugate shear joints are commonly used in geological research to invert paleo-tectonic stress fields (Negrete-Aranda et al., 2010; Federico, Crispini, & Capponi, 2010; Veloso et al., 2015; Mazzoli, Santini, Macchiavelli, & Ascione, 2015; Naimi-Ghassabian, Khatib, Nazari, & Heyhat, 2015). The distribution of joints produced by the same tectonic stress field has a certain regularity, usually a large area is developed in the rock mass to form a specific structural pattern. The research area often experiences the multi-stage tectonic stress field. Each tectonic stress field forms a joint with a specific direction and mechanical properties. The joints formed in the early stage may be reconstructed by the late tectonic stress places, even superimposed with the joints formed by the late tectonic stress fields. Therefore, how to accurately match and stage the joint data is crucial for determining the direction and timing of the tectonic stress field. The staging of joints is to classify the joints produced by the tectonic stress field in different periods and divide the joints generated by the same tectonic stress field into a group. The matching of the joints is to determine whether the joints of different directions and properties are the products of the same tectonic stress field, that is, whether it is possible to form a conjugate shear joint. The shear joints of conjugate shear joints are formed in the same tectonic stress field, which should have similar spacing and density, and the joint fillings should be similar (Tang, Yang, Lv, Tang, Wang, 2018; Jiang et al., 2016; Fang, Sang, Wang, Shiqi, & Ju, 2017). Conjugate shear joints generally have microdislocations, and one set on the left, the other group on the right. The two shear joints with the above characteristics can be judged as conjugate shear joints, and conversely, they are not conjugate shear joints. If the observed joints are at the horizontal level or approximately at the horizontal level, the three principal stress directions can be directly inverted (Eyal et al., 2001; Rawnsley, Peacock, Rives, & Petit, 1998; Arlegui & Simon, 2001). The relationship between the spatial orientation of the three principal stresses and the conjugate shear joint is: The direction of the bisector of the acute angle between the two sets of shear joints is the action direction of σ1, and the direction of the blunt angle of the obtuse angle is the action direction of the minimum principal stress σ3. The intersection line direction of the two sets of shear joints face is the action direction of the intermediate principal stress σ2 (Fig. 4).

The rock formation usually has a certain angle with the horizontal plane, especially the structural areas such as faults and folds that may intersect the horizontal plane at a large angle. When using the shear joints in the inclined rock to carry out the stress field inversion, the joint production needs to use

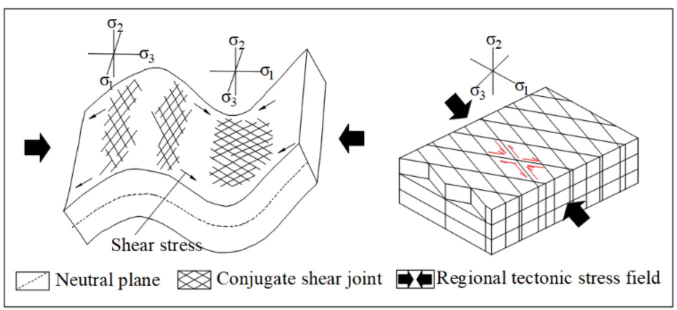

Figure 4. Relationship between plane conjugate shear joint and principal stress axis

the stereographic projection method for azimuth correction (Eyal et al., 2001; Rawnsley et al., 1998; Arlegui & Simon, 2001). The projection tool of the stereographic projection is a sphere. The planar structure such as joint and linear structure can be expressed by the surface or line passing through the center of the sphere. The intersection of the planar, linear structure and the projection sphere is a circle and a point, respectively. All intersections between the planar structure and the lower hemisphere are connected to the pole (divided into upper and lower poles) by straight lines. These lines form part of the conical surface, and the intersection of this cone and the horizontal plane passing through the center of the sphere is an arc. This arc is the stereographic projection of the planar structure (Fig. 5), the projection principle of the linear structure is similar to the planar structure, and its red projection is a little (Fig. 6) (Fosse, 2010). The above pole is the connection point, called the lower hemisphere projection, otherwise, it is called the upper hemisphere projection. In the joint analysis of this paper, the lower hemisphere projection is used in this paper. The correction of the joint occurrence of the inclined rock layer is to project the observed joint onto the red plane through the stereographic projection theory. Around the strike line, the joint rotation is at the same angle as the inclination angle, and the rotation direction is opposite to the joint tendency, that is, the corrected shear joint data is obtained. The corrected joint occurrence data can be solved according to the relationship between the conjugate shear joint and the three principal stresses. In this paper, the conjugate shear joint occurrence is corrected by the stereo projection analysis software Stereonet 10.0, and the

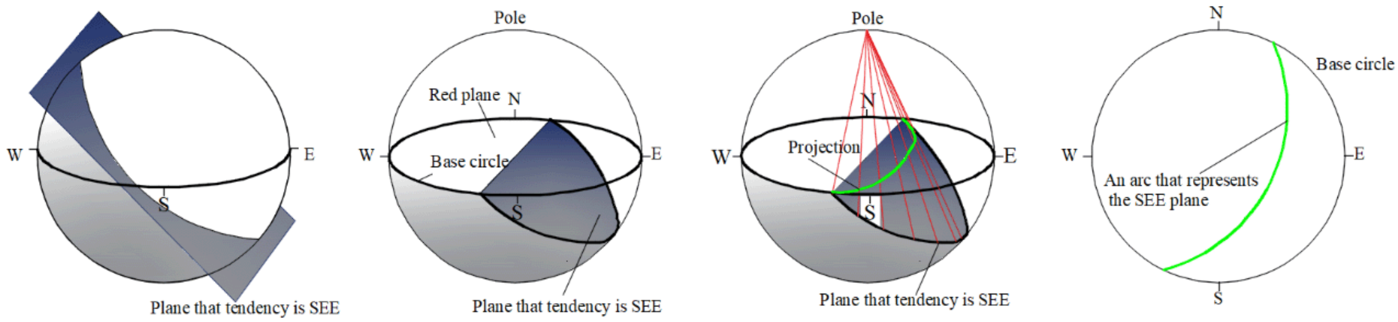

Figure 5. The principle of plane stereographic projection

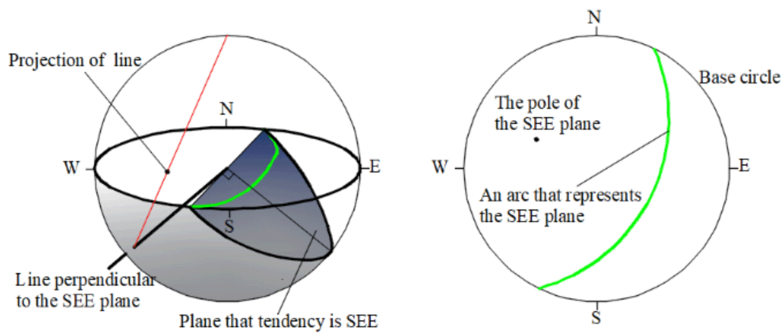

Figure 6. The principle of a stereographic projection of points

direction of the tectonic stress field is analyzed by the software. Conjugate shear joint inversion of paleo-tectonic stress fields has been successfully used in several studies (Federico et al., 2010; Mazzoli et al., 2015; Foeken, Bertotti, & Dunai, 2006).

Joint features of the eastern mining area of Pingdingshan

In this paper, in the study of the tectonic stress field in coal mining areas, the underground conjugate shear joint is innovatively combined with the field conjugate shear joint to invert the tectonic stress field, which improves the accuracy and has significant significance for studying the tectonic stress field evolution in the mining area. Considering the topography, the field geological structure, and the underground geological structure factors, 32 conjugate shear joint points are finally selected. Among them, there are 26 field measurement points, at least 40 joints are measured at each measurement point, and a total of 1483 joints are measured. The stratum is mainly the Triassic lower purple-red layered medium-grain sandstone and the Permian Shiqianfeng group coarse-grained sandstone; There are 6 downhole measuring points, and at least 40 joints are tested at each measuring point. A total of 333 underground joints are tested. The stratum is mainly composed of Permian lower ash fine sandstone. The distribution of field and underground conjugate shear joints measurement points is shown in Figure 7. In this section, according to the conjugate shear joint data of the test, the rosette diagram of the joints occurrence of each test point is drawn, the dominant orientation and representative occurrence of the conjugate shear joint are determined, and the extrusion direction of the paleo-tectonic stress field in each stage of the mining area is finally analyzed.

The joint features of different measuring points have common features and differences. The common features of joints are: most of the measuring points develop 2-3 stable shear joints, and the rock is often cut by the shears joint in a rhombic shape or a checkerboard shape, and the two shear joints of the conjugate shear joint are almost isometric arrangement; The shear joint is generally smooth, and the shear joint is usually closed when it is not filled, and the scratches left by the shear stress field are occasionally observed on the joint surface; the conjugate shear joints are larger and the density is smaller when the rock layer is thicker, on the contrary, the scale is smaller and the development density is larger. (Figs. 8-9). There are differences in the shear joints of different measuring points. Some shearing joints have small scales, and the conjugate shear joints have a diamond-shaped side length of only about 10 cm, but the conjugate shear joints have a higher density. While some of the measuring points have larger scales, the diamond or chess side is up to 50 cm long and its density is relatively small (Figs. 8-9).

Figure 7. Measuring point and Joint strike rose distribution diagram in the eastern mining area of Pingdingshan

The conjugate shear joints in the eastern part of Pingdingshan are mostly high-angle joints, and the rose diagram of joint strike and the dip distribution histogram are drawn for the 1816 joints measured (Figs. 10-11). The results show that the joint trend is most developed with NEE, followed by EW and NNW, which reflects the role of the multi-period tectonic stress field in the study area. The joint inclination angle is most developed at 80-85°, followed by 75-80° and 85-90°. The high-angle joints belong to the early plane conjugate shear joints, after the slope of the stratum in the later period, the joint occurrence changes. Therefore the joint occurrence is corrected first, and then the direction of the tectonic stress field can be analyzed.

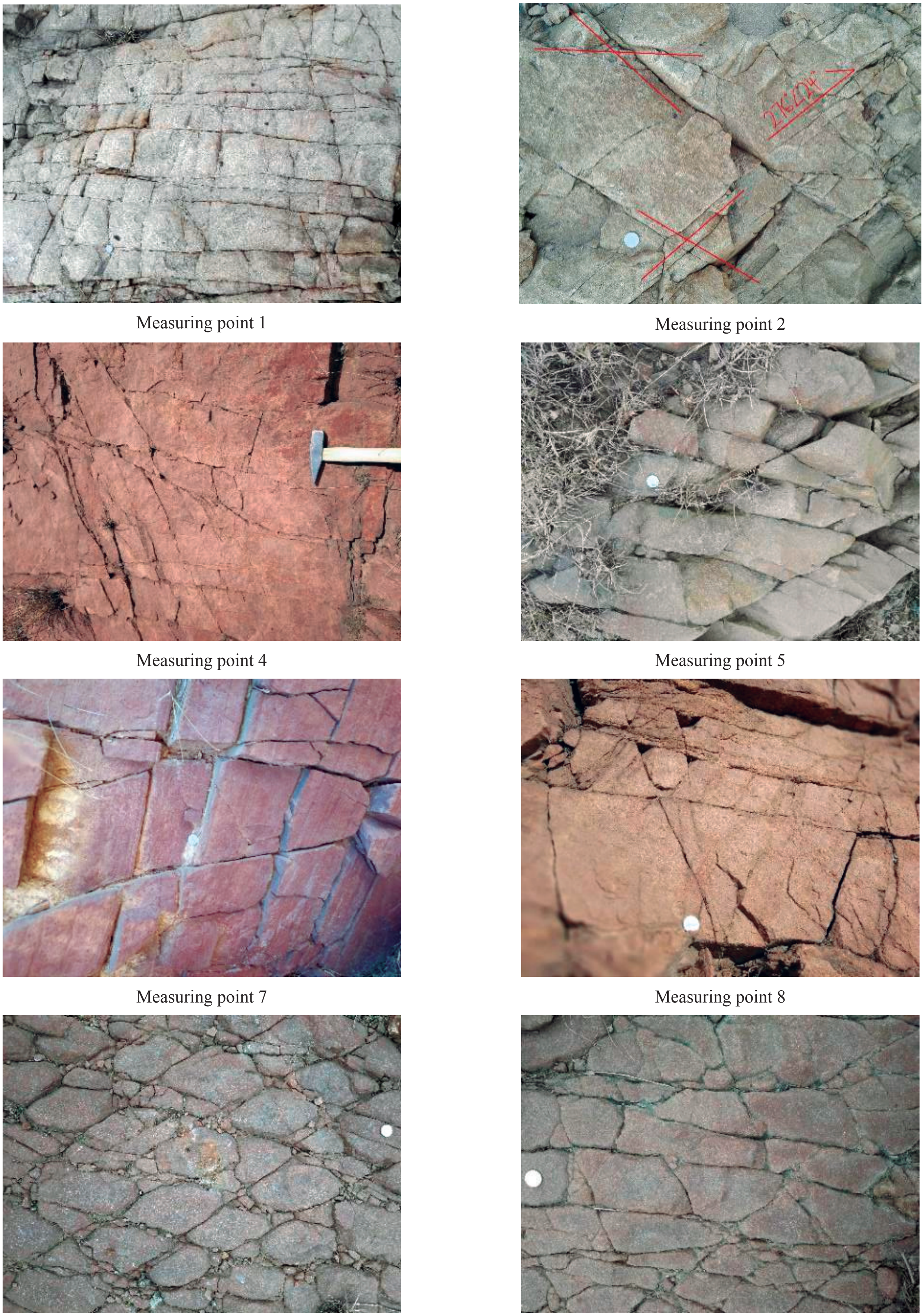

Figure 8. Joint development characteristics of field measurement points

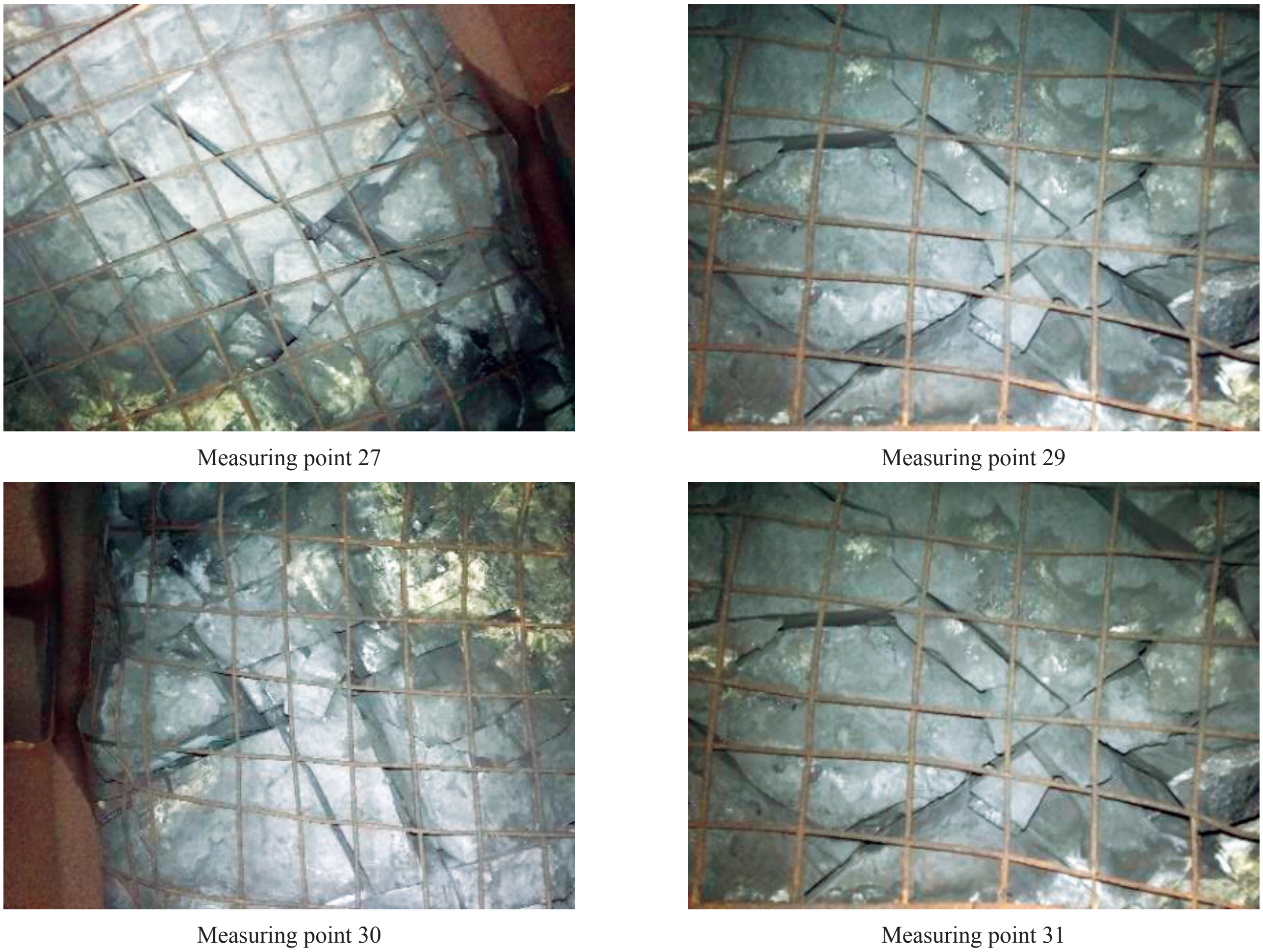

Figure 9. Joint development characteristics of underground measuring points

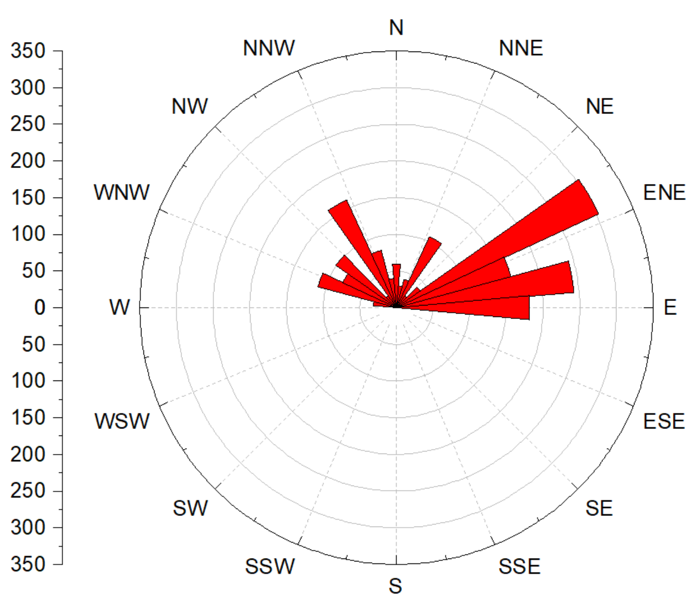

Figure 10. The rose diagram of shear joints strike

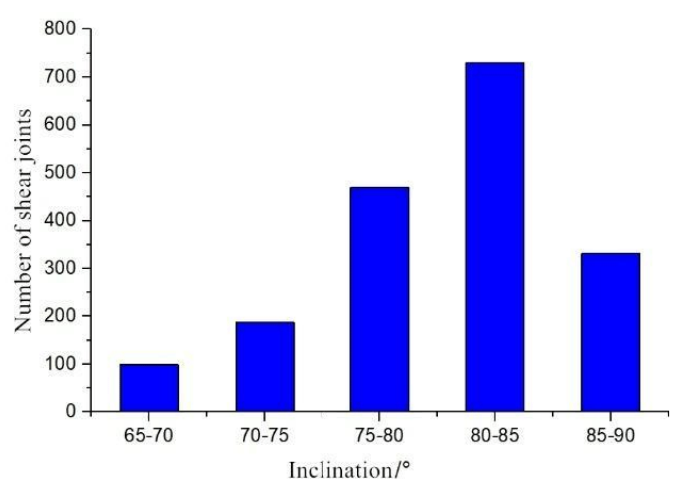

Figure 11. The distribution histogram of shear joints inclination

Inversion results of the paleo-tectonic stress field

The shear joints were corrected by Stereonet 10.0 software, and the stress field inversion was finally performed. The inversion results are shown in Figure 12 and Table 1. The maximum principal stress direction of the inversion results is mainly concentrated in four directions. The direction of the 12 measuring points is near the NE direction, the specific orientation is 212.6-239.5°, and the average is 222.7°; the maximum principal stress direction of 8 measuring points is nearly NW. The specific orientation is 305.8-336.9°, with an average of 317.9°; the maximum principal stress direction of 8 measuring points is near NNE, the specific azimuth range is 194.6-200.9°, and the average is 198°; the maximum principal stress direction of 4 measuring points is near NS direction, the specific orientation is 354.1-6.3°, with an average of 359.1° (Table 1). According to the above results, the eastern mining area of Pingdingshan has experienced at least four tectonic stress fields. The first stage tectonic stress field is in the direction of NS, the conjugate shear joints preserved in this tectonic stress field are the least, indicating that the tectonic movement in this period is relatively early, combined with the evolution process of the paleo-tectonic stress field of the North China Plate, the tectonic stress field should be the Indosinian tectonic stress field; The direction of the second-stage tectonic stress field is near NW direction. The conjugate shear joints produced by the tectonic stress field in this period are more preserved, indicating that the stress field in this period is more intense. Combined with the

Table 1 Inversion results of principal stress directions of joint points in the eastern mining area of Pingdingshan

Measuring point number	Representatives occurrence of joint set 1	Representatives occurrence of joint set 2	Principal stress axes			Period of tectonic stress field action
			σ_1	σ_2	σ_3	
1	86°∠78°	355°∠84°	311°∠4.2°	58.9°∠76.6°	220∠12.7°	The Indosinian Period
2	115°∠78°	344°∠80°	229.1°∠25.1°	51.9°∠64.9°	319.6°∠1.1°	The late Yanshanian Period
3	60°∠83°	118°∠80°	359.4°∠3.1°	106.9°∠79.8°	268.9°∠9.7°	The Indosinian Period
4	95°∠80°	344°∠82°	219.3°∠15.6°	43.9°∠74.3°	309.6°∠1.2°	The late Yanshanian Period
5	174°∠85°	85°∠78°	219°∠5°	106.5°∠77.1°	310°∠11.8°	The late Yanshanian Period
6	182°∠83°	89°∠70°	317.2°∠10.2°	110.3°∠68.7°	224.0°∠8.9°	The early-middle Yanshanian Period
7	146°∠69°	70°∠85°	20.4°∠12.8°	123.2°∠73.9°	339.5°∠13.1°	The Himalayan Period
8	254°∠89°	143°∠80°	19.1°∠9.6°	169.1°∠78.9°	288.2°∠5.5°	The Himalayan Period
9	75°∠82°	168°∠80°	214.4°∠3.7°	112.5°∠72.7°	305.5°∠16.9°	The late Yanshanian Period
10	84°∠80°	191°∠82°	317.7°∠14.9°	132.7°∠75°	227.4°∠1.2°	The early-middle Yanshanian Period
11	328°∠82°	241°∠84°	194.6°∠1.5°	293.1°∠80.3°	104.4°∠9.6°	The Himalayan Period
12	165°∠70°	93°∠75°	40.1°∠4.2°	140.8°∠68.2°	308.4°∠21.3°	The late Yanshanian Period
13	260°∠85°	182°∠69°	308.7°∠12.6°	183.2°∠69°	42.5°∠16.5°	The early-middle Yanshanian Period
14	45°∠89°	123°∠86°	354.1°∠2.4°	120.6°∠86°	264.9°∠3.2°	The Indosinian Period
15	332°∠75°	248°∠83°	200.9°∠6°	312.4°∠74.1°	109.3°∠14.7°	The Himalayan Period
16	186°∠72°	103°∠75°	55°∠2.3°	150.7°∠68.3°	324.1°∠21.6°	The late Yanshanian Period
17	92°∠82°	20°∠79°	145.7°∠2.6°	43.5°∠78°	236.2°∠11.7°	The early-middle Yanshanian Period
18	255°∠80°	25°∠83°	140.5°∠19.5°	315.25°∠70.4°	49.9°∠1.7°	The early-middle Yanshanian Period
19	76°∠79°	324°∠85°	199.4°∠14.1°	34.3°∠75.4°	290.3°∠3.6°	The Himalayan Period
20	310°∠87°	82°∠81°	195.3°∠14.5°	28.6°∠75.1°	286.1°∠10.3°	The Himalayan Period
21	270°∠80°	340°∠82°	34.8°∠1.7°	295.8°∠78.9°	125.1°∠10.9°	The late Yanshanian Period
22	175°∠83°	92°∠78°	223°∠3.8°	116.7°∠76.8°	313.9°∠12.6°	The late Yanshanian Period
23	215°∠88°	97°∠79°	336.9°∠12.5°	133.3°∠76.4°	245.7°∠5.2°	The early-middle Yanshanian Period
24	240°∠76°	116°∠82°	356.9°∠22.5°	186.4°∠67.2°	88.3°∠3.4°	The Indosinian Period
25	167°∠80°	136°∠75°	239.5°∠9.3°	114.9°∠74°	331.7°∠13°	The late Yanshanian Period
26	152°∠81°	62°∠86°	17.3°∠3.5°	128.2°∠80.2°	286.7°∠9.2°	The Himalayan Period
27	77°∠88°	175°∠84°	305.8°∠6.1°	149.5°∠83.4°	36.1°∠2.6°	The early-middle Yanshanian Period
28	342°∠85°	263°∠88°	212.6°∠2.4°	330°∠84.9°	122.4°∠4.5°	The late Yanshanian Period
29	309°∠84°	244°∠82°	6.3°∠1.9°	263.7°∠81.5°	96.6∠8.3°	The Indosinian Period
30	323°∠84°	73°∠78°	197.3°∠15.4°	31.3°∠74.1°	288.3°∠3.7°	The Himalayan Period
31	122°∠76°	161°∠81°	230.1°∠7.4°	109.3°∠75.7°	321.7°∠12.2°	The late Yanshanian Period
32	90°∠76°	343°∠82°	215.7°∠18.1°	48.2°∠71.5°	306.9,°∠3.7°	The late Yanshanian Period

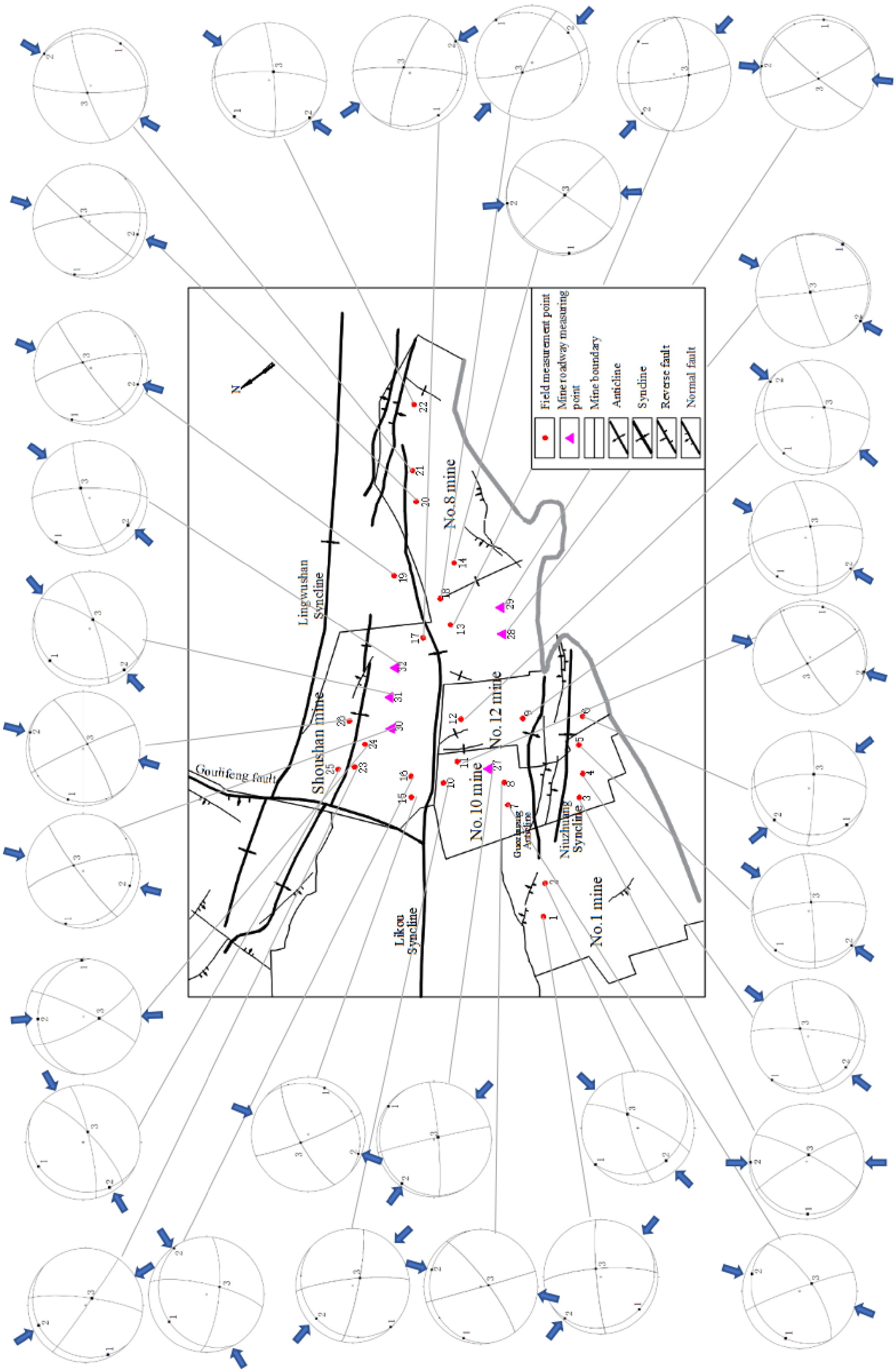

Figure 12. Schematic diagram of the action direction of paleo-tectonic stress field at each measuring point in the eastern mining area of Pingdingshan

tectonic movement evolution process of the North China plate and previous research data, it is believed that the period of tectonic stress field in this period should be Yanshan early-middle; The direction of the tectonic stress field in the third stage is near NE direction. The shear joints generated by the tectonic stress field in this period are the most preserved in the study area, indicating that the tectonic stress field has a strong effect in this period, and a large number of tectonic deformations are formed in the mining area. Combined with the regional tectonic evolution process, the direction of the tectonic stress field in this period is consistent with the late Yanshanian, and it should be the late Yanshanian tectonic stress field; The direction of the tectonic stress field in the fourth stage is near NNE. The shear joints generated in this period of tectonic stress field are preserved in the study area, but the intensity of the action is weak and the late Yanshan tectonic stress field, combined with the regional tectonic evolution history, the stress field should be Himalayan tectonic stress field. In summary, according to the measured shear joint data, the strata of the eastern Pingdingshan mining area have experienced at least the Indosinian, Yanshanian, Yanshanian and Himalayan period four tectonic stress fields.

Tectonic evolution since the Mesozoic in the eastern mining area of Pingdingshan

The stratum of the eastern mining area of Pingdingshan was uplifted in the Caledonian period, causing the surface to be denuded and the mining area to develop into a quasi-plain. This is an important factor affecting the stable deposition of the Carboniferous and Permian coal seams in the Pingdingshan mining area. The Pingdingshan mining area finally formed a Carboniferous-Permian coal-bearing stratum with a thickness of 800 m, of which the thickness of the coal seam is nearly 30 m, and the coal quality is mainly coal, fat coal, and coking coal. After the formation of the coal-bearing strata, the eastern mining area of Pingdingshan mainly experienced the Indosinian period, the Yanshan early-intermediate period, the late Yanshanian period, the Himalayan period tectonic stress field.

(1) Indosinian tectonic stress field

The Indosinian tectonic movement occurred in the early Mesozoic era and was of great significance to the entire Chinese region. Yin and Nie believe that the splicing of the North China Plate and the Yangtze plate in the Indosinian period is completed from east to west, and the splicing line is the Yanlu fault-Dabieshan-Qinling structural belt. The large number of tectonic traces generated by the tectonic stress field in the North China plate has been identified by many scholars. These studies all indicate the existence of the Indosinian tectonic stress field. The study area is located in the southern part of the North China Plate, which was the ancient Qinling ocean during the early Indosinian period, and the ancient Qinling ocean disappeared in the late Indosinian period, then the area was elevated to land. The conjugate shear joint data observed in the study area shows that the direction of the Indosinian tectonic stress field in this area is close to the N-S direction, and the intensity is not strong. The Indosinian tectonic stress field has little effect on the tectonic pattern of the Pingdingshan mining area, and there is almost no EW structure in this area which can support this view very well (Fig. 13). The Indosinian tectonic stress field is also weak for the coal seam transformation, mainly manifested by the gradual uplift of the coal-bearing strata. The coal seam reaches the maximum depth (more than 2000 m) at the end of the Early Triassic, and the coal body undergoes deep metamorphism during the ascending process, the effect is accompanied by a large amount of gas generation.

(2) The early-middle Yanshanian tectonic stress field

The early-middle tectonic stress field of Yanshan movement is mainly caused by the subduction of the western Pacific plate to the North China plate, which causes the North China plate to be subjected to the near NW direction of the compressive stress field. The tectonic stress field has a strong effect on the eastern part of the North China plate, and a series of NNE thrust structures are formed in the eastern part. However, the energy loss in the eastern part is large, and the energy transfer to the southwestern part of the North China plate is weak. The eastern mining area of Pingdingshan is located at the southern margin of the North China plate. Therefore, the mining area is weakly affected by the near NW-oriented compressive tectonic stress field in this period, and does not form a controlled structure of the mining area. Only a small number of secondary and small fold structures with a near-NE direction are formed, such

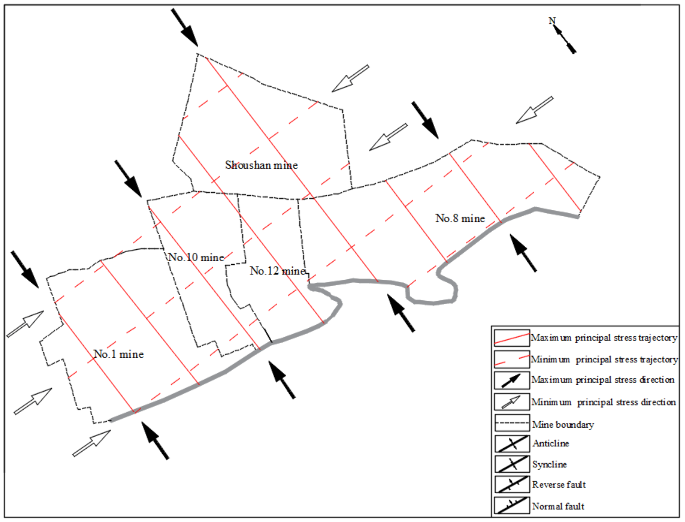

Figure 13. Indosinian tectonic stress field in the eastern mining area of Pingdingshan

as the Jiaozan syncline and some small folds in the 12 minefields. Moreover, a small amount of near-NW secondary strike-slip faults and normal faults are also formed under the stress field of this period, such as the Huoyan normal fault (Fig. 14). A large number of small normal faults with NW or NNW strike are developed in the coal-bearing strata of the mining area. These faults are mainly formed by the tectonic stress field in this period. Though the coal-bearing strata in the eastern part of Pingdingshan are in the gradual uplifting stage in the early-middle Yanshan, the buried depth of the coal seam is still very deep, and the gas storage conditions in the coal seam are good, so it is still an important period for the massive formation of coalbed methane and the deep metamorphism of coal.

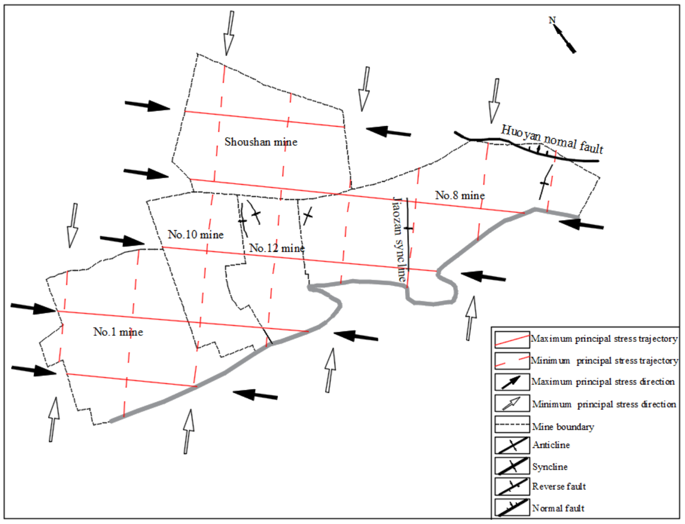

Figure 14. The early-middle Yanshanian tectonic stress field in Pingdingshan eastern mining area

(3) The late Yanshanian tectonic stress field

At the end of the Eocene, the Pacific plate swooped directly into the East Asian continent, moving in the direction of NWW, and acting strongly on the East Asian continent in the form of strong convection, leading to the rifting climax of the period during this period; At the same time, from the Late Jurassic to the Early Cretaceous, the Qinling-Dabieshan tectonic belt experienced a strong thrust-overlifting movement in the near-NS direction. The above tectonic movement caused the late Yanshanian North China plate to be subjected to the near-NE thrusting tectonic stress field. According to the inversion result of the conjugate shearing joint in the previous section, the study area was also subjected to a strong compressive stress field near NE in this period. The near NE direction of the compressive stress field causes the regional strata to undergo more intense fold orogeny on the basis of the pre-structural movement. A series of controlled fold structures and reverse faults in the mining area approaching the NW direction were formed during this period, such as Likou Xiangshi, Baishishan anticline, Lingwushan syncline, Guozhuang anticline, Niuzhuang syncline, Niuzhuang inverse. Fault, Baishigou reverse fault, the original eleventh reverse fault (Figs. 15-17).

In this period, the tectonic stress field exhibits a stretching effect in the NW direction. Some near-NE positive faults are formed in the study area, such as the Goulifeng normal fault, but the NE-trending tectonic development is far less than the NW-trending structure. The NW and NWW structure are often cut off by the NE and NNE structures, such as the Likou syncline, the Lingwushan syncline, and the Baishishan anticline, which are cut by the Goulifeng normal fault, indicating that the NE and NNE structures were formed later than NW and NWW structures. Likou syncline and Lingwushan syncline are the two longest fold structures in the mining area. Likou syncline NE wing inclination angle is 8-23°, the SW wing inclination angle is 10-25°, and the SW wing is steeper than the NE wing. Lingwushan is asymmetric with two wings, the SW wing is steep, the dip angle is 10-25°, the NE wing is slow, and the dip angle is 10-18°. Both of the synclines show that the SW wing is steep, reflecting that the active force direction of the compressive stress field should be on the southwest side. In addition, a large number of small normal faults with NE strike and a few of small reverse faults with NW strike are developed in the coal seam by the late Yanshanian tectonic stress field, and tectonic coals in these tectonic zones are widely developed. A large amount of magmatic activity occurred in the eastern and northern parts of the North China Plate during this period. However, almost no magmatic intrusion activity was found in each mine in the eastern mining area of Pingdingshan.

(4) Himalayan tectonic stress field

In the late Eocene, the North China plate entered the Himalayan tectonic movement, and the northward movement of the Indian plate collided with the Eurasian plate. The northeastern part of the Indian plate wedged northward into the Tibet-Yunnan foreland basin, and the stress field appeared as an extruded type. In the western part of the Chinese mainland, the Himalayas and the Gangdese Mountains were formed. In this period, the tectonic stress field is mainly characterized by large-scale sedimentation and stratigraphic depression in the east, and the North China plate was dominated by regional sedimentation that accompanied the uplift of the surrounding mountainous areas. According to the results of the conjugate shearing inversion in the previous section, the eastern mining area of Pingdingshan is subject to the near NNE-oriented

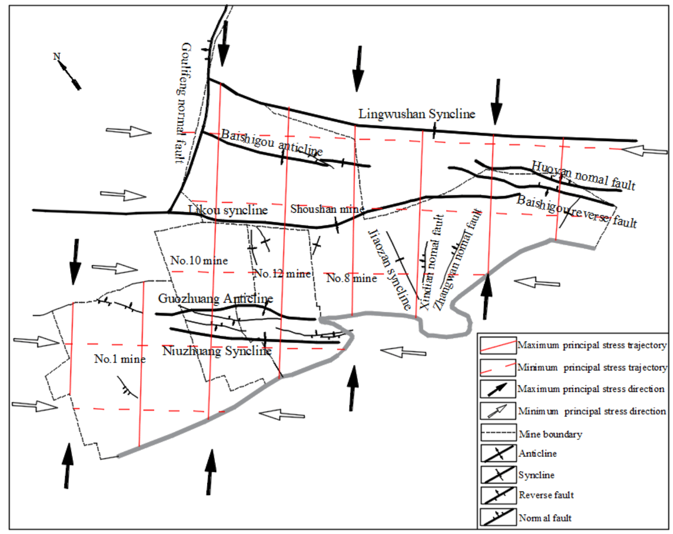

Figure 15. The late Yanshanian tectonic stress field in Pingdingshan eastern mining area

squeeze tectonic stress field during the Himalayan period, but the stratigraphic deformation in this tectonic movement is weaker than that in the late Yanshanian tectonic movement, some secondary or small folds and faults were formed during this period. The structure formed in the early stage is reconstructed by the tectonic stress field in this period. For example, the strike of the Zhangwan normal fault is deflected from the near NEE to the near EW direction (Fig. 18).

Conclusion

(1) Through the field and underground conjugate shearing joint observation, the direction of paleo-tectonic stress field in the eastern mining area of Pingdingshan was determined by using stereographic projection method. The results show that the eastern mining area of Pingdingshan has experienced the Indosinian, Yanshan early-middle, Yanshanian and Xishanian tectonic stress fields, with the directions of NS, NW, NE, and NNE, respectively. The late Yanshanian tectonic stress field has the strongest intensity and the Indosinian period has the lowest intensity.

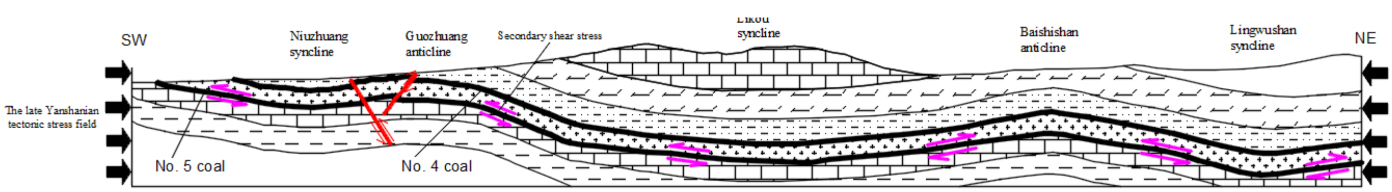

Figure 16. The formation of the partition style folded belt

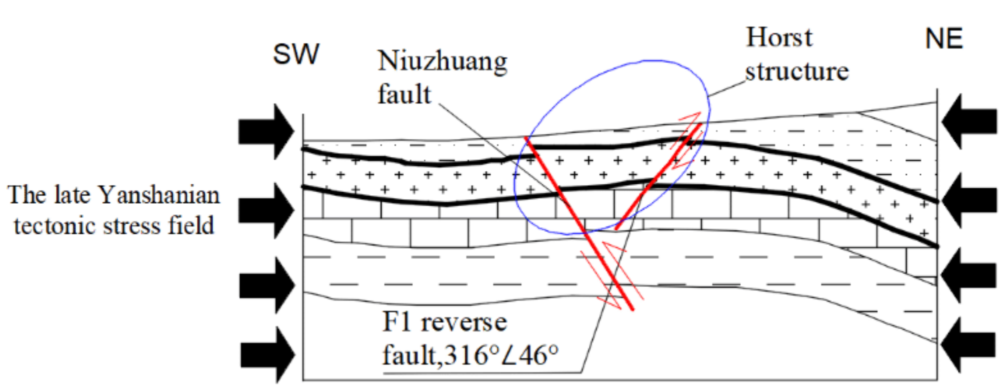

Figure 17. The formation of horst structure

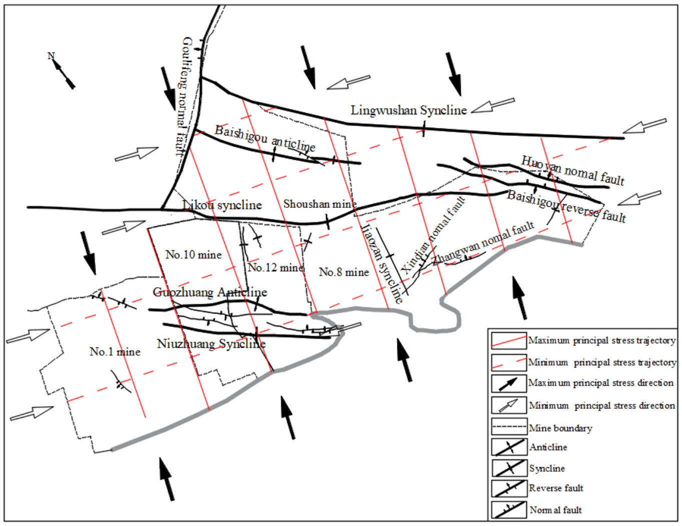

Figure 18. Himalayan tectonic stress field in eastern Pingdingshan mining area

(2) Indosinian tectonic stress field is mainly characterized by the gradual uplift of coal-bearing strata, and a small number of near-EW-oriented small structures are formed in this period; The early-middle Yanshanian tectonic stress field is stronger than the Indosinian period. A small number of secondary and small fold structures with a near-NE direction are formed, such as the Jiaozan syncline. A small amount of near-NW secondary strike-slip faults and normal faults are also formed, such as the Huoyan normal fault. Moreover, a large number of small normal faults with NW or NNW strike are developed in the coal-bearing strata of the mining area; The late Yanshanian tectonic stress field has the strongest effect. A series of controlled fold structures and reverse faults in the mining area approaching the NW direction were formed during this period, such as Likou Xiangshi, Baishishan anticline, Lingwushan syncline, Niuzhuang reverse Fault, Baishigou reverse fault, et al. In addition some near-NE positive faults are formed in this period, such as the Goulifeng normal fault; Some secondary or small folds and faults were formed by the Himalayan tectonic stress field, and the structure formed in the early stage is reconstructed by the tectonic stress field.

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