Analysis on characteristics of tectonic stress field of fractured rock mass based on surface joint distribution

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Abstract. Tectonic stress is an important factor influencing the development of joints. The tectonic stress in Jijicao is preliminary analyzed based on joints measurement, structural features tracing and stereographic projection. It is considered that the NW and NE trending tectonic systems in the study area belong to the products of different tectonic processes in different times. After intrusion, Jijicao granite rock mass has been forced in normal fault type stress, and the NW steeply dipping joints under vertical maximum principal stress and horizontal minimum principal stress squeezing on NE generated. Thereafter, the in-plate action is adjusted, and the minimum principal stress is deflected from NE to NW, resulting in a steep inclined joint system with the maximum principal stress nearly perpendicular and the minimum principal stress being subjected to NW horizontal extrusion.

1. Introduction  
Because of well engineering properties, granite has been selected as one of the surrounding rock types of radioactive waste geological repository [1]. However, in the long geological evolution process, due to the internal and external dynamic geological action, a large number of discontinuities of different sizes and occurrences (such as faults, joints and weathering cracks) have been produced on the surface and inside of rock mass, which destroys the integrity of rock mass and affects the mechanical properties of rock mass. And the large number of joints in rock mass also provide a flow channel for groundwater and affect the migration of radionuclide. One of the main factors of migration and diffusion [2]. Structural transformation is the main factor affecting the formation of many rock mass structures. Tectonic stress often determines the generation and development of interruptions and joints in strata [3,4]. Therefore, the analysis of tectonic stress field has important practical significance for understanding the overall mechanical properties and permeability characteristics of rock mass.

In the analysis of tectonic stress field, it is a key link to select the appropriate structural fracture to restore the paleostress state [5,6]. Based on this idea, the tectonic stress characteristics of the Jijicao rock mass are analyzed by means of structural trace screening and stereographic projection on the basis of joints measurement.

2. Geological overview of Jijicao unit rock mass
The Jijicao rock mass extends in NW-SE direction. Granite outcropped well in the eastern part of the rock mass, while the central and western parts have a large number of metamorphic and gabbroresidues, which make the contact zone in the shape of a harbour. It is 13 km long in the northwest and 3–4 km wide in the northeast, with an area of about 26 km². It is a small Gobi beach landform in low hills. The metamorphic rock horns at the top of the rock mass are obvious. There are a
large number of granite veins, pegmatite veins, fine-grained veins and basic veins in the rock mass and in the top and edge rocks.

The study area is located at the junction of Dunhuang massif, Caledonian fold belt in North Qinling Mountains and Caledonian fold belt in Qilian Mountains. The formation of the tectonic traces in the area and its spatial distribution, as well as the characteristics of each stage of tectonic stress field, are closely related to the tectonic effects of the three tectonic units.

3. Overview of the distribution of structural planes in the study area
The structure of the study area is mainly a complex structural system composed of faults, veins and a series of structural fractures. According to the spatial distribution of structural traces in the study area and its surrounding areas, the structural traces can be divided into NE and NW structural systems:

(1) NE trending tectonic system
It is mainly composed of a series of faults, veins and joints in the NE-NEE trend, including two sets of structural planes inclined to NW and SE respectively. Among them, the structural planes tending to NW are more developed. The two sets of structural planes are mainly torsional, and tensile structural planes also occupy a certain proportion, but most of them are related to the later tectonic transformation. It is formed in the stress environment where the maximum principal stress is vertical and the minimum principal stress is horizontal.

(2) NW trending tectonic system
It consists of a series of faults, veins and fissures in the direction of NW-NWW, including two groups of medium and steep inclined structural planes and a set of gently inclined structural planes, which tend to NE and SW respectively. Among them, the structural plane with the tendency SW is the most developed, and the structural plane of NE tends to be the second, while the gently inclined structural plane does not have obvious azimuth advantage. In stereographic projection, only the strips are shown to be connected from the sides of NE and SW to the center respectively. Although the strike of the gentle dip structural planes is consistent with that of the middle and steep dip structural planes, the tectonic environment and the sequence of their formation are different from those of the steep dip structural planes, which are the products of the later tectonic processes. Among the structural planes of each group, the two structural planes with steep inclination are mainly torsion and tension (twist), while the medium and gentle inclined structures are mainly torsion and compression. The stress environment formed by NW trending tectonic system is relatively complex, which has undergone repeated and superimposed effects of multi-stage tectonics.

According to the joints occurrence data measured in the study area, the equal density graph of the joints is drawn (Figure 1). The joints in the survey area are divided into five sets. The distribution range and dominant position of each set are shown in the Table 1.

![Figure 1 Equal density graph of the joints (episphere)](image)
Table.1 Grouping and Major azimuths of joints

| Sets | Strike      | Dip        | Dominant strike | Dominant dip |
|------|-------------|------------|-----------------|--------------|
| 1    | 199~270     | 43~89      | 239             | 74           |
| 2    | 272~332     | 34~89      | 303             | 66           |
| 3    | 13~92       | 42~89      | 56              | 63           |
| 4    | 101~170     | 60~87      | 136             | 72           |
| 5    | 0~360       | 0~30       | 97              | 12           |

4. Joints matching by stage

The tectonic joints in the Jijicao rock mass were formed after the emplacement of the granite. From the number, density and scale of the tectonic joints, it can be seen that the rock mass in the area has undergone many stages of structural changes and structural transformation, which corresponds to the formation of a multi-stage complex fractures system. Generally speaking, structural planes formed by the same period of tectonic change often have certain systematic characteristics. Therefore, rationalizing the derivative relationship between the structural plane system and the stress environment is the key to clarify the evolution of the tectonic stress field and the evolution process of the structural plane. For this reason, based on the basic principle of structural analysis and detailed statistical investigation of various structural planes in the survey area, the structural trace screening method is used to stage with various types of joints[7].

4.1 Staging of tectonic joints

The staging of joints is usually based on two aspects. One is based on the intersection and restriction of the joint group, and the other is relations between joints of different stages and related geological bodies. However the most direct basis is the intersection relationship of the joint group.

(1) Intersection of joints

Acidic veins are widely developed in the study area, and filled in the joint fissures corresponding to NE and NW tectonic systems. Their intersection and dislocation with the joint formations better reflect the early-late relationship and development stages of joints. Figure 2 shows the intersection of several typical non-filling joints and dike filling joints observed in the study area.

![Figure 2 Intersection relationship between non-filling and vein filling joints](image)

It can be seen from the figure that the 3rd set joints of the NE trending unfilled cuts the NW strike and the NWW strike pegmatite veins ① and ②. The NE is displaced to the SW direction in the north side of the joint, and the south side of the joint is displaced laterally in the NE direction. The corresponding points of the rock vein are staggered by about 40~80 cm. The veins along the NE are in
the middle and steeply inclined. The staggered column features that the joint formation of the NE direction is later than the joint of the NWW and NW trend filled by the veins.

It can be concluded that the NW trending and NE trending steep dipping joint systems in the survey area belong to the products of different stages of tectonism, in which the NW trending structural system is mainly the product of early tectonism, and the formation of the NE trending structural system is obviously later than that of the NW-trending structure.

(2) Restriction of joints

Unlike the joint intersection, the restriction between joints is mainly manifested in that the development of late joints is confined to the early joints, and usually stops before extending to another group of joints, and the corresponding dislocation can not be found on the other side of the joints being cut. In the study area, the steep inclined joints in NE direction limit the development of the gentle inclined joints in NW direction, and the NW direction joints are basically confined between the NE direction joints. The "dislocation" gentle inclined joints on both sides of any NE direction joint can not correspond to each other. The restriction of NE steep dip joints on NW gentle dip joints indicates that the formation of NW gentle dip joints is later than that of NE steep dip joints.

Based on the intersection and restriction relationship of the above joints, it can be determined that the NW and NE to the tectonic system in the study area belong to different tectonics. From the order of formation, the medium-deep-dip joints in the NW trending system are mainly the early products of tectonic action, and the NE trending tectonic system is formed later than the NW trending tectonic formation, while the NW trending tectonic system slow-tipping joints are the product of later periods.

4.2 Matching of tectonic joints

Figure 3 Intersection of the conjugate joints

The conjugate characteristics of NE trending series joints ② and ③ in Figure 3 show that they are synchronous joint systems formed under the action of unified stress field. The pole of the joint ② is located in the SE domain of the large plane of the stereographic projection, which falls into the in the distribution area of the fourth set of joints in the joints groups of the study area, and the joint ③ falls within the second set of joints of the NW field of the large flat projection. It is considered that the second or fourth group of joints in the study area are basically conjugate joints. Compared with the joint distribution map (Figure 4), the NW-trending joints fall into the SW domain of the projection network (the first group of joints in the study area), while the NWW-trending joints fall into the SW domain or the NW domain (the third group of joints in the study area). Therefore, the first and third groups of the joint grouping are another pair of conjugate joints.
Figure 4: Correspondence between joints stereographic projection and grouping (episphere)

5. **Evolution of tectonic stress field**

The NW and NE trending joint systems determined by the joint staging are conjugate joint combinations, and the two sets of conjugate joints are characterized by small sharp angles. Conjugate joints, as a structural product under the action of unified stress field, have a certain corresponding relationship with the principal stress. Generally speaking, \( \sigma_1 \) in the principal stress corresponds to the sharp-angle bisector of conjugate joints, while the minimum principal stress \( \sigma_3 \) corresponds to the blunt-angle bisector of conjugate joints, and the intermediate stress \( \sigma_2 \) corresponds to the intersection of conjugate joints. According to the spatial orientation combination of principal stress, there are three types of stress states: normal fracture, reverse fracture and strike-slip fracture. The principal stress orientation of each type is shown in Figure 5. Stereographic projection analysis of conjugate joints determined by stages in the survey area shows that NW trending joints are formed in NW trending tectonic compressive stress environment, while NE trending joints are formed in NE trending tectonic compressive stress environment. However, the analysis of the principal stress state shows that the orientation of the maximum principal stress \( \sigma_1 \) of the NE and NW joints is in the straight direction, and the minimum principal stress \( \sigma_3 \) should be the one that really plays the role of plane extrusion. Therefore, the NW and NE joints are formed in a normal stress environment (Figure 6).

(a) Normal fault type; (b) Reverse fault type; (c) Slip fault type

Figure 5: The perspective view and stereographic projection of relationship between conjugate joints and major stress orientation
From the perspective of regional tectonic setting, the Late Paleozoic in Beishan area has entered the intraplate tectonic period, which is the product of magmatic emplacement under the rift of Permian granite series. Because of the uplift of lower mantle, it shows the characteristics of crustal melt and late orogenic granite [8]. This is consistent with the principal stress state of the early NW conjugated joint system determined by this joint stage, indicating that the rift type or normal break stress environment is maintained and continued for a long time after the granite embedding. Therefore, the NW trending joint system with the maximum principal stress near vertical and the minimum principal stress under NE horizontal compression is formed. Thereafter, the inplate action changes, and the minimum principal stress shifts from NE to NW, forming a steep inclined joint system with the maximum principal stress nearly perpendicular and the minimum principal stress acting as NW horizontal extrusion.

After the formation of NE trending joints, the tectonics readjusted again. The principal stress state changed from normal fracture type to strike-slip fracture type. The maximum principal compressive stress was NE-SW direction and the minimum principal stress was NW-SE direction. This shows that the uplifting trend of magmatic emplacement under rift action has basically disappeared since Mesozoic. The NE trending horizontal compression has become the main stress mode in this area, and from the initial stage of horizontal compression. The strike-slip stress environment of the NE direction is rapidly transiting to the reverse fracture stress environment, while the extrusion of the NE direction continues to this day.

6. Conclusion
In summary, it is preliminarily concluded that the joint formation, evolution and tectonic stress field changes in the study have area mainly go through the following three stages:

(1) Formation stage of NW trending joint system: Since Mesozoic, the region has inherited the rift-type stress environment of Permian granite emplacement, and formed NW-trending middle-steep joint system under the action of vertical maximum principal stress, horizontal minimum principal stress and NE-SW compression.

(2) The forming stage of NE trending joint system: The adjustment of the action in the plate causes the minimum principal stress to change from NE to NW. Under the action of vertical maximum principal stress and NW-SE direction compression, the NW direction joint system with medium and steep inclination is formed. The stress state in this stage is generally in the continuous stage of continuous activity in the tensional rift environment, so it is also the production stage of a large number of veins.

(3) The formation stage of NW trending joint system: The inertia of magma emplacement disappeared, the stress environment changed into NE-SW direction horizontal compression, and the
strike-slip stress environment in the initial stage of horizontal compression quickly transited to reverse-fracture type stress environment, forming NW trending joint system.

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