Tectonic Characteristics and Geological Significance of Joints on the Southwest Bank of Yangzonghai Lake

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Abstract. Affected by the movement of the Xiaojiang Fault Zone, frequent tectonic activities have occurred in the Yangzonghai Lake area, and a large number of joints have developed in the rock formations. The analysis of joints in the study area shows that there are 6 sets of dominant joints, of which 4 sets are two conjugate joint systems; the analysis of stereographic projection for conjugate joints shows that the direction of the maximum principal stress indicated by the tectonic stress field in the area has a tendency to turn from NWW to NNW, which is consistent with the tectonic stress field reflected by faults and folds in the study area and conforms to the characteristics of the tectonic stress field in the middle of the Xiaojiang Fault Zone.

Keywords: Conjugated joint, Tectonic stress field, Principal stress, Yangzonghai Lake

1. Instruction
Xiaojiang Fault Zone, located in the Sichuan-Yunnan area, is a famous active fault zone, and has extremely complex structure with its adjacent areas [1-3]. Yangzonghai Lake, located in the west branch of the middle section of Xiaojiang Fault Zone, is a faulted lake and is closely related to Xiaojiang Fault Zone in its origin. Affected by the movement of the Xiaojiang Fault Zone, frequent tectonic activities have occurred in the Yangzonghai Lake area, and a large number of joints have developed in the rock formations. The rose diagram, pole diagram and isodensity diagram of the joints directly reflect the degree of development of the joints and their dominant direction, which is an important auxiliary basis for restoring palaeotectonic stress field, determining the geometric form, occurrence direction and combination law of the geological structure and its origin and development process. This paper will analyze the regional tectonic stress field by the research on the joint characteristics of the southwest bank of Yangzonghai Lake.

The study of joints has a long history, including the origin (Gilbert.1882, Becker.1891, Van. Hise 1896), field observations, and experimental studies of joints (Sheldon.1912), joint mechanics formation mechanism, and Bucher's deduction in 1921 of the bisected acute Angle of the maximum principal stress and the bisected obtuse Angle of the minimum principal stress when the joint ruptures. It is proved to be a reliable method to invert the tectonic stress field using joints. Through the inversion of joints to the stress field [4-6], Chen C [7], Qin L M [8], Deng B [9], Zhang Z P [10], Dong L [11], et al. also proved that joints have very good indicative significance.

2. Geological Background
Xiaojiang Fault Zone can be roughly divided into north section, middle section and south section. The study area is the diamond massif sandwiched by the east and west faults in the middle section, which has developed a series of secondary faults tending to the NNE. The exposed strata dip in this area is...
relatively steep, such as Canglangpu Formation ($E_1^c$), Longwangmiao Formation ($E_1^l$), and Douposi Formation ($E_2^d$) of Cambrian System; Haikou Formation ($D_2^h$) of Middle Devonian Series, Zaige Formation of Upper Devonian ($D_2^z$); Datang Formation ($C_1^d$) of Lower Carboniferous Series, Weining Formation ($C_2^w$) of Middle Carboniferous Series; Datang Formation ($C_2^d$) of Lower Carboniferous Series, Weining Formation ($C_2^w$) of Middle Carboniferous Series; Daoshitou Formation ($P_1^d$), Yangxin Formation ($P_1^y$), Emeishan Basalt Formation ($P_e$) of Lower Permian Series, Lufeng Formation ($J_l$) of Middle Jurassic Series. The structure in this area is relatively complex, with developed folds and faults; the folds axis mainly NE-trending, while the faults are mainly NE, EW, and NS trending faults (as shown in the figure 1).

3. Joint Development Features

3.1. Geometrical Features
More than 500 joints of 15 observation points are obtained through detailed observation and measurement of the field outcrop joints of the Cambrian System's Douposi Formation, Devonian System's Zaige Formation, Carboniferous System's Datang Formation and Weining Formation, and Jurassic System's Lufeng Formation's formation. In general, the surface deformation in the study area is relatively weak, mainly low-strain brittle fracture deformation, forming outcrop multi-phase joints structures; the joint surface is straight, and the dip angle is steep with good extension (as shown in the table 1).

![Figure 1. Geological Sketch of the Southwest Bank of Yangzonghai Lake.](image-url)

| Stratigraphic Age, Position and Lithology | Occurrence of Stratum | Joint occurrence | Joint Mechanical Property | Density of Joint | Joint Surface Characteristics and Filling |
|-----------------------------------------|-----------------------|------------------|--------------------------|-----------------|------------------------------------------|
| Douposi Formation ($E_1^d$)             | Thin-bedded yellow-310°$\angle50°$ gray shale, arenaceous shale. | 1: 200°$\angle210°$ $\angle60°$ $\sim$ $70°$ 2: 140°$\angle145°$ $\angle35°$ $\sim$ $40°$ | shear joint | 35 strip/m | The joint surface is straight and smooth. |
|                                        | Zaige Formation ($D_2^z$) Grey-white aplitic dolomite limestone | 1: 240°$\angle255°$ $\angle39°$ $\sim$ $45°$ 2: 70°$\angle85°$ $\angle30°$ $\sim$ $40°$ | shear joint | 15 strip/m | The joint surface is straight and smooth. |
3.2. Control Factors for Joint Formation
It is basically concluded from the field primary observation that the development degree of joint is mainly controlled by factors such as lithology, formation thickness and stress intensity.

The main exposed limestone and sandstone in this area have strong brittle strain characteristics. The comparison of joints in the field shows that the dominant joints in this area are mainly developed in the Zaige Formation (D₃z) and Lufeng Formation (JI); Douposi Formation (Є₁d) is mainly thin-bedded yellow-gray shale and sandy shale, with thin thickness and high density of joint development.

3.3. Joint Movement and Mechanical Properties
Joint analysis can be performed directly in areas where the rock formation is close to flat, without the need to correct the rock formation to flat; dip correction is first performed when measuring areas where rock formations are dip. Most of the data points in this analysis are from dip stratum, so flat correction is required, and strGraphPrj software is used for flat correction. After flat correction, the Excel is used to draw rose diagram, and the Stereonet (version 10.1) software is used to complete stereographic projection drawing.

| Formation     | Dip Angle | Strike Angle | Joint Type | Density |
|---------------|-----------|--------------|------------|---------|
| Datang Formation (C₁d) | 140°∠37° | 270°~285° ∠55°~68° | shear joint | 16 strip/m |
| Weining Formation (C₂w) | 125°∠50° | 305°~315° ∠38°~46° | shear joint | 10 strip/m |
| Lufeng Formation (JI) | 104°∠41° | 55°~63° ∠68°~73° | shear joint | 5 strip/m |

The joint surface is straight and smooth.

Figure 2. Strike and Dip Rose Diagrams of Joints on the Southwest Bank of Yangzonghai Lake. (Strike rose diagram radius=55 strips; dip rose diagram radius=41strips)

From the field data and strike and dip rose diagrams of joints(as shown in the figure 2), it can be clearly concluded that there are six sets of joint systems in the study area: set 1: 10°~20° ∠69°~80°, set 2: 30°~40° ∠43°~57°, set 3: 120°~130° ∠84°~86°, set 4: 250°~260° ∠72°~81°, set 5: 290°~300° ∠65°~73°, set 6: 340°~350° ∠54°~60°. Among them, the two sets of strike to NE-SW and dip to SE, and strike close to SN and dip to W have developed more joints, mainly exposed in the gray-white aplitic dolomite limestone of Zaige Formation (D₃z) and the amaranth sandstone of Lufeng Formation.
(JI), and basically the same as the strike of the Hujiazhuang reverse fault and the Taiyanggou reverse fault exposed in the study area, reflecting that this area was once extruded by the NW-SE trending.

Based on the matching principle of conjugate joints and combined with the field intersection relationship of joints, the joints are further analyzed and it is concluded that there are two sets of conjugate joints in the study area (as shown in the table 2).

Table 2. Features of the occurrence of Conjugate Joints on the Southwest Bank of Yangzonghai Lake.

| Joint System | Variation Range of Joint occurrence | Joint Mechanics Relationship | Direction of Maximum Principal Stress | Affiliation of Structure |
|--------------|------------------------------------|-----------------------------|----------------------------------------|--------------------------|
| System 1     | 1: 250°~260° ∠72°~81°  2: 340°~350° ∠54°~60° | Plane conjugate shear joint | 290°~301° ∠54°~63° | NE - SW |
| System 2     | 1: 30°~40° ∠43°~57°  2: 290°~300° ∠65°~73° | Plane conjugate shear joint | 330°~346° ∠42°~54° | NE - SW |

The features of conjugate joints in the System 1: this joint system is mainly developed in the Zaige Formation, with steep dip angles that belong to the plane conjugate joint set; the strike of the two sets of joints are NW-SE, and NE-SW, controlled by the tectonic stress field of NW-SE extrusion.

The features of conjugate joints in the System 2: the dip angles of this system are slower than that of System 2, which belong to the plane conjugate joint set, controlled by the tectonic stress field of NW-SE extrusion.

4. Joint Instructions for Palaeotectonic Stress Field

Joints are sensitive signs of micro-stress fields. To explore the history of tectonic deformation and palaeotectonic stress field in this area, joint staging and matching are often carried out. The analysis of the joints in the study area shows that there are 4 sets of shear joint surfaces in the area that are nearly perpendicular to the rock stratum, which are matched with two sets of plane conjugate shear joint systems. Through the stereographical projection on the joints based on the analysis principle that the intersection line of the two sets of shear joint surfaces is σ₂, the acute-angle bisector is σ₁, and the obtuse-angle bisector is σ₃, it is concluded the features of the tectonic stress field of the two sets of conjugate joints in this area as follows (as shown in the figure 3, table 3):

![Figure 3](image_url)
### Table 3. Tectonic Analysis of Conjugate Joint.

| Dominant occurrence of conjugate joints | Principal stress axis occurrence | Corresponding Affiliation of Structure |
|----------------------------------------|----------------------------------|---------------------------------------|
| 255° $\angle$ 76°, 347° $\angle$ 57°   | 296° $\angle$ 58°, 54° $\angle$ 55°, 35° $\angle$ 77° | Set 1, NE - SW                        |
| 34° $\angle$ 50°, 296° $\angle$ 70°   | 338° $\angle$ 48°, 94° $\angle$ 46°, 80° $\angle$ 77° | Set 2, NE - SW                        |

The analysis of the changes in the opposite directions of the maximum principal stresses of the two sets of conjugate shows that the direction of the tectonic stress changes from NWW to NNW, which is consistent with the tectonic stress field of Xiaojiang Fault Zone inverted using seismic data by Lin X D [12] and Shen Y H [13].

### 5. Conclusion

1. There are six sets of joint systems in the study area: 1: 10°–20° $\angle$ 69°–80°, 2: 30°–40° $\angle$ 43°–57°, 3: 120°–130° $\angle$ 84°–86°, 4: 250°–260° $\angle$ 72°–81°, 5: 290°–300° $\angle$ 65°–73°, 6: 340°–350° $\angle$ 54°–60°.

2. The two sets of conjugate joints in the study area are both controlled by the tectonic stress field of the extrusion in the NW-SE trending in terms of macroscopic characteristics.

3. The changes in the opposite directions of the maximum principal stresses of the two sets of conjugate joints in the study area show that the direction of tectonic stress changes from NWW to NNW, which is consistent with the tectonic stress field reflected by faults, folds, and joints in this area.

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