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Seismic anisotropy of the crust in Yunnan, China: Polarizations of fast shear-waves*

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Abstract

Using seismic data recorded by Yunnan Telemetry Seismic Network from January 1, 2000 to December 31, 2003, the dominant polarization directions of fast shear-waves are obtained at 10 digital seismic stations by SAM technique, a systematic analysis method on shear-wave splitting, in this study. The results show that dominant directions of polarizations of fast shear-waves at most stations are mainly at nearly N-S or NNW direction in Yunnan. The dominant polarization directions of fast shear-waves at stations located on the active faults are consistent with the strike of active faults, directions of regional principal compressive strains measured from GPS data, and basically consistent with regional principal compressive stress. Only a few of stations show complicated polarization pattern of fast shear-waves, or are not consistent with the strike of active faults and the directions of principal GPS compressive strains, which are always located at junction of several faults. The result reflects complicated fault distribution and stress field. The dominant polarization direction of fast shear-wave indicates the direction of the in-situ maximum principal compressive stress is controlled by multiple tectonic aspects such as the regional stress field and faults.

Key words: **seismic anisotropy**; **polarization of fast shear-wave**; **principal compressive stress**; **active faults**; **GPS**
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Introduction

Anisotropy of the crust is a common phenomenon (Crampin, 1984). Shear-wave splitting can be used to study the earthquake anisotropic characteristic in crust, to analyze crustal stress field condition, and to describe the static and the dynamic state of the related anisotropic parameters (GAO *et al*, 1999). Shear-wave splitting is quite sensitive to anisotropy. The domestic scholars applied shear-wave splitting to studying the crustal anisotropy (YAO *et al*, 1992; GAO and FENG, 1990).

The studies indicate that the complex geological structure can result in the difference of the polarization of shear-wave splitting (GAO *et al*, 1995; 1999; LEI *et al*, 1997). Because the polarization of shear-wave splitting reflects the direction of the principal compressive stress of the crust in-situ under the seismic station, it can be used to study the crustal stress field characteristics (Crampin, 1978). Recent research indicates that the parameters of the shear-wave splitting can

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reflect the process of stress accumulation and the stress release before earthquakes, and also can be used to predict the earthquake (Gao and Crampin, 2004).

Yunnan region locates east to Tibetan Plateau. It is at the south end of the north-south earthquake belt. The earthquake structure of Yunnan area is complex, and it is one of the strongest seismically active areas of continent. The seismic activity is extremely frequent. From January 1, 2000 to November 30, 2005, there are more than 22 earthquakes with $M\geq5.0$, including three earthquakes with $M\geq6$ occurred there. They are Yao'an earthquake with M=6.5 on January 15, 2000; Dayao earthquake with M=6.2 on October 27, 2001; and Dayao earthquake with M=6.1 on October 16, 2003. In view of the complex structure of Yunnan area, this paper will use the digital seismic data to preliminarily study the anisotropy of Yunnan area, to analyze the stress distribution characteristics in this region and its relation with the fault.

1 Background

There are mainly 3 groups of strikes of active faults in Yunnan area, that is, N-S, NW and the NE, and the distribution has an obvious regional characteristic (Figure 1). Taking the Red River

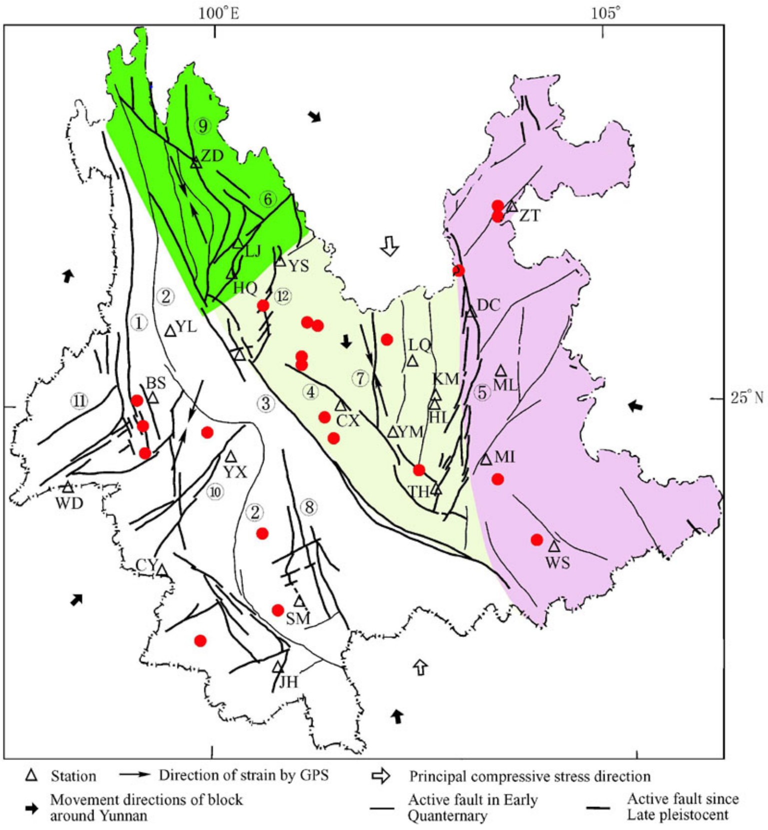

Figure 1 Distribution of seismic stations, fault and earthquake activity in Yunnan

Triangles are stations of the regional telemetry seismic network in Yunnan, the crosshatched circles are earthquakes with M=5, Time is from January 1, 2000 to November 30, 2005. ① Nujiang fault; ② Lancangjiang fault; ③ Red River fault; ④ Chuxiong-Tonghai fault; ⑤ Xiangjiang fault; ⑥ Lijiang-Jianchuan fault; ⑦ Yimen fault; ⑧ Wuliangshan fault ; ⑨ Zhongdian fault; ⑩ Nandinghe fault; ⑪ Longling fault; ⑫ Chenghai fault. The direction of principal compressive strain is from YANG *et al* (2003) by GPS fault zone as a boundary, east part is mainly N-S fault, and some NE fault; and in the west NW fault is dominated with NE fault and NW fault forming an intersected network in local areas. The big fault zone in this area is Red River fault, Nujiang fault, Xiaojiang fault and so on (DENG *et al*, 2002). Red River fault crosses Central Yunnan area and Dali area, passing through Midu area and other areas toward SE, and is a rather active fault zone. Nujiang fault is a gigantic fault zone with long history. It controls the west boundary of Baoshan area, and is a lithosphere fault, a seismically active zone nowadays. The Sichuan-Yunnan rhombic block is one of the most seismically active areas. The south of Sichuan-Yunnan rhombic block locates within Yunnan Province. The east and west sides of this area are Xiaojiang-Anning River strike-slip fault with near N-S striking, Red River strike-slip fault with near N-S or NW striking (YANG and MA, 2003). In this region including boundary, strike-slip type earthquake is the main earthquake (WU *et al*, 2004).

The principal compressive stress axis of Yunnan area is near N-S (KAN *et al*, 1983). The result of GPS survey indicated that Yunnan area could be divided into four regions according to the strain and the stress characteristics (Figure 1). The directions of local principal compressive strains are approximate N-S in the west and the central Yunnan area. The principal compressive strain rate of eastern area is nearly zero (YANG *et al*, 2003). According to the moderate and small earthquake focal mechanism, the direction of compressive stress field in Yunnan area is from NNW direction turning to the near N-S direction (WU *et al*, 2004).

The regional telemetry seismic network of Yunnan is a digital seismic network with 23 digital seismic stations (Figure 1). The bandwidth of seismograph is 120 s~20 Hz, and the sample is 50 SPS (sample/second) (YANG and YANG, 2005). GAO *et al* (2004a) suggested that the crustal anisotropy in Yunnan area could be investigated using the data of regional telemetry seismic network. In this paper, we analyze digital waveform data from regional telemetry seismic network from 2000 to 2003 in Yunnan and discuss the result of stations with more data.

In the west of Yunnan, the earthquake mainly concentrates in the area of Dali-Chuxiong and Baoshan-Lincang-Simao (SU, 2002) for that there are several quite large active fault zones in this area. Quite active Xiaojiang fault zone locates in the eastern area. The stations of Lijiang (LJ), Heqing (HQ), and Tuanshan (TS) *etc.* distribute on or near Honghe fault zone. Chuxiong (CX) locates at the Chuxiong–Tonghai fault zone. Baoshan (BS) is at the edge of Nujiang fault zone. Dongchuan (DC) is at the Xiaojiang fault zone. It is extremely helpful to analyze waveform of these stations and understand the predominant direction of the crustal crack as well as the anisotropic characteristic for realizing the character of crust, the stress of crust, the fault characteristic and its mutually relationship.

2 Techniques and data

When the seismic wave travels in the anisotropic medium, the shear-wave split into fast shear-wave and slow shear-wave with different velocity, both of them have the nearly-orthogonal polarizations character. In the crustal rock, cracks are erect and parallel, namely EDA cracks (Crampin and Atkinson, 1985). The EDA cracks medium is anisotropic structure, and the shear-wave would split into fast and slow shear-waves when it travels in this kind of structure. The polarization direction of the fast shear-wave is consistent with the direction of the crack caused by stress, that is, the direction of polarization of the fast shear-wave is in accordance with the direction of local maximum principal compressive stress. The time delay of slow shear-wave reflects the anisotropic degree of crust, which is influenced by the physical features of the crack and the character of the fluid-saturated.

When shear-wave encounters free surface, reflection will be occurred if the incident angle is greater than the critical angle. The critical angle is about 35º in Poisson medium, which is also the limited range of the shear-wave window. This window may be enlarged to 40°~45° for wave front curved and surface deposition with low velocity.

The shear-wave splitting system analytic method: SAM method proposed based on the correlation function (GAO *et al*, 2004b) is used in this paper. It includes three contents of the calculation of cross-correlation function, elimination of time-delay and analysis of polarization, and has function of self-examination (GAO and ZHENG, 1995; GAO *et al*, 2004b). The theory of SAM method is briefly introduced as follows.

1) Calculation of cross-correlation function: According to the arrival time of the shear-wave, two horizontal direction shear waveforms are intercepted. By modifying the rotation angle α and the time delay Δt, the cross-correlation function is calculated. The beginning direction of the angle α is north and it clockwise change within [0, 180°]. Supposed the time difference between the fast and slow shear-wave is not more than $2T$, the time delay Δt will changed within $[-T, T]$. If the polarization direction of the fast shear-wave is α, that of the slow shear-wave is approximately vertical. The correlation functions of $x(t)$ and $y(t+\Delta t)$ is calculated. When the function is maximum, the rotation angle α and Δt will be the polarization direction of the fast shear-wave and the time delay of the slow shear-wave respectively.

2) Elimination of time-delay: The waveform of the slow shear-wave is moved up the time Δt to keep the consistency of the time of first motion and the fast shear-wave and eliminate the effect of the time delay.

3) Test analysis of polarization: The polarized figures before and after the adjustment of the time delay are compared to test the accuracy of the results. If there is linear feature in the polarized figure after eliminating the effect of the time delay, the result is reliable; otherwise the result is unreliable and should be recalculated.

Heqing (HQ) station preliminarily data processing results are shown in Figure 2. The recorded earthquake occurred on January 24, 2001, with depth of 20 km and magnitude 1.1. The epicenter is located at 26.43°N, 100.11°E and epicentral distance is 13.71 km. According to the velocity structure (WU *et al*, 2001), the incident angle is 28.0°, and the back azimuth is 197.33°. According to the results in Figure 2, the direction of polarization is about 115°, and the time delay of the slow shear-wave is about 0.11 s.

The tracks of the particle movement of two horizontal shear-waves are shown in Figure 3. Because the shear-waves have split, the track of the particle movement is non-linear for the two components of the horizontal direction.

Based on the results in Figure 2, the waveform in Figure 3 is rotated to obtain the fast and slow shear wave (The middle and the bottom in Figure 4), Then the slow shear-wave is moved up to eliminate the effect of the time delay and the figure of polarization is obtained (The top in Figure 4). If there is something wrong with the polarization direction of the fast shear-wave, no fast and slow shear-wave will be gotten because two waveforms are mixed together. If the time delay is not correctly calculated, there will be non-linear feature in the polarization. If there is some inconsistency in the result, the waveform and the polarization will be modified. The result in Figure 4 shows that the parameters of the shear-wave splitting are reliable with SAM method. In the case, the direction of the fast shear-wave is correct but the time delay of the slow shear-wave is not so accurate and is adjusted to 0.06 s.

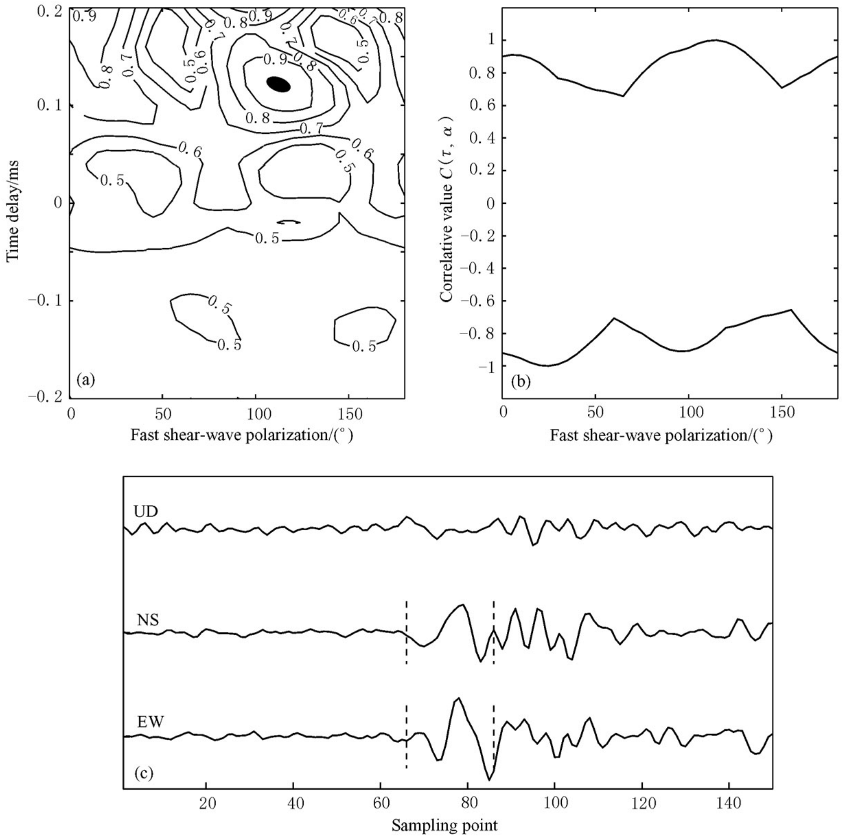

Figure 2 Calculation of cross-correlation function

The event is recorded at HQ station on January 24, 2001 with focal depth 20 km and M_L=1.1. The waveform intercepted includes 150 sampling points. (a) Isoline of cross-correlation function with the different delay time and the different polarization, the black solid ellipse is the position of biggest cross-correlation function value; (b) The maximum value and the minimum value distribution of the cross-correlation function. (c) Three components of waveform: UD, NS and EW, which separately represent vertical, north-south and east-west direction component, two erect dashed line frame the extension of shear-waveform which is used to computation of cross-correlation function

For there are many complex factors affecting records in fact, the result calculated from the cross-correlation function is usually a little inconsistency with the real observation, as shown in Figure 4. However the calculation of cross-correlation function gives us some effective information for the polarization test. The best case is Dongfang isolation earthquake swarm in Hainan for SAM method (GAO *et al*, 1996). For the records of general station, the polarization feature test must be done. The preliminary result in the paper (Figure 2) is 115°, 0.11 s for the polarization direction of the fast shear-wave and the time delay of the slow shear-wave, respectively, while they are 115°, 0.06 s as shown in Figure 4. For the result of the fast shear-wave is relatively accurate, it assists the analysis of the time delay of the slow shear-wave. The above results show that the comprehensive analysis like the SAM is a reliable and effective way at present.

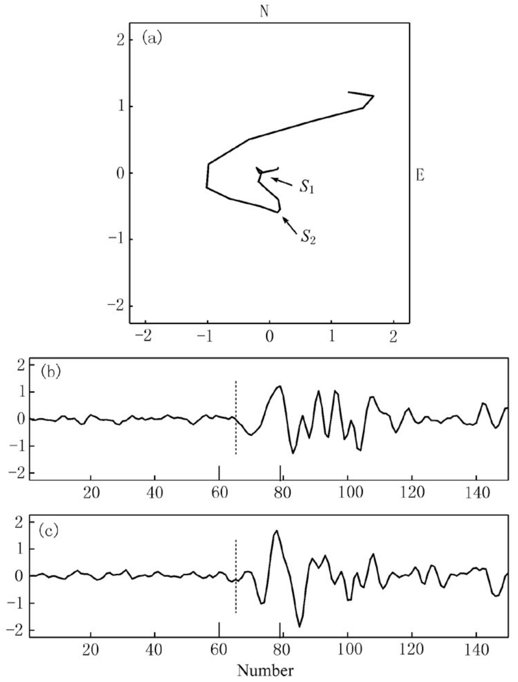

Figure 3 Movement trail of particle of two rows of horizontal shear-waves (polarization figure)

(a) The movement trail of particle of shear-wave. S_1, S_2 in the polarization figure indicate the start position of fast and slow shear-wave, respectively. (b) and (c) Shear-waveform on north-south (NS) and east-west (EW) direction respectively. Two short erected solid lines point out the scope of shear waveform showed in polarization figure. The erected dotted line indicates the start position of shear-wave. The others are same to Figure 2

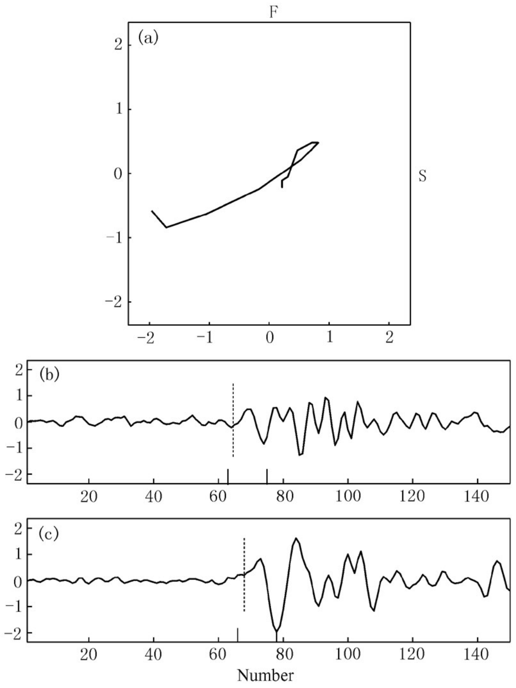

Figure 4 Analysis and test of polarization

(a) The trails of particle of fast shear-wave and slow shear-wave, which have been eliminated the effect of time delay. (b) and (c) Fast shear-wave form (F) and slow shear-wave form (S). Two solid short lines point out the scope of shear waveform showed in polarization figure. It is equal to advancing a quantity of time delay of slow shear wave, thus the influence of time delay on polarization figure was subtracted. The long dotted lines respectively indicate the arrival of fast shear-wave and slow shear-wave. The others are same to Figure 3

3 Results

The data of Yunnan Telemetry Seismic Network from January 1, 2000 to December 31, 2003 were used in this research. According to the velocity structure of the shear-wave of Yunnan area (WU *et al*, 2001), shear-wave incident angles of the earthquake recorded by each station of Yunnan Telemetry Seismic Network were calculated. The earthquakes which fit to the restraint condition of shear-wave window were analyzed. 37° shear-wave window was adopted instead of 45° for a more strictly restraint conditions of the shear-wave window.

Because of the limited earthquake data of telemetry seismic network, the depths of many earthquakes were not known. Thus it affects the quantity of the samples. Most depths of the earthquakes are about 10 km or deeper than 10 km in Yunnan area. According to the understanding of the shear-wave window, the data without focal depth and with epicentral distance less than 10 km were also included in this paper as supplement data. Figure 5 compares the polarization of fast shear-wave of the data with the focal depth with that of supplement data. It can be seen from Figure 5, the data of 10 stations have been increased, and the fast shear-wave polarization of the increased extension data is roughly consistent with the calculated results of the selected earthquakes of the shear-wave window. Especially Dongchuan (DC), Mile (MI) and Tonghai (TH) stations *etc.* with focal depth, their original data were few. The principal polarization of the fast shear-wave is clearer after data supplement. According to Table 1, there is hardly any difference of calculated results between original data and supplement data. The biggest difference of the polarizations of fast shear-wave is smaller than 10°, except the DC station. The main reason is that the data with focal depth in DC station is scarcity. The results indicate that the data processing technique could increase the reliability of the results under the specific data condition, especially for that with very limited data, and it could be taken as a fast data processing technique. This result in the paper demonstrates that the error of the polarization of fast shear-wave calculated with more than 10 records is less than 10°.

After processing the data of regional telemetry seismic network in Yunnan, Only the results of stations with more than three effective data in the shear-wave window were shown in Figure 5 and Table 1 for the reliability of the results, which are 10 stations.

The polarization of the fast shear-wave is consistent with the direction of the local principal compressive stress. They are controlled by the local stress field and related to fault distribution

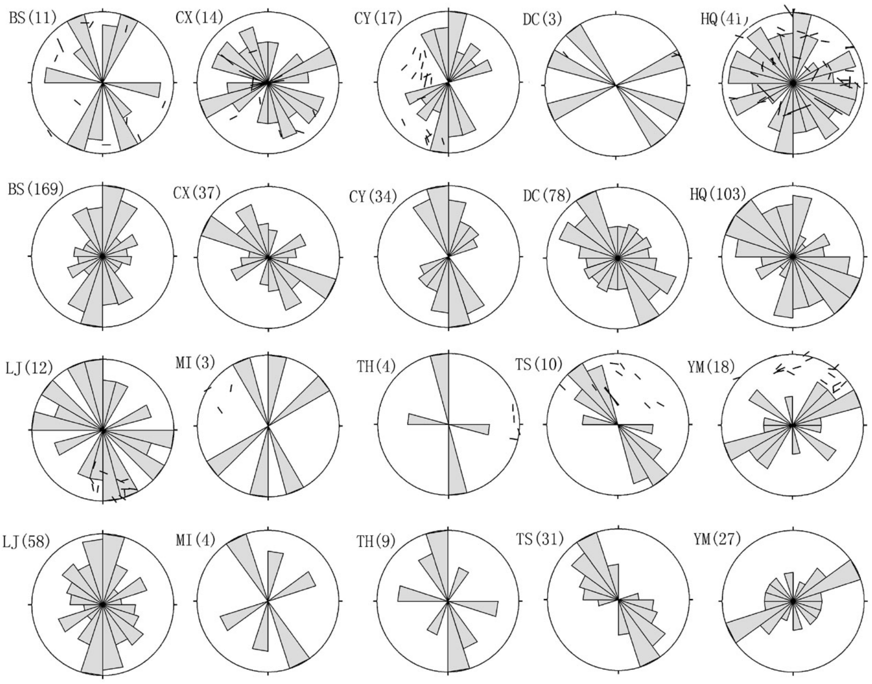

Figure 5 Comparison of polarizations of the fast shear-wave splitting.

The homolographic projection graph and the homolographic projection rose graph are shown in the figure. The first and third lines are results calculated from the data with focal depths within shear-wave window. The directions of the short lines are polarizations of the fast shear-wave at stations. The outside large circle is the shear-wave window. The second and the fourth lines are the results calculated from the data including more supplement data which are without focal depth localization and epicenters less than 10 km. The numbers within bracket behind station codes are numbers of events

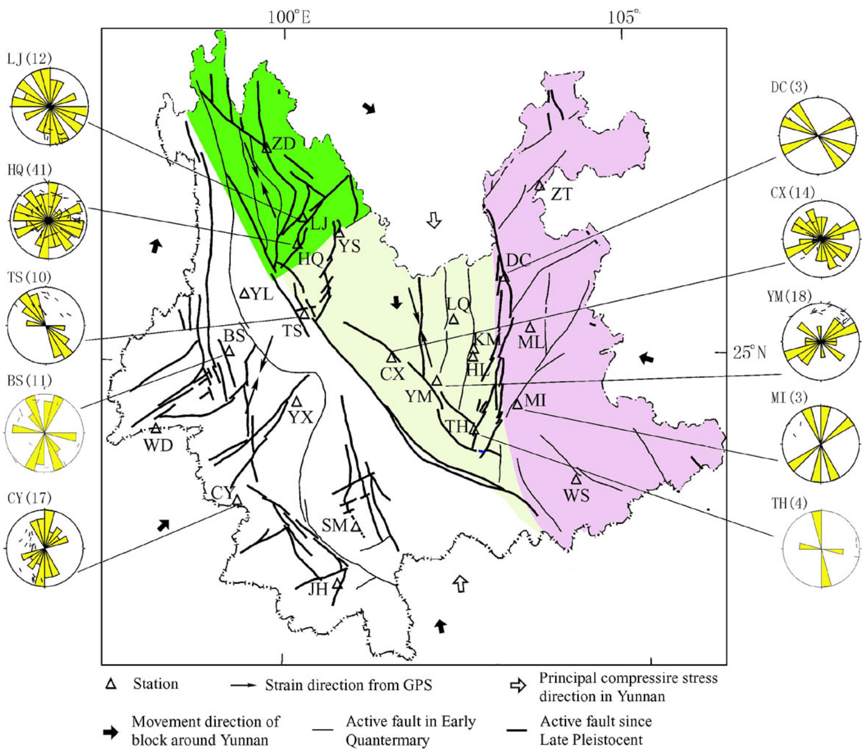

Figure 6 Polarization of fast shear-wave in Yunnan area

The homolographic projection graph and homolographic projection rose graph are shown in the figure and only the result from data with focal depths within shear-wave window. Other meanings are same as Figure 1 and Figure 5.

Table 1 Polarization of fast shear-wave of the regional telemetry seismic network in Yunnan

Station		Polarization of fast shear-wave (shear-wave window)		Polarization of fast shear-wave (supplement data)		Difference of equally polarization
Name	Code	Equally polarization	Number	Equally polarization	Number	
Lijiang	LJ	152.3°±32.3°	12	161.5°±34.1°	58	−9.2°
Heqing	HQ	138.0°±38.7°	41	136.3°±31.2°	103	1.7°
Tuanshan	TS	137.0°±11.2°	10	136.9°±17.2°	31	0.1°
Baoshan	BS	3.8°±32.5°	11	9.8°±27.0°	169	−6.0°
Cangyuan	CY	0.7°±22.0°	17	2.1°±20.6°	34	−1.4°
Chuxiong	CX	149.3°±30.6°	18	140.1°±30.7°	37	9.2°
Dongchuan	DC	111.0°±27.3°	3	143.5°±32.0°	78	−32.5°
Mile	MI	1.0°±29.3°	3	2.0°±29.5°	4	−1.0°
Tonghai	TH	155.0°±27.5°	4	155.9°±26.8°	9	−0.9°
Yimen	YM	67.3°±24.3°	18	66.5°±23.8°	27	0.8°

and geological structure. The polarizations of the fast shear-waves splitting of 10 stations in Yunnan area are shown in Figure 6. It can be seen from Figure 6 that that there are five stations (LJ, BS, CY, MI, TH) with the polarization of fast shear-wave splitting near N-S, three stations (TS, CX, DC) with the polarization of fast shear-wave splitting of NW or NNW; one station (YM) with the polarization of fast shear-wave splitting of ENE, one station (HQ) are complex and have not predominant direction.

4 Discussion

Shears wave velocity structure has very strong lateral heterogeneity in the Yunnan area. Research by WU *et al* (2001) indicated that shear-wave velocity in north is obviously lower than that in south above 10 km depth, while the north is faster than south in the depth range from 10 km to 20 km. The crustal thickness in northeast is approximately 62 km and that in southeast is approximately 32 km. The complex distribution of fault (Figure 1) reflects the local complex structure. In addition, because Tibetan Plateau moves toward east (ZENG *et al*, 1992); and the western area of Yunnan is intensively affected by the Europe-Asia Plate and the Indian Plate, surface movement pattern becomes more complex (YANG *et al*, 2003). By comparison, the influence is relative weaker in east Yunnan. This special complex geological structure background of Yunnan area results in local regional characteristic of crustal stress field of Yunnan area. This research demonstrates the complex stress field.

The Lijiang is located in the southwest of the Sichuan-Yunnan rhombic block. Lijiang fault divides the Sichuan-Yunnan rhombic block into two parts, and it is seismically active region. According to optical axis determination of the calcite crystal by YU *et al* (2002), the direction of principal compressive stress is not certainly consistent in the Lijiang area, and there is a quite large stress adjustment in this region, which causes the direction of the regional stress field turning from NW into NE or N-S. HAN *et al* (2004) suggested that the local principal compressive stress direction is N-S after research on Lijiang M=7.0 earthquakes occurred on February 3, 1996. This polarization of fast shear-wave splitting of LJ station obtained in the paper is near N-S direction (Figure 6), which indicates the direction of local principal compressive stress is near N-S. This direction is consistent with that obtained by YU *et al* (2002) and HAN *et al* (2004), and also approximately consistent with compressive strain of NNW by the GPS survey (YANG *et al*, 2003).

The local geological structure is complex in Heqing. This area is mainly basin controlled by NE and E-W fault (XING *et al*, 1986). There is near N-S Red River fault across this basin, the seismic activity is strong in this area. The dominated polarization of fast shear-wave gained in the paper is not obvious in HQ area, and the result only shows two unobvious relative dominated directions of near N-S and near WNW (Figure 6). According to focal mechanism of two earthquakes in 1986, the direction of P axis is near N-S in this area. The direction of compressive strain is NNW by GPS (YANG *et al*, 2003). The difference is not large. The polarization graph of fast shear-wave of HQ station indicates the direction of local principal compressive stress is extremely complex around HQ station and is mainly approximately N-S, however the direction is limited in a small area and is different from obviously dominated N-S direction of LJ station 50 km north to HQ station. HQ station is located at the juncture of two partial faults (Figure 6). The stress is variable at fault crossing-area as well as the inflection point of fault (LI, 1992). The research of Jianchuan area 20 km west to HQ station indicates that the polarization of fast shear-wave splitting is complex in this area, that of eastern stations is basically consistent and is near N55°W, but there is not single direction in one station (LEI *et al*, 1997). GAO *et al* (1995; 1999) and LEI *et al* (1997) both obtained the complex polarization graph of fast shear-wave splitting in the crust. The result of HQ station in the paper has further demonstrated that polarization of fast shear-wave splitting have very strong local regional character.

Tuanshan (TS) station locates in the Dali area where is an intersection area of Red River fault zone and other fault zones. According to mechanics analogy of Dali seismic structural environment by the finite element method, the direction of principal compressive stress of Dali area is

N15°W to N20°W, that is the NNW direction (XING and MA, 1985) that is consistent with the polarization of fast shear-wave splitting of TS station in this paper (Figure 6). The result is also consistent with principal compressive stress direction from GPS survey in TS area (Figure 6). TS station locates at Red River fault, which is the Late Pleistocene active fault. According to the study of large-scale active fault, polarization of fast shear-wave splitting of station near an active fault is different from that of station away from fault, and is often consistent with strike of fault (Crampin *et al*, 2003; WU *et al*, 2007). The result of TS station supports this conclusion.

Baoshan (BS) station locates in the east of Nujiang fault (Figure 1). Taking width of fault zone into consideration, BS station can be thought as locating in the Nujiang fault zone. According to analysis of 11 records with the focal depth and 169 records with epicentral distance within 10 km in the paper, the polarization of shear-wave splitting of BS station is N-S and slightly turning to NNE, and this direction should be the direction of local principal compressive stress around BS (Figure 6). This result is consistent with the principal compressive strain of NNE direction obtained by the GPS survey (YANG *et al*, 2003). According to eight earthquake records, GAO *et al* (2004a) obtained the polarization of fast shear-wave splitting is near E-W in BS station that is different from the result in the paper, and is consistent with the second principal direction of our research. The possible reason is that the data used by GAO (2004a) are just from the edge of shear-wave window, and the angle between seismic ray of partial earthquakes and local horizontal compressive stress direction is large. Because of the influence of crack aspect ratio, polarization of fast shear-wave could be different from the direction of local principal compressive stress (GAO and Crampin, 2006). The data used by GAO *et al* (2004a) were recorded newly; most shear wave incident angles of them are bigger than 45°. According to the velocity structure from WU *et al* (2001), stricter shear-wave window of 37° was recomputed; most of data were not included in this research.

Cangyuan (CY) station locates at the boundary area of China. Although there is no data obtained from foreign country, NE-striking and NW-striking fault can be seen near CY station in China. These two faults respectively distribute northwest and northeast to CY station (Figure 6). Polarization of fast shear-wave splitting obtained from this research is obvious N-S, and is consistent with the principal compressive strain of NNE direction from GPS survey by YANG *et al* (2003).

Chuxiong-Tonghai fault is a Late Pleistocene active fault, Chuxiong (CX) station is nearly at the fault zone (Figure 1). Polarization of fast shear-wave splitting of CX station obtained in the paper is the NW direction and is consistent with the direction of principal compressive strain by GPS (YANG *et al*, 2003) as well as strike of the active fault (Figure 6). Using data from temporary seismic network, QIAN *et al* (2002) obtained the polarization of fast shear wave splitting mostly ranges from NE140° to NE164° and the average is NE152.4°. The small seismic network and the earthquake event they used is over 70 km northwest to Chuxiong and are also near Chuxiong-Tonghai fault zone and nearby regions. The polarization of fast shear wave splitting of this paper is consistent with that obtained by QIAN *et al* (2002), and is parallel to the strike of active fault. There is no large difference with the direction of local principal compressive strain by GPS and the direction of regional principal compressive stress in Yunnan area (KAN *et al*, 1983; WU *et al*, 2004).

Yimen locates in the Sichuan-Yunnan rhombic block, at the juncture of Yimen fault and Chuxiong-Tonghai fault. Polarization of fast shear-wave is ENE, and near E-W direction in YM area, which is approximately vertical to the direction of local principal compressive strain by GPS, the direction of local principal compressive stress and the strike of main fault in this area, and it is inconsistent with polarization of CX station located in identical fault zone. The possible reason is YM station locates at a special cross. It is not only located at the joint of Chuxiong-Tonghai fault and Yimen fault, and also at the joint of two secondary fault of Chuxiong-Tonghai fault and an Early Quaternary active fault with near N-S direction. In the joint of fault, the direction of stress field also changes complexly. This special position results in inconsistence of polarization of fast shear-wave splitting between YM and CX station.

Dongchuan area located in the eastern Yunnan is a strong seismically active area. Structure line is near N-S direction. Xiaojiang fault is the major active fault in this area (Figure 1). DC station is located in the N-S-striking Xiaojiang fault zone. According to the research by LIU (2002), when Sichuan-Yunnan rhombic block moves toward south SSE direction, Dongchuan area is in a turning point of structure, the fault is hard to wiggle, crust stress is easy to be concentrated and strain energy easy to be accumulated in the place. There are few medium-strong earthquakes and small earthquakes, therefore the strain energy accumulated in the crust is not easy to release in this area. According to the focal mechanisms for several years, the axis of principal compressive stress in Dongchuan area is NW-SE. The polarization of fast shear-wave in DC area obtained in this paper is NW (with data in shear-wave window) or NNW direction (with supplement data). Because there are only three records in the shear-wave window, the reliability of results obtained from 78 records (extension data) are higher by comparison. Polarization of fast shear-wave splitting of DC station is consistent with the direction of principal compressive strain from GPS, and the strike of active fault as well as direction of principal compressive stress in Yunnan area (Figure 6).

MI station is also located in the east of Yunnan area, east to Xiaojiang fault zone. Although there are not a lot of data from MI station, the polarization of fast shear-wave is near N-S. According to focal mechanism, the direction of principal compressive stress is N60.3°E in eastern Yunnan area (LIU *et al*, 2002). There is an early Quaternary active fault less than 5 km to northwest of MI station. It can be seen from Figure 6 that although MI station is 20~25 km away from active fault zone and is located in relative stable structure area, its local principal compressive stress direction is still controlled by Xiaojiang fault zone west to it and about N-S, consistent with the direction of principal compressive strain as well as regional principal compressive stress.

Tonghai is located at the southeast end of Sichuan-Yunnan rhombic block. Approximate N-S-striking Xiaojiang fault is cut by NW-striking Red River fault, forming an acute angle area. Xiaojiang fault and Red River fault are both the boundary of Sichuan-Yunnan rhombic block. The movement of Sichuan-Yunnan rhombic block toward SSE occurs by both of them, which results in the concentration of stress in this acute angle region. Two earthquakes with M_S=6.5 in 1965 and M_S=7.7 in 1970 occurred in the area. The direction of principal compressive stress axis is NNE from focal mechanisms of both earthquakes (KAN *et al*, 1977; LIU *et al*, 1999). The predominate polarization direction of fast shear-wave is about N-S, consistent with principal compressive strain direction from GPS and strike of active fault as well as regional principal compressive stress (Figure 6) and there is little difference from direction of principal compressive stress axis of NNE obtained from focal mechanism. The result suggests Xiaojiang fault zone has larger influence on local principal compressive stress field.

During the period from January 1, 2000 to December 31, 2003, there were not appropriate waveforms or only two effective records from the other stations in Yunnan Telemetry Seismic Network. These stations will not be discussed in the paper. A related discussion will be made after processing enough data.

5 Conclusions

The Yunnan area is strongly influenced by the Europe-Asia Plate and the Indian Plate. The geophysical and geological characteristics of the deep, the shallow and surface are all very complex. Using the waveform data recorded in four years from Yunnan Telemetry Seismic Network, some preliminary understandings about crustal anisotropy in Yunnan area can be obtained through research on shear-wave splitting.

Polarization direction of fast shear-wave represents the direction of principal compressive stress of the local region (a station and neighboring). This study shows that polarizations of fast shear-wave are consistent with the direction of principal compressive strain from GPS and the direction of local principal compressive stress, and it is strongly related to the direction of principal compressive stress of the Yunnan region.

Fast shear-wave polarizations of the stations located at the active faults are consistent with the strikes of active faults, principal compressive strain from GPS and regional principal compressive stress, for example, TS, BS, CX, DC and TH stations.

Due to the effect of local stress field, polarizations of the fast shear-wave of the stations away from active fault are consistent with the principal compressive strain of GPS, for example, CY and MI stations; For stations located between two faults, the polarizations of the fast shear-wave are also consistent with the local direction of principal compressive stress and the direction of principal compressive stress from GPS, for example, LJ station.

Research on the characteristic of the fast shear-wave polarization in Yunnan area shows that the distribution of the polarization of the fast shear-wave can be used to judge whether the faults are active or not. This result is consistent with the research of WU *et al* (2007).

A complex local structure could control or influence the principal direction of polarization of the fast shear-wave of stations, which result in that this direction is inconsistent with the strike of the major active fault, or there is greater difference between neighboring stations. The complex geological structure can also lead to the fast shear-wave polarization to be scattered or to appear many dominated directions such as HQ, YM stations.

According to researches on geological background and seismic activity research, while without precise depth localization data, waveform of earthquake occurred near the station can be used as a supplement. This kind of data supplement technique is helpful to enhance the reliability of the polarization of fast shear-wave splitting analysis in the case of limited data. Thus the direction of principal compressive stress of the crust can be obtained. This technique may be applied as a fast processing technique.

Yunnan area structure is complex with many fault zones and many feeling earthquakes. More data are needed to conduct the precise seismic research in this area.

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