J Seismol (2009) 13:267–275
DOI 10.1007/s10950-008-9126-y

ORIGINAL ARTICLE

Shear-wave splitting in the southeast of Cathaysia block, South China

Yuan Gao · Jing Wu · Jin-An Cai · Yu-Tao Shi · Shu Lin · Ting Bao · Zu-Ning Li

Received: 8 June 2007 / Accepted: 26 February 2008 / Published online: 4 September 2008

Abstract This study is focused on Fujing Province in China, southeast of Cathaysia block (SECB). The present work benefits from the data provided by the Fujian Seismic Network (FJSN) to study the seismic anisotropy in the crust. By means of a systematic analysis and adequate software package, we examine shear-wave splitting from data recorded at ten FJSN stations during the period January 1999 to December 2003. The results demonstrate that the average fast wave polarization is N109.4° E ± 42.6°, corresponding to the horizontal principal compressive stress in the test zone, and the average normalized slow wave time delay is 2.5 ± 1.5 ms/km. The predominant polarizations at stations in the eastern part of SECB are in the N–W direction, which suggests that they are related to the regional horizontal principal compressive stress and also to the strikes of faults. In contrast, the predominant polarizations at two stations in the western part of SECB are in the N–E direction. This polarization direction does not coincide with the direction of the horizontal principal compressive stress, but it follows the strikes of near faults, thus suggesting the influence of the local tectonics and a change in the stress field. The results prove that the predominant polarizations are parallel to the strikes of faults whenever the stations are on active faults. At a few stations near the coastal line, some polarizations show a certain amount of scatter which may be caused by crossing faults and irregular topography. Finally, the spatial distribution of time delays depicts strong lateral variations near the coast just where the seismic activity is comparatively bigger, so that the magnitude of anisotropy seems to be consistent with the most seismically active area.

Keywords Shear-wave splitting · Seismic anisotropy in the crust · Stress · Active fault · Cathaysia block · China

Y. Gao (✉) · J. Wu · J.-A. Cai · Y.-T. Shi
Institute of Earthquake Science,
China Earthquake Administration,
Beijing 100036, China
e-mail: gaoyuan@seis.ac.cn

S. Lin · T. Bao · Z.-N. Li
Earthquake Administration of Fujian Province,
Fuzhou 350003, China

1 Introduction

Fujing Province is southeast of Cathaysia block in China, which is part of the southeastern Eurasian Plate, relatively near the Philippine Plate. Cathaysia block is a major tectonic structure whose evolution decides the geological history in South China. It is influenced by the interaction of blocks in Chinese mainland due to the collision between the Indian and Eurasian Plates. Moreover, it is also influenced by Taiwan Island from upward compression of the Philippine Plate (Zhou et al. 2000). The tectonic setting makes the stress field be complex in the test area which is also one of the most seismically active areas in South China. One of the main tectonic characteristics is that many faults with NW and NE directions cross each other. Relatively strong earthquakes occur usually in the crossing zones that are more seismically active inshore and less inland (Ding et al. 1989). Ding and Wu (1999) obtained P-axes in the NW–SE direction from focal mechanisms of 11 strong earthquakes that occurred between 1986 and 1997 and found that they are consistent with the regional stress field. Chen et al. (1999) concluded that Fujian area is influenced by both compression NW of the Pacific–Philippine Plate and compression first northward and then eastward of the Indian Plate. Zhou et al. (2000) studied the horizontal crustal movement in Fujian from global positioning system (GPS) data and concluded that the horizontal principal compressive strain is NW–SE or W–NW–E–SE. Xu (2001) have studied the present tectonic stress field in East Asia from seismic data and suggest that the average principal compressive stress is NW–SE of South China. More recently, using data supplied by the China Crust Movement Observation Network in 1999, 2001, 2004, and other temporary observations, Niu et al. (2005) have investigated the velocity field of the present crustal movement in Chinese mainland and concluded that the South China block moves in the E–SE direction. All the above results are nearly consistent; however, the seismic and geological characteristics of Cathaysia block still remain unclear.

Because of the existence of extensive-dilatancy anisotropy cracks, shear wave splits into two wavetrains when it travels through anisotropic crustal media (Crampin 1981). Many results show that seismic anisotropy exists widely in the crust and upper mantle (Zhang et al. 2000; Crampin and Peacock 2005; Gao et al. 1995). The shear-wave splitting is related to the stress field, and results in the polarization of fast shear wave being parallel to the direction of the horizontal principal compressive stress in situ, and the time delay of slow shear wave is related to the change in the stress field (Gao et al. 1998; Crampin et al. 2002; Gao and Crampin 2004). It is also found that the polarizations of fast shear waves are however scattered in the case of locally complex tectonic zones (Gao et al. 1995, 1999; Peng and Ben-Zion 2004; Shi et al. 2006; Wu et al. 2007). The above results show that shear-wave splitting is an efficient tool to get information about the regional stress field and seismic characteristics in the crust. In this paper, we study the seismic anisotropy in the Fujian area, southeast of Cathaysia block, and the relation between shear-wave splitting and faults.

2 Faults and data

During the Late Jurassic, the Fujian area (23°–29° N, 116°–120° E) was compressed in NW direction by the Pacific–Philippine Plate, resulting in some compressive shear faults striking NE and other tensional shear faults striking NW (Chen et al. 1999). Both sets of faults cross each other to form the tectonic frame of the area. The regional faults in Fujian are shown in Fig. 1. The Zhenghe-Dapu fault, which is part of the Lishui–Lianhuashan fault, South China Folded Belt, crosses the whole study area in the NE direction (Fig. 1) and divides the region into two parts, East Fujian and West Fujian. Since the beginning of the Proterozoic period, the Zhenghe–Dapu fault controls the geodynamics and volcanic activity of the zone.

The Fujian Seismic Network (FJSN) was installed in 1996, but it was not in operation until December 1998, and became the first provincial digital seismic network in Chinese mainland. In the 2000s, 29 stations were installed: 20 of them with short-period seismometers and nine stations with broadband seismometers. The FJSN array can detect earthquakes of magnitude $M_L \geq 1.0$ (Hong and Yang 2005). Up to 263 small events of M_L-magnitude between 1.0 and 3.5 and depth from 7 to 28 km occurred in the Fujian area from January 1999 to December 2003, which were recorded at distances from the stations <30 km and initially listed for this study. These earthquakes, which are all located in the crust and whose epicenters are distributed around ten

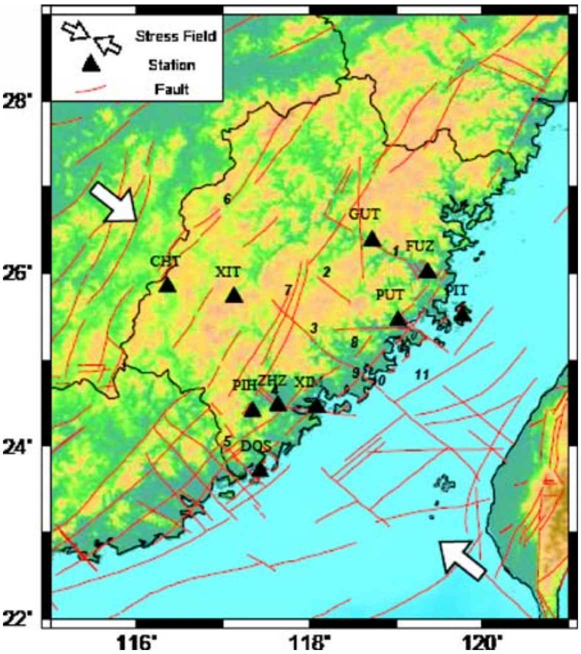

Fig. 1 Faults and seismic stations in Fujian, China, southeast of Cathaysia block. *Short lines* represent faults, *black triangles* are stations, and *arrows* indicate the direction of horizontal principal compressive stress in the area (Xu 2001). Key to symbols: *1* Min River fault, *2* Shaxian-Nanridao fault, *3* Yongai-JinRiver fault, *4* Lower Jiulong River fault, *5* Shanghang–Shaoan fault, *6* Shaowu–Heyuan fault, *7* Zhenghe–Dapu fault, *8* Fuqingdongzhang–Shaoantingyangpu fault, *9* Changle–Dongshanqianwu–Guangdongnanao fault, *10* Pingtan Basin–Donshanaojiao fault, *11* Niushan Island–Xiongdiyu fault. Faults 1–5 are in the N–W direction, and faults 6–11 are in the N–E direction

control stations (Fig. 1), generated short-period seismograms which were recorded at a sampling rate of 50 Hz. High-quality waveforms within the shear-wave window were selected for shear-wave splitting analysis at those stations.

To avoid the effect due to the free-surface interaction, only quality records within the shear-wave window were considered in our analysis. This window is about an incidence angle of 35° if Poisson ratio is ×0.25. Nevertheless, those records with incidence angle ≤45° can also be used owing to a shallow low-velocity sediment layer at surface (Crampin and Peacock 2005). Figure 2 shows the filtered seismic waveforms generated by the 23 June 2000 earthquake of M_L-magnitude 1.4 and depth 14 km recorded at station GUT.

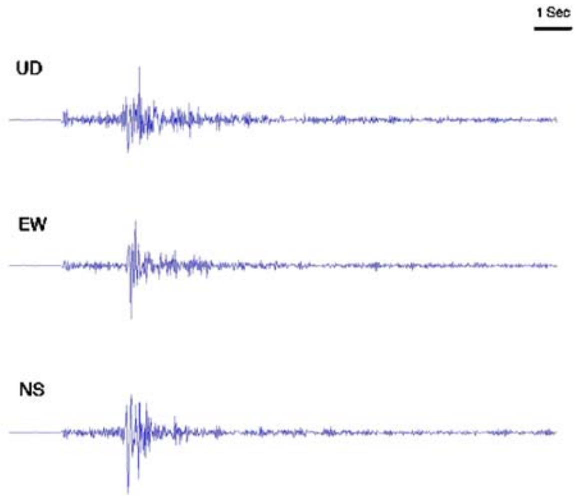

Fig. 2 Waveforms generated by the 23 June 2000 earthquake (20 h55 min) of M_L-magnitude 1.4 and depth 14 km recorded at station GUT. From *top to bottom*, vertical (UD), east–west (EW) and north–south (NS) ground motion components

Figure 3 (left column) shows the east–west and north–south horizontal components of the ground motion including shear waves and the nonlinear particle motion.

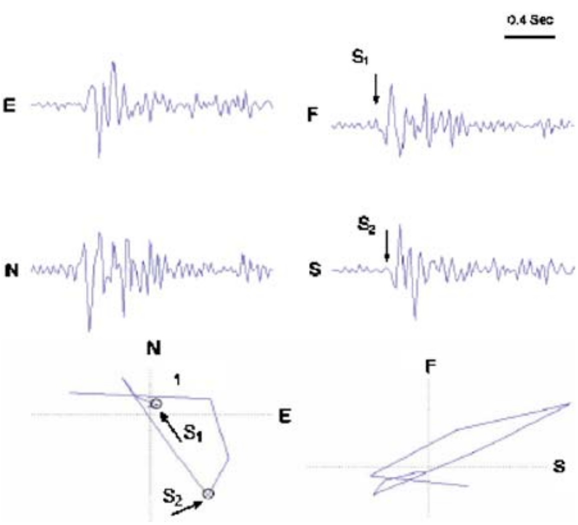

Fig. 3 Shear-wave splitting analysis. *Left* and from top to bottom: east–west (E) and north–south (N) shear wave components and particle motion as extracted from the original seismic signal (Fig. 2). Right and from top to bottom: fast shear wave (F, S_1) and slow shear wave (S, S_2) and particle motion as derived from polarization analysis

3 Method

As is well known, when a shear-wave travels through an anisotropic medium, it will split into a fast shear wave and a slow shear wave, so that the polarization of fast shear wave is parallel to the vertically aligned microcracks, while the polarization of slow shear wave is nearly perpendicular to the aligned microcracks. The key parameters in shear-wave splitting analysis are the polarization of fast shear wave and the time delay of slow shear wave that gives the magnitude of seismic anisotropy of the medium. Theoretically, both the fast shear wave and the slow shear wave originate from the same source, and therefore, they should be similar as to its form. Based on this consideration, the correlation analysis is used in order to estimate the splitting parameters. The north–south and east–west shear-wave components are rotated and shifted in time. Then, the correlation coefficients are calculated for possible values of time-shift of the split shear waves. Lastly, the splitting parameters are determined from the maximum of the correlation coefficients (Gao and Zheng 1995; Gao et al. 1995, 1998). Early researches successfully applied correlation coefficients for estimating seismic anisotropy in the mantle (Bowman and Ando 1987); but shear-wave splitting in the crust is different because of the more complex short-period waveforms, what leads to a more complicated analysis method (Gao and Zheng 1995; Gao et al. 2004).

Many factors may however influence the results, such as crustal structure, surface topography, geological/tectonic conditions around the station, waveform data, applied method, etc. In some cases, the shear-wave splitting parameters cannot be obtained properly by cross correlation only, and polarization analysis is then necessary (Gao and Zheng 1995; Gao et al. 1995, 1998). Let us suppose that the polarization angle of fast shear wave is α; then, after rotating the north–south and east–west components by angle α, these horizontal components become the fast and slow shear-wave components (Fig. 3, right column). If the time delay of slow shear wave is Δt, the slow shear wave can be moved forward just this time Δt to eliminate the time delay, and the particle motion becomes practically linear as can be seen in the polarization diagram (Fig. 3, bottom). Therefore, by rotation of waveforms, time delay correction, computation of the particle motion, and polarization analysis of split shear waves, it is possible to control the process and to estimate reliable shear-wave splitting parameters. Here, these splitting parameters are always systematically adjusted by these operations (that we identify by its acronym SAM in a previous work by Gao et al. (2004)) since the direct calculation often results in some mistakes (Crampin and Gao 2006).

The shear-wave splitting parameters are so obtained at ten FJSN stations (Fig. 1). Table 1 contains the station parameters and the shear-wave splitting results from measurements made at the ten control stations. From among these stations, there are two, PIH and XIT, with only one record and the rest with more than three to five records. Even though PIH and XIT have only one record

Table 1 Station parameters and shear-wave splitting results in the Fujian area

Station name	Station code	East longitude	North latitude	Altitude (m)	Number of records	Polarization (in degrees East of North)	Standard error (±degrees)	Time delay (ms/km)	Standard error of time delay (±ms/km)
ChangTing	CHT	116.4	25.8	340	11	40.91	16.63	1.89	1.93
DongShan	DOS	117.4	23.7	47	8	160.63	42.68	2.18	0.77
FuZhou	FUZ	119.4	26.0	110	14	114.29	12.94	2.00	0.98
GuTian	GUT	118.7	26.4	120	28	115.89	25.36	2.62	1.30
PingHe	PIH	117.3	24.4	50	1	90.00	–	3.91	–
PingTan	PIT	119.8	25.5	20	5	150.00	37.82	3.03	1.74
PuTian	PUT	119.0	25.4	49	7	115.71	39.23	4.49	1.61
XiaMen	XIM	118.1	24.5	49	8	92.50	35.62	1.78	1.06
XiaoTao	XIT	117.1	25.7	250	1	50.00	–	1.71	–
ZhangZhou	ZHZ	117.6	24.5	42	3	130.00	0.00	3.11	0.35

each, the data are of high quality and do not affect the reliability of the results. As is well known, only stations with one splitting measurement or with several measurements, but for waves coming from one source region, do not show directional dependence of the measurements, and therefore, neither support any trial to find a relation with the orientation of faults. But it is true in the mantle, where anisotropy is very much dependent on orientations of source-station pairs. However, the problem is different in the crust, where there is no obvious relationship between polarizations of fast shear waves and azimuths, and the polarizations of fast shear waves should be consistent (neglecting the influence of fluid pressure on seismically active fault planes).

4 Results

The fast shear-wave polarizations in the Fujian area are shown like a rose diagram in Fig. 4. There are two predominant polarization directions, in NW and NE directions, in accordance with the two series of crossing faults. This means that the regional stress field is mainly influenced by the two groups of faults. Furthermore, the faults with NW direction control the regional stress field (Fig. 4), at least near the coast of Fujian. GPS measurements reveal that the movement of the crust takes place in E–SE direction (Niu et al. 2005), and the main tectonic faults are in NW direction (Zhou et al. 2000). However, because of the heterogeneous structure of the study region, the stress field presents local variations, and the crustal seismic anisotropy in SECB is quite different at distinct places.

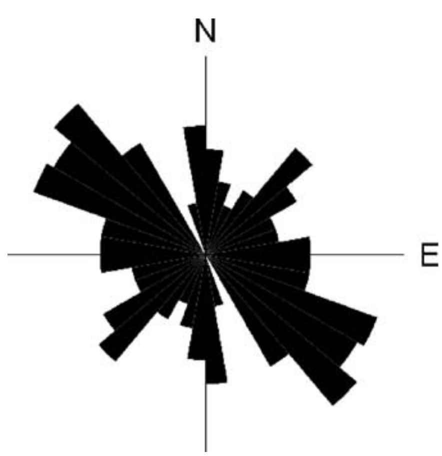

Fig. 4 Rose diagram of fast shear-wave polarizations observed in the Fujian area. The results correspond to the waveforms recorded at ten FJSN stations during the period January 1999 to December 2003

Statistically, the average polarization at the ten stations belonging to the FJSN array is N109.4° E ± 42.6°, which is consistent with the regional compressive stress field and strain (Zhou et al. 2000; Xu 2001; Niu et al. 2005). However, due to the complex regional tectonics, the polarizations show different patterns at the FJSN stations (Table 1, Fig. 5): half of the stations such as FUZ, GUT, PUT, XIM, and ZHZ exhibit predominant polarization in the NW direction; stations CHT and XIT present polarization in the NE direction, and station PIH does in nearly the E–W direction; and two stations, DOS and PIT, show polarization in the N–S direction.

The time delay "density" and its SD at each station are given in Table 1. All the time delays fall into the range 1.71–4.49 ms/km, and their respective deviations are between 0.35 and 1.93 ms/km. The minimum and maximum values are 1.71 ms/km at XIT and 4.49 ms/km at PUT, respectively. The average normalized time delay is 2.5 ± 1.5 ms/km. Compared to the results for the Capital area in North China and the Yunnan area in South China, it is obvious that both the average time delay and the variation ranges of time delays in Fujian are clearly smaller than in the two mentioned areas (Qian et al. 2002; Shi et al. 2006; Wu et al. 2007), which suggests that the magnitude of anisotropy in Fujian, southeast of Cathaysia block, is not so strong as in the cited areas.

5 Spatial distribution of polarizations and time delays

The average fast shear-wave polarization at FJSN stations and, therefore the spatial distribution of average polarizations in SECB, is displayed in Fig. 6a, whereas the rose diagrams at FJSN

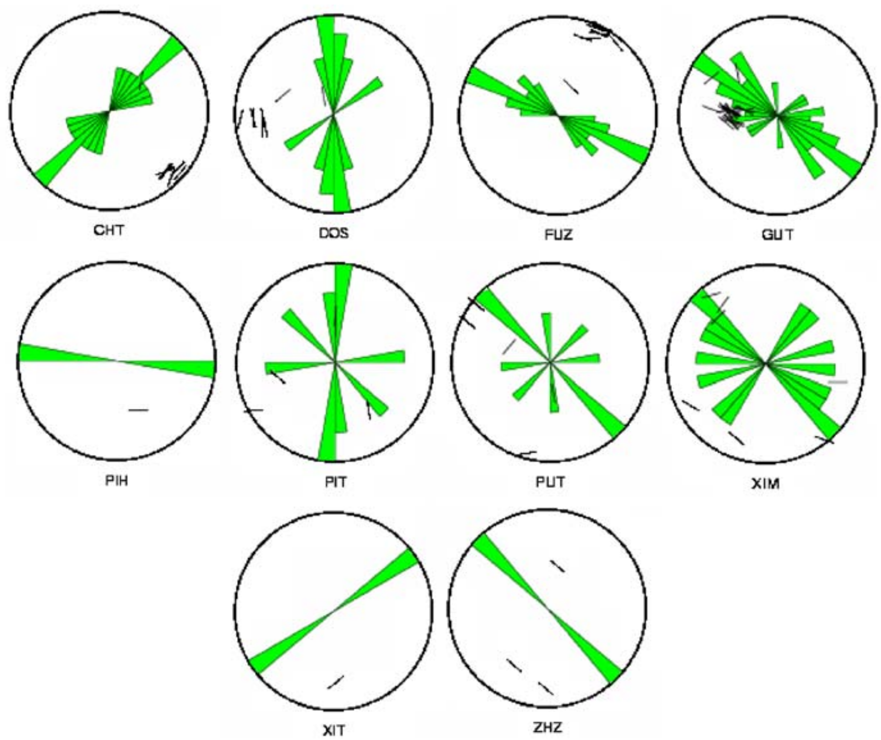

Fig. 5 Equal-area rose diagram (lower hemisphere projection) of fast shear-wave polarizations at the ten FJSN stations installed in SECB. In this diagram, the center of a circle represents the position of the respective station, and within each circle, the midpoint and direction of a short segment mark the position of an event and the fast shear-wave polarization, respectively

stations can be seen in Fig. 6b. Site-dependent polarizations of fast shear wave are clearly observed. Although many stations display polarization directions in agreement with the horizontal principal compressive stress, some stations show inconsistent results likely related to changes in the stress field owing to local tectonics and faulting (Gao et al. 1999; Lei et al. 1997). The regional faults have different strikes in the two areas, namely, West Fujian and East Fujian, separated by the Zhenghe–Dapu fault (Fig. 1), and the polarizations of fast shear wave at the stations installed in one or another zone are likewise different. In West Fujian, where faults are mainly in NE direction, stations CHT and XIT reveal polarizations of N40.91° E and N50.00° E, respectively (Table 1, Fig. 6a), i.e., polarizations parallel to the strikes of the faults, albeit quite different from the horizontal compressive stress dominant in the region. Station CHT is just near the active Shaowu–Heyuan fault, but station XIT is not on an active fault, so that the polarization observed at XIT seems to be influenced by the strike of the nearby fault in NE direction.

East Fujian displays however a more complex local tectonics with five series of faults striking in NW direction and two series of faults in NE direction in the coastal area, and faults crossing in NW direction in the seaside (Fig. 1). Most of the stations show that the predominant polarizations are consistent with the strikes of nearby active faults. Stations GUT, FUZ, PUT, and ZHZ are in East Fujian, and the average polarizations at these four stations are, respectively N115.89° E, N114.29° E, N115.71° E, and N130.00° E (Table 1, Fig. 6a), i.e., similar and parallel to the strikes of the faults. Stations GUT and FUZ are on the Min River fault, station PUT is on the Shaxian–Nanridao fault, and station ZHZ is on the Jiulong River fault, all of them in NW direction. In change, the predominant polarizations of N150.00° E and N160.00° E at stations PIT and DOS (Table 1, Fig. 6a) are almost north–south, while the predominant polarizations of N90.00° E and N92.50° E at stations PIH and XIM (Table 1, Fig. 6a) are east–west. However, station XIM exhibits a strong scatter in polarization (Figs. 5 and 6b) and suggests a first predominant polarization in NW direction,

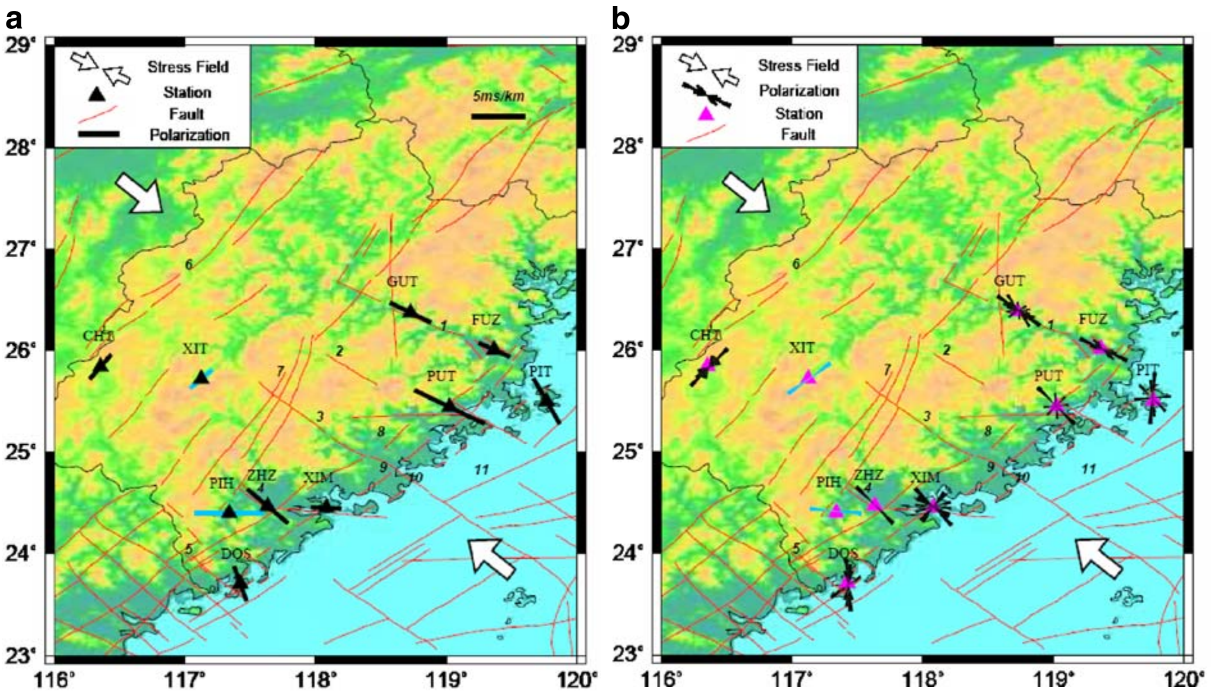

Fig. 6 **a** Average fast shear-wave polarization at FJSN stations (Fig. 1). The directions of the short segments show the average fast shear-wave polarization at the respective station, while the lengths of the segments are proportional to the average slow wave time delay at each station. *Black segments* correspond to stations with more than three records, and *blue segments* to stations with only one record. A time delay scale is inserted on the top right corner. Local faults are the same as in Fig. 1. **b** Equal-area rose diagrams showing the fast shear-wave polarization distribution at FJSN stations. *Black* segments correspond to stations with more than three records and blue segments to stations with only one record

but also a second polarization in nearly NE direction. The observed scatter in some fast shear-waves polarizations, for instance at stations DOS, PIT, and XIM (Fig. 5), suggest that this splitting parameter is influenced by both faults striking NW and faults striking NE in the seaside. These three last stations are on small islands or peninsulas, and the irregular topography might be a factor for such a scattering (Gao and Crampin 2006). Anyhow, the respective predominant polarizations at stations PIT and XIM are parallel to the strikes of the nearby faults and are consistent with the horizontal principal compressive stress in SECB. The focal mechanisms of events near active fault zones in the Fujian seaside area (Ding and Wu 1999) make clear that the horizontal principal stress is in W–NW-E–SE direction, as expected, due to the action of the Philippine Plate. Furthermore, Li et al. (2005) have studied the horizontal principal stress near active faults in the zone by measurements of hydraulic fracturing and have obtained that the horizontal principal compressive stress is in the NW direction along the shoreline from the north to south. Therefore, the predominant polarization at station XIM, which is close to the seaside, can be considered as NW in agreement with the reported results on regional focal mechanisms and horizontal principal compressive stress.

The magnitude of seismic anisotropy in the context of the splitting analysis is given by the time delay. By way of mere tendency, Fig. 7 shows the spatial distribution of this parameter by isolines on the Fujian area. A scattered behavior of the time delay from one station to another depicts very local features for anisotropy at each station, although this pattern must be taken with caution as the contour map of Fig. 7 might erroneously

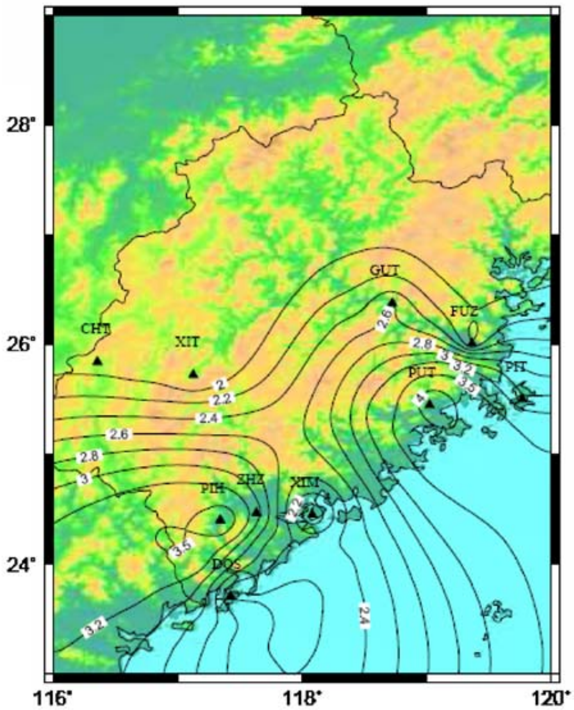

Fig. 7 Map of contour lines showing the spatial distribution of time delays (in ms/km) of the slow shear-wave in SECB (Fujian, China)

extend some properties that are only real in the vicinity of each station. The highest values of time delay extend over the coastal band around stations PUT and PIH, while the lowest ones concentrate near station XIM. Nearly 89.5% of strong earthquakes occur in the seaside in SECB (Ding et al. 1989). Although some strong earthquakes happen inland, its total number is less, and its magnitude is smaller when compared to the magnitude of the seismic events near the sea or offshore. In spite of the correlation between time delays and regional seismicity is not straightforward, the magnitude of anisotropy seems to be consistent with the most seismically active area. This aspect needs more data and further research.

6 Conclusions

Shear-wave splitting parameters in SECB (Fujian) have been obtained by a systematic analysis of waveforms generated by earthquakes that occurred from January 1999 to December 2003 and recorded at FJSN stations. The statistical analysis gives the average fast shear-wave polarization of N109.4° E ± 42.6° at the NW direction and the average slow shear-wave time delay of 2.5 ± 1.5 ms/km. The horizontal principal stress in SECB as derived from shear-wave splitting is nearly consistent with the stress field determined from earthquake focal mechanisms, the horizontal principal compressive stress obtained by GPS measurements, and additional fracturing measurements.

Many polarization directions at stations of the FJSN array are in agreement with the horizontal principal compressive stress and the polarizations on active faults are parallel to the strikes of the faults. However, site-dependent polarizations of fast shear-waves, as a consequence of local changes in the stress field owing to local tectonics and faulting, are a feature of the study area. In West Fujian, the predominant polarization is in the NE direction and follows the strikes of the nearby faults, but it differs from the horizontal compressive stress dominant in the region. In East Fujian, the predominant polarization is in the NW direction, and it agrees with the tectonics and the horizontal principal compressive stress. Both directions of predominant polarization are really consequences of the influence of the two series of faults in SECB.

The map of contour lines imaging the spatial distribution of time delays of the slow shear-waves depicts lateral variations much larger near the coast than in other zones. This pattern seems to be consistent with the fact that the seismic activity is comparatively stronger along the coastal line than inland. Nevertheless, more information is needed to support this feature.

Acknowledgements Helpful comments and criticism from anonymous referees that led to significant improvement of the early manuscript are gratefully acknowledged. The IES-CEA Project 2007-24, Science Project of Fujian Province (Grant 2002-004), and the Joint Seismological Science Foundation of China (Grant 606045) supported this research.

References

Bowman RJ, Ando M (1987) Shear-wave splitting in the upper-mantle wedge above the Tonga subduction zone. Geophys J R Astron Soc 88:25–41

Chen Y, He D, Chen X, Xu B, Li G (1999) Preliminary study of geotectonic stress field in Fujian—I. Late Jurassic period to Middle Pleistocene period. Journal of Oceangraphy in Taiwan Strait 18(3):291–296, (in Chinese)

Crampin S (1981) A review of wave motion in anisotropic and cracked elastic-media. Wave Motion 3:343–391

Crampin S, Peacock S (2005) A review of shear-wave splitting in the compliant crack-critical anisotropic Earth. Wave Motion 41:59–77

Crampin S, Gao Y (2006) A review of techniques for measuring seismic shear-wave splitting above small earthquakes. Phys Earth Planet Inter 159:1–14

Crampin S, Volti T, Chastin S, Gudmundsson A, Stefánsson R (2002) Indication of high pore-fluid pressures in a seismically-active fault zone. Geophys J Int 151:F1–F5

Ding X, Wu C (1999) Study on the resource mechanism of moderately strong earthquakes in Fujian and its coast. Crustal Deformation and Earthquake 19:95–97 (in Chinese)

Ding X, Chen Y, Huang Q, Chen G (1989) Fujian seismic tectonic$ lithospheric dynamics atlas of China, in state seismological bureau of China. China Cartographic Publishing House, Beijing, p. 39 (in Chinese)

Gao Y, Zheng S (1995) Cross correlation function analysis of Shear wave splitting-method and example of its application. J Earthq Predict Res 4:224–237

Gao Y, Crampin S (2004) Observations of stress relaxation before earthquakes. Geophys J Int 157:578–582.

Gao Y, Crampin S (2006) A further stress-forecast earthquake (with hindsight), where migration of source earthquakes causes anomalies in shear-wave polarizations. Tectonophysics 426:253–262

Gao Y, Zheng S, Sun Y (1995) Crack-induced anisotropy in the crust from shear wave splitting observed in Tangshan region, North China. Acta Seismol Sin (English edition) 8(3):351–363

Gao Y, Wang P, Zheng S, Wang M, Chen Y, Zhou H (1998) Temporal changes in shear-wave splitting at an isolated swarm of small earthquakes in 1992 near Dongfang, Hainan Island, southern China. Geophys J Int 135:102–112

Gao Y, Zheng S, Zhou H (1999) Polarization patterns of fast shear wave in Tangshan region and their variations. Chinese J Geophys (English edition) 42(2): 228–232

Gao Y, Liu X, Liang W, Hao P (2004) Systematic analysis method of shear-wave splitting: SAM software package. Earthq Res China (English edition) 18(4): 365–372

Hong X, Yang G (2005) Monitoring ability of Fujian digital seismic network to the historical strong earthquake region of Quanzhou. Seismological and Geomagnetic Observation and Research 26(2):89–96 (in Chinese)

Lei J, Wang P-D, Yao C, Chen Y-T (1997) Near field shear wave characteristics and its relation with structure in Jianchun, Yunnan. Chinese J Geophys 40(6):791–801 (in Chinese)

Li H, An Q, Xie F (2005) Study on in situ stress measurement around coastal marginal land in Fujian. Acta Seismologica Sinica (English edition) 18(5):544–551

Niu Z, Wang M, Sun H, Sun J, You X, Gan W, Xue G, Hao J, Xin S, Wang Y, Wang Y, Li B (2005) Velocity field of present crust movement of China. Chin Sci Bull 50(8):839–840 (in Chinese)

Peng Z, Ben-Zion Y (2004) Systematic analysis of crustal anisotropy along the Karadere-Duzce branch of the North Anatolian fault. Geophys J Int 159:253–274

Qian X, Li B, Qin J (2002) Study on shear wave splitting for sequence of the aftershocks of Yao'an Ms 6.5 earthquake in Yunnan. Earthq Res China (English edition) 17(1):32–41

Shi Y, Gao Y, Wu J, Luo Y, Su Y (2006) Seismic anisotropy of the crust in Yunnan, China: polarizations of fast shear-waves. Acta Seismologica Sinica (English edition) 19(6):620–632

Wu J, Gao Y, Chen Y, Huang J (2007) Seismic anisotropy in crust in Northwest Capital area. Chinese J. Geophys (English edition) 50(1):210–221

Xu Z-H (2001) A present-day tectonic stress map for eastern Asia region. Acta Seismologica Sinica (English edition) 14(5):524–533

Zhang Z, Li Y, Lu D, Teng J, Wang G (2000) Velocity and anisotropy structure of the crust in the Dabieshan orogenic belt from wide-angle seismic data. Phys Earth Planet Inter 122:115–131

Zhou S, Wu Y, Qin X, Shuai P, Shi S, Deng G, Zhou X (2000) Study on the crustal horizontal movement in Fujian and its neighbouring sea region based on several kinds of GPS measurements. Chinese J Geophys 43(4):471–479 (in Chinese)