

Crustal Structures and Anisotropy in Southeastern China: Continental Collision and Intraplate Earthquakes

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Crustal Structures and Anisotropy in Southeastern China: Continental Collision and Intraplate Earthquakes

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Key Points:

- Crustal structures reveal the differential evolution between continental blocks
- Stratified anisotropy inherited from foliation and shearing due to past subduction.
- Present collision reactivates the fault and seismicity along the block boundaries.

Abstract

This study investigates the role of crustal structures and anisotropy in southeastern China in the context of intraplate earthquakes resulting from concentrated and perturbed tectonic stresses. The region is characterized by a complex multiphase tectonic history and undergoing collision between the Philippine Plate and the South China Margin. Using the teleseismic receiver function method, we provide a detailed picture of crustal structures and layered anisotropy in Guangdong and Fujian, two earthquake-prone regions. The results show that the crustal anisotropy is stratified into two layers, with the upper-middle crust having an orogen-perpendicular slow axis and the lower crust with a fast axis aligned with the orogen. The lateral heterogeneity and anisotropy of the crustal structure highlight the boundary and differential movement between the continental blocks. The increase in density and intensity of intraplate earthquakes across this boundary supports our conclusion of a link between decoupled crustal deformation and seismicity. Specifically, foliation of the metamorphic rocks during the Mesozoic collision generated the orogen-parallel fabrics in the upper-middle crust, ductile shearing yielded orogen-perpendicular fast directions at the lower crust, and mismatch evolution between continental blocks reactivated by present collision provides stress conditions conducive to the occurrence of earthquakes in southeastern China. Our findings provide insights into the mechanism of intraplate earthquakes and the tectonic evolution of continental collision zones.

Plain Language Summary

How intraplate earthquakes happen is a topic of interest in the study of continental collision at plate margins. We investigate the role of crustal structures and anisotropy in southeastern China in the context of these earthquakes. This region, undergoing collision between the Philippine Plate and the South China Margin, has a multiphase tectonic history including

remnants of paleo-Pacific subduction. Using the receiver function method, we provide a detailed picture of crustal structures and layered anisotropy in Guangdong and Fujian, two earthquake-prone regions in southeastern China. The results show that anisotropy in the crust is stratified into two layers: an upper-middle crust with an orogen-perpendicular slow axis, and a lower crust with a fast axis aligned with the orogen. The lateral heterogeneity and anisotropy of the crustal structure highlight the boundary and differential movement between the continental blocks. The increase in density and intensity of intraplate earthquakes across this boundary supports a link between decoupled crustal deformation and seismicity, in which (1) metamorphic foliation in the upper-middle crust was caused by the Mesozoic collision (2) the lower crust characterizes ductile shearing, and (3) mismatch evolution between continental blocks reactivated by present collision provides stress conditions conducive to the occurrence of earthquakes.

1 Introduction

Intraplate earthquakes have been recorded in stable continental interiors, oceanic plates, and continental collision zones. The mechanisms underlying intraplate earthquakes are generally related to the presence of preexisting faults or fractures in the Earth's crust, which can be reactivated by ongoing geologic processes (Vilotte et al., 1982; Gray and Pysklywec, 2012). The relationship between intraplate earthquakes and continental collision is a subject of ongoing research, and there are still many unanswered questions about the precise mechanisms that lead to seismic activity in these regions. However, recent studies have shed light on some of the key factors involved, including the role of crustal structures and anisotropy. For example, using the shear-wave splitting method, a study by Meltzer et al. (2007) found that the crustal anisotropy in southeastern Tibet is related to the ongoing collision between the Indian Plate and the Eurasian Plate. Similarly, a study by Duan et al. (2022) found that the 2019 Ridgecrest earthquakes in

California were related to preexisting faults in the Earth's crust that were reactivated by the ongoing tectonic stresses associated with the collision between the Pacific Plate and the North American Plate. Therefore, continental collisions result in concentrated and perturbed tectonic stresses in the crust, and how these stresses evolved has important implications for understanding the Earth's tectonic processes and the effects on intraplate earthquakes.

Seismic anisotropy, which refers to the variation in seismic velocity in different directions, can provide insight into the lithospheric deformation and stress state in collided continents (Godfrey et al., 2002). Anisotropy in the brittle crust is often associated with the presence of cracks and can reflect the direction of current regional stress (Bianchi et al., 2015; Levin and Park, 1998). For example, when the maximum compressive is perpendicular to the crack plane, it closes the cracks and causes the seismic waves to travel faster in that direction. In the middle and lower crust, under high confining pressures, the formation of anisotropy is dominated by the preferential alignment of minerals and strain-related crystal orientation (Fry et al., 2010). As a result, regions that have been subjected to intense tectonic activity tend to show fast anisotropy along the strike of geological terranes. However, local tectonic processes such as active faults or magmatic intrusions can affect the background anisotropy and reveal structural heterogeneity (Audet, 2015; Boness and Zoback, 2006).

In this study, we investigated the crustal thickness and Poisson's ratio in Southeastern China (SC) using teleseismic receiver functions (RFs) recorded by permanent stations in Fujian and Guangdong Provinces (Figure. 1). These areas experienced multiphased continental collisions between various plates since the Mesozoic, and the intraplate earthquakes are also noticeable and have been the focus of the research (Hsu et al., 2004; Zhu et al., 2020). We employed harmonic decomposition and waveform inversion of the RFs to determine the depth

variable anisotropy and dipping layer in the crust of the SC and to explore the connection between the crustal deformation and the imprinted tectogenesis. Additionally, we analyzed the potential impact of the tectonically active Bashi Fault Zone (BFZ) on crustal anisotropy and the mechanism for triggering the intraplate earthquakes in the region.

2 Geological Settings

The SC lies at the junction of a passive South China Sea continental margin and an active orogenic belt across Taiwan (Figure. 1). Collision and subduction in the paleo-Tethyan and Pacific tectonic domains have contributed to the geologic structures of the SC (Li et al., 2019; Suo et al., 2019). The collage of distant paleocontinents with various basement ages was completed after the subduction between the paleo Pacific and Eurasian Plates in the Mesozoic (Hsu et al., 1988; Zhou and Li, 2000). As a result, the region is characterized by extensive tectonic mélange zones and nappe structures that run roughly SE-EW (Li et al., 2020). As an overlay of multiple collision processes, how the orogeny constructed and modified the geological structures in time and space has been a global concern. Particularly, in which way the lithospheric materials were deformed and redistributed provides insights into the dynamics and mass circulation of the Plate motion system.

The collision between the Philippine Sea plate and the South China Sea continental plate is causing significant crustal deformation in the SC. The collision is occurring in the northwest direction at a speed of ~82 mm/yr (Huang et al., 2015b). However, GPS studies have shown that the vertical motion of the crust in the SC coastal area is far less compared to the east coast mountains of Taiwan (Hu et al., 2001; Liu et al., 2007; Yu et al., 1997). This means that most of the stress generated by the collision is absorbed in the thrust front. Despite this, nonnegligible compressive stresses have been transported to the SC by a series of NW trending faults such as

the BFZ (Ding and Liang, 1992). These transverse structures interact with the NE trending faults in the SC and are increasing the risk that strong and intense earthquakes in the conjunction zones (Hsu et al., 2004). Especially, southern Fujian and eastern Guangdong, where the BFZ extends, experience the highest frequency of earthquakes with magnitudes above M6.0. There have even been repeated earthquakes with magnitudes greater than M7.0, which are rare in the entire SC region (Zhu et al., 2020). However, the extent and mechanism of these earthquakes are not well understood, as the impact of the multiple collisions on the current deformation and stress state of the lithosphere is not well known.

3 Methods and Results

3.1 Data Processing and RF Computation

Since the groundbreaking work of Langston (1979) and Owens et al. (1984), the RF has been established as an effective technique for isolating the structural responses beneath the seismic station (Ammon, 1991; Ball et al., 2014; Huang et al., 2015a). The method, which unitizes the P-to-S converted waves (Ps) generated when a propagating P wave encounters a velocity boundary along its path, enables high-vertical-resolution imaging of crustal and mantle discontinuities. For isotropic structures, the RF method can be used to estimate crustal thickness and V_p/V_s ratio by stacking amplitudes at predicted Ps and multiple reflection times from different epicenters and directions ($H-k$ stacking) (Zhu and Kanamori, 2000). For anisotropic structures, systematic variations in amplitudes, polarity, and travel times of the radial and transverse components of the RF along the ray paths are observed due to azimuth-dependent anisotropy (Levin and Park, 1998). Based on these observations, the RF modeling will provide

constraints on the depth and degree of the anisotropy structures on horizontal scales of several kilometers in the crust.

This study analyzed data from 126 permanent seismic stations run by the China Earthquake Administration between 2009 and 2015. Teleseismic waveform recordings with a magnitude greater than M6.0 and epicentral distances ranging from 30° to 90° were considered. The back azimuth coverage of these events is overall adequate for anisotropy analysis (Figure.2). The RFs were computed following the source equalization procedure with a water-level parameter of 0.001 and a Gaussian width of 2.5 (Ammon, 1991). We manually evaluated these receiver functions by checking the Ps signals, and a total of 24874 pairs of radial and transverse RFs were selected for further processing. For anisotropy modeling, the RFs were moveout corrected at a slowness of 0.06 s/km and stacked into 10° back azimuths.

3.2 Anisotropy Analysis and Harmonic Decomposition

The investigation of crustal anisotropy was mainly based on the variation in the waveform of the radial and transverse RFs with azimuth. The moveout-corrected RFs were plotted as a function of back azimuth and showed significant amplitudes and periodic variations on the transverse and radial RFs (Figure.2a). On the radial RFs, the Ps phase from the Moho was observed to arrive at approximately 3.5s and exhibit a periodic variation of 180° with azimuth (Figure.2a), which is indicative of anisotropy in the crust. In addition, polarity reversals were often observed at the zero-lag time on the transverse RFs with a period of 360° , indicating the presence of a dipping boundary in the shallow layer (Frederiksen and Bostock, 2000; Tsang-Hin-Sun et al., 2021). The presence of additional reversed polarity sequences prior to the arrival of the Ps phase further confirmed the existence of anisotropy layers with plunging axes or dipping interfaces in the crust (Figure.2b).

To analyze the periodic characteristics of various sources, we employed harmonic decomposition in the study of inclined boundaries and anisotropy (Audet, 2015; Bianchi et al., 2015; Shiomi and Park, 2008). This technique represents the RF ensemble as a combination of $\cos(k\varphi)$ and $\sin(k\varphi)$, where k is the harmonic degree and φ is the back azimuth (Supporting Information). The degree-0 harmonic (A) represents the contribution from flat-layered isotropic media and can be used to determine the velocity structures unaffected by azimuthal heterogeneity. The degree-1 harmonics ($B1$, $B2$) indicate a dipping boundary or anisotropy with a plunging axis, while the degree-2 ones ($C1$, $C2$) denote anisotropy with a horizontal axis. Based on Audet (2015), we constructed the decomposition system and solved the matrix to identify the direction in which a particular harmonic component is optimized. We choose to minimize the variance of $B2$, and the optimized azimuth can be interpreted as the tilt direction of the isotropic layer, or it can be directly related to the trend of the anisotropy axis. In accordance with Audet (2015), we used the time range of 0 ~ 7.0 s to obtain stable harmonics originating from both dipping boundaries and crustal anisotropy. Additionally, we examined the time window from -1.0 s to 1.0 s to find the signals from shallow dipping layers.

Figure.3 illustrates the five scaling factors for the harmonic degrees 0, 1, and 2 at stations NPDK and YND. Both stations display positive amplitudes for isotropic component A at around 3.5 s, indicating the presence of P-to-S converted phases from the Moho boundary. In addition, many stations show negative amplitudes before the Moho phases, indicating a potential low-velocity layer, as reported in previous studies (Huang et al., 2020; Zhou et al., 2020). Component $B1$ is characterized by alternating positive and negative pulses, with the strongest pulse appearing at the start and suggesting the presence of a dipping boundary at the top. A second set of double-polarity phases can be seen between about 2 and 3 s, which could be due to depth-

dependent crustal anisotropy or dipping layers. This is further supported by the signals in B_2 , as a uniform azimuth model may not fully account for layered anisotropic axes. We have compared the spatial characteristics of the anisotropy by drawing the harmonic profiles across different regions (Figure. 4). The similarity between the degree-1 and degree-2 profiles would suggest a gentle plunge of the anisotropy axis.

3.3 Synthetic Modeling and Anisotropy Uncertainty

The optimization of variance in multiple time windows for the backazimuthal harmonics may not accurately separate the depth-variable anisotropy (Supporting Information, Figure.1S-7S). Instead, we resort to synthetic modeling and nonlinear inversion of the binned RFs using the method proposed by Frederiksen and Bostock (2000) and Frederiksen et al. (2003). The synthetic modeling and inversion of the RFs use the techniques of efficient forward-modeling of the RFs and a directed Monte Carlo search of the model space guided by the neighbourhood algorithm (Frederiksen et al., 2003; Sambridge, 1999). The model that best synthesizes the weighted radial and transverse RF pairs is found by generating a number N of random points in the model space, dividing the remaining space into neighborhoods closest to one sampled point using the L2-norm distance metric, and selecting a number M of points in the neighborhoods with low misfit to the real RF data for further search. The model space is iterated by repeating the search steps.

The initial model was parameterized into three layers based on geological information and harmonic analysis: weathered granite and volcanic layer, and two anisotropy layers with slow and fast axes. The slow axis was found to well represent the minerals and cracks in the upper crust while the fast axis better approximated mineral alignment or rock fabric in the lower crust (Cossette et al., 2016). The upper mantle was assumed to be constant during the inversion. First, the thicknesses of the weathered granite layer and the dipping angle and strike were

searched, using an averaged crustal thickness and seismic velocity, with weight coefficients for the radial and transverse RFs set to be 0.1 and 0.9, respectively. The dipping strike can generally be determined by the polarity reversal of the signals around zero time. After determining the inclined layer, the thickness and anisotropy of the two crustal layers were searched through 60 iterations using sample sizes N of 30 models and retention samples M of 10 models. Forward modeling was then performed to simplify the structures and modify the anomalous results that overfit the data. If necessary, the misfit was reduced further by adding a layer to the crustal model obtained from inversion. The inverted model parameters can be found in the Supporting Information ([Table 2S](#)). The strikes of the inclined layer of the top layer and the anisotropy axes were not always consistent between the harmonic analysis and waveform modeling ([Table.2S](#)). However, the anisotropy axes obtained from the harmonic analysis are generally consistent with the inversion results in azimuth ([Figure.2c](#)) but show a more dispersed distribution, possibly due to the influence of the inclined interface or separation failure of layered anisotropy. [Figure.5](#) shows the RF modeling from stations of GD_XNH with two anisotropic layers and FJ_HAHF with single anisotropic layer, and both stations have shallow dipping layers on top of the models.

To understand the contribution of the accepted model to the RFs, each inverted model parameter was used to generate theoretical RF waveforms ([Figure.6](#)). While the monolayer model was acceptable at some stations ([Figure.5a](#)), the bilayer model could better reproduce the pulses on the two components in most cases ([Figure.5b and Figure.6](#)). As shown in [Figure.6](#), the results indicate that the inclined weathered granite layer generates polarity reversal around 0 s, while the layered anisotropy contributes to the signals from 1 to 4 s, especially in the transverse RF. With the addition of the fast anisotropy layer, the positive signals at around 1.8 s in the radial and transverse RFs were better fitted. In the following discussion, we focus on the

directions among the model parameters, as the orientation of the anisotropy axes and the strike of the dipping layer are more robust (Bianchi et al., 2015). The results are summarized in Figure.2c, including the strike of the dipping layer and the orientation of the slow and fast axis. In which, the strikes of the dipping layers have a concentrated distribution with an average value of 225°. The azimuth of the slow and fast axes had two peaks at 140° and 225°, with the former being the dominant one.

3.4 Crustal Thickness and V_p/V_s Ratio Estimation

Crustal thickness and V_p/V_s ratio beneath each station were estimated by applying the H - k method to the unsorted RFs. For stations with missing available data, we referred to the results from Huang et al. (2015a) obtained using recordings from 2001 to 2008. We used the same stacking parameters to make sure that the results are comparable. The updated map of the thickness and V_p/V_s ratio is similar to the previous results, but it provides more detailed evidence of block partitioning and corresponding petrological differences (Figure.7). Combined with the spatial characteristics of the relocated seismicity (Lu et al., 2022), the map shows two subzones roughly belonging to Fujian and Guangdong respectively with a boundary consistent with the BFZ in location and strike. The V_p/V_s value shows a scattered anomaly greater than 1.9 along this boundary, but it is normal on both sides and increases slightly toward the sea and reaches the minimum value in Guangdong (Figure.7b). Overall, the mean V_p/V_s value across the whole region is 1.76, but it shows a higher value (~ 1.77) in the northeast of the BFZ than the southwest (~ 1.74). The crustal thickness has an overall mean value of ~ 29.5 km and shows obvious zoning characteristics, in which Fujian has a mean value of ~ 31 km, about 2 km higher than Guangdong and its adjacent area (~ 29 km). The region with thickened crust was bounded by the BFZ in the

northeast and the Changle-Nanao fault zone (CNFZ) in the northwest, forming a sharp junction zone at Nanao Island (Figure.7a).

4 Discussion

4.1 Crustal Structure and Tectonic Boundaries Between Collided Blocks in the SC

The tectonic evolution of the South China (SC) region is governed by the rheological properties and deformation mechanisms of the continental crust, which have been investigated using various methods such as stratigraphy, petrology, and geophysical surveys (Kang et al., 2006; Li et al., 2020; Li et al., 2019). However, there is still a lack of evidence from deep structures in this area. Our study reveals a significant difference in the crustal thickness between Guangdong and Fujian Province (Figure.7a), with Fujian's crust being approximately ~3 km thicker than that of Guangdong and Taiwan Strait, separated by the BFZ and the CNFZ. While the V_p/V_s ratio of Fujian slightly increases towards the sea, the entire region displays a relatively low value of around 1.73 (Figure.7b). The precision of the crustal thickness in the Taiwan Strait is limited by the availability of offshore stations. However, joint modeling of artificial seismic data and free-air gravity anomalies confirms the difference in crustal thickness across the CNFZ (Wang et al., 2017). The SC has experienced collisional orogeny and crustal thickening since the Mesozoic, with modification by volcanism. The slightly increased crustal thickness and low V_p/V_s ratio in Fujian may suggest that the felsic upper crust has accreted to a greater extent (Huang et al., 2014; Huang et al., 2020), consistent with the presence of widespread low-velocity layers and negative RF pulses beneath the upper crust (Zhou et al., 2020), which could act as a napping interface for the upper crust.

Lithospheric extension during the Late Mesozoic and Cenozoic periods played a significant role in shaping the collisional blocks and likely led to the opening of the South China Sea. Many Cenozoic basins are located primarily in the southeastern part of the SC, and previous research has confirmed the existence of a rifting center in Guangdong (Huang et al., 2020; Lu et al., 2022). The relatively thin crust in this region is consistent with the continental extension. The decrease in the V_p/V_s ratio at the same time would draw the assumption that the mafic middle-to-lower crust may have flowed or been stretched more significantly (Ji et al., 2009). Isotopic characteristics of the granite in SC indicate limited contamination of the mantle material in its formation. The upwelling mantle only transferred the heat into the crust, causing the melting of felsic rocks in the middle-to-lower crust, which may further maintain a low V_p/V_s ratio (Huang et al., 2020).

The distinct crustal structures and rock composition properties result in different deforming mechanisms between the continental blocks of Guangdong and Fujian. GPS-based leveling measurements show that crustal deformation within the contacting zone along the BFZ is intensive, where the crustal movement has the most significant differential activity (Liu et al., 1998). The offset of the Moho across the BFZ may indicate the assembly of microcontinents in the SC. Tomography studies have also found that prominent low-velocity areas can extend throughout the entire crust along this boundary, and it may act as a conduit for the upwelling mantle materials (Cao et al., 2022; Li et al., 2014). According to this study, the area with a high V_p/V_s ratio along this boundary may have been affected by the fracturing and volcanism during the continental collision and shearing along the BFZ.

4.2 The Interplay between Inherited and Current Orogeny

Our study reveals a depth-dependent anisotropy in the crust, with the upper layer exhibiting slow anisotropy that is roughly parallel to the fast one in the lower layer (Figure.7). This bilayer anisotropy, which varies in type and orientation, may reflect the decouple crustal deformation and unique sources of the anisotropy. We propose that the presence of strain fabric and cracks in the crust are the two main factors behind the observed crustal anisotropy. If cracks were responsible for the anisotropy in the upper crust, the current axis of the maximum compressive stress (NW-oriented) would result in a slow axis in the NE direction, which contradicts the observations made through GPS and the focal mechanism (Levin and Park, 1998; Yang et al., 2011). Furthermore, the first layer's depth (5-15 km) may be too deep for cracks to remain open (Nakamura et al., 1996). An alternative explanation for the slow direction of the brittle crust is orogen-parallel anisotropy (OPA), which indicates strain-related anisotropy (Fry et al., 2014). Compression during collision causes foliation in metamorphic rocks and alignment of mica in the crust, leading to deformational fabrics that are parallel to the fold structures. The NEE-SWW orientation of the P-wave ellipsoid in the widely distributed Paleozoic S-type granitoids in Guangdong also suggests strong compression in the NNW-SSE direction (Jiang et al., 1995), which is in agreement with the field schistosity. The tilt direction of the dipping layer is also found to be similar to the strike of the slow anisotropy axis (Figure.7), indicating that the dipping layer formed during the same deformation process as the schistosity (Schulte-Pelkum and Mahan, 2014). The top low-velocity crustal layer is believed to represent weathered or eroded granite and volcanic bodies caused by uplifting due to compression. Local cracks or tectonics should not be excluded, as some studies using noise tomography and shear wave splitting of regional earthquakes have obtained scattered results (Wu et al., 2007).

The lower crustal anisotropy is typically interpreted as aligned anisotropy minerals resulting from ductile deformation and shear-induced crustal flow (Bianchi et al., 2015; Fry et al., 2014). The NW-oriented anisotropy axis in SC aligns with the widespread collision and the late lithospheric extension caused by the subduction between the paleo-Pacific Plates and the Eurasian Plate. The layered anisotropy structures like those observed in the SC have been observed in many other orogenic places (Fry et al., 2010; Huang et al., 2015b; Lu et al., 2014), and have been proposed to be present in the ongoing Taiwan orogeny (Huang et al., 2015b), which supports a common mechanism for crustal deformation during orogeny (Figure.8). The widely distributed low-velocity layer in the lower crust of SC could be considered a remnant shearing zone that accommodates the layered deformation of the upper and lower crust (Huang et al., 2020; Li et al., 2020).

4.3 Significance for Intracontinental Earthquake Analysis

In Southeastern China, recent and historical earthquakes are distributed along the NE-trending fault zones, which intersect with the NW-trending BFZ (Ding and Liang, 1992; Zhu et al., 2020). The contrasting structures of the crustal thickness and V_p/V_s ratio suggest that the Fujian and Guangdong provinces have distinct properties in lithospheric strength. Among the transverse structures spanning the SC and Taiwan strait, the crustal deformation in the south is more intense and complex due to the compression between the SC and the Philippine Sea plate (Shen et al., 2009). As Fujian is located at the front of the Taiwan orogenic belt, the napping of the upper crust makes it more brittle and likely to deform (Fry et al., 2010). GPS measurements also show that the Fujian area is bounded by two high-strain crustal deformation belts in the SW and NE edges, with non-uniform horizontal velocity within the region (Liu et al., 1998). This results in inconsistent azimuths of the anisotropy axis in Fujian (Figure.7 and Figure.8),

particularly along the BFZ in both the upper and lower crusts. Across the BFZ, the axis azimuth rotated from NW to NNE, and the dipping direction also shows variation. The above-mentioned anomaly suggests a mismatch in block evolution separated by the BFZ, leading to the potential for pervasive strain accumulation along the boundary.

The boundary is also a seismic gap zone, and the earthquake at the edge of the two regions is the most intensive in the whole area. Nanao Island has experienced repeated devastating earthquakes in conjunction with the BFZ and the littoral fault belt (Xia et al., 2020). In the plane view, crustal structures in this conjunction area are quite distinct in terms of crustal thickness, V_p/V_s ratio, and anisotropy. However, the precise location and focal mechanism of these earthquakes are unclear due to the lack of recorded seismic data (Kang et al., 2006). We propose that the decoupled crustal deformation and block boundary may provide proper conditions for stress concentration and release, thus allowing for dense seismicity. Anisotropy and structural changes can be used as indicators to assess the risk of large earthquakes, but the aftershock effect on the regional stress field and crustal deformation should be investigated in the future (Wang and Shen, 2020).

5 Conclusions

We utilized teleseismic receiver functions to examine the crustal structure and seismic anisotropy in the coastal region of southeast China. The results revealed a difference in the crustal thickness and V_p/V_s ratio between Guangdong and Fujian provinces, which are separated by the high-intensity earthquake zone along the NW-trending BFZ. The crust exhibits decoupled deformation processes, including thickening of the upper-middle crust due to paleo-Pacific subduction beneath the South China margin and flows in the lower crust in response to the lithospheric extension. The V_p/V_s ratio has a low-to-intermediate value throughout the region,

but shows a dispersed high value along the BFZ, indicating fracturing during the continental collision and stress transportation. Harmonic decomposition and modeling of the receiver function indicate layered anisotropy overlaid by a dipping weathered granite layer. The upper-middle crust has a slow-axis anisotropy parallel to the orogen, resulting from strain-related rock foliation due to subduction-induced thrusting. Below the upper-middle crust, a fast anisotropy is found and interpreted as aligned anisotropy minerals caused by ductile shearing and crustal flow. The anisotropy axis rotates from NW in Guangdong to NNE in Fujian across the BFZ, suggesting mismatch evolution between the two blocks. Pervasive strain accumulation and stress perturbation in the BFZ could be reactivated by the present collision of the Philippine Sea Plate onto the South China margin. The decoupled crustal deformation and mismatch evolution of the continental blocks could provide seismogenic conditions for intraplate earthquakes.

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Open Research

Seismic data for this study are provided by Guangdong Seismic Network, Guangdong Earthquake Agency, and the data can be found at the link <http://doi.org/10.5281/zenodo.7794196>.

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Figure.1 Map of faults and seismicity in southeastern China. The red and black triangles represent the seismic stations with and without acceptable anisotropy results, respectively. The yellow dots indicate the earthquake epicenters as reported in (Lu et al., 2022). The solid lines represent the regional faults that were identified through field investigation and seismic exploration. The dashed lines with triangles mark the nappe belts formed by the collision between Taiwan and the Philippine Sea plate. The green dashed line represents the Changle-Nanao Fault Zone (CNFZ). BFZ: Bashi Fault zone. The inset map highlights the locations of teleseismic events, represented by red stars, and the earthquake station SHG is marked by a black triangle.

Figure.2 The radial (a) and tangential (b) receiver functions recorded at the station SHG. The red and blue colors represent positive and negative phases, respectively. The dashed line indicates the periodic variation of the Ps phases, which correspond to anisotropy. (c). The Rose diagram shows the azimuths of the slow axis (represented by gray), the fast axis (light blue), and the optimized angle obtained through harmonic decomposition (green). The strike of the dipping layer is depicted in orange. The radii of the vectors are proportional to the frequency of the corresponding value, and the sectors have a width of 8° in degrees.

Figure.3 Harmonic decomposition of receiver functions for stations NPDK in Fujian (a) and YND in Guangdong (b). Each harmonic component is represented by a vertical trace and labeled at the bottom. The time range in which the B2 was searched for the minimum value was from 0 to 7 s. The direct P wave and its primary converted phase Ps are marked on component A.

Figure. 4 Results of harmonic decomposition showing the B1 (a, b) and B2 (c, d) of all the stations. Station names and the corresponding optimized angle are indicated at the top and bottom of the figures. Red and blue colors show positive and negative amplitudes.

Figure.5 Two examples of the synthetic modeling of the binned RFs from the station FJ_HAHF (a) in Fujian and GD_XNH (b) in Guangdong. The solid lines indicate the theoretical RFs, while the color-shaded curves are observed RFs. The anisotropy structures can be found in Supporting Information ([Table. S2](#)).

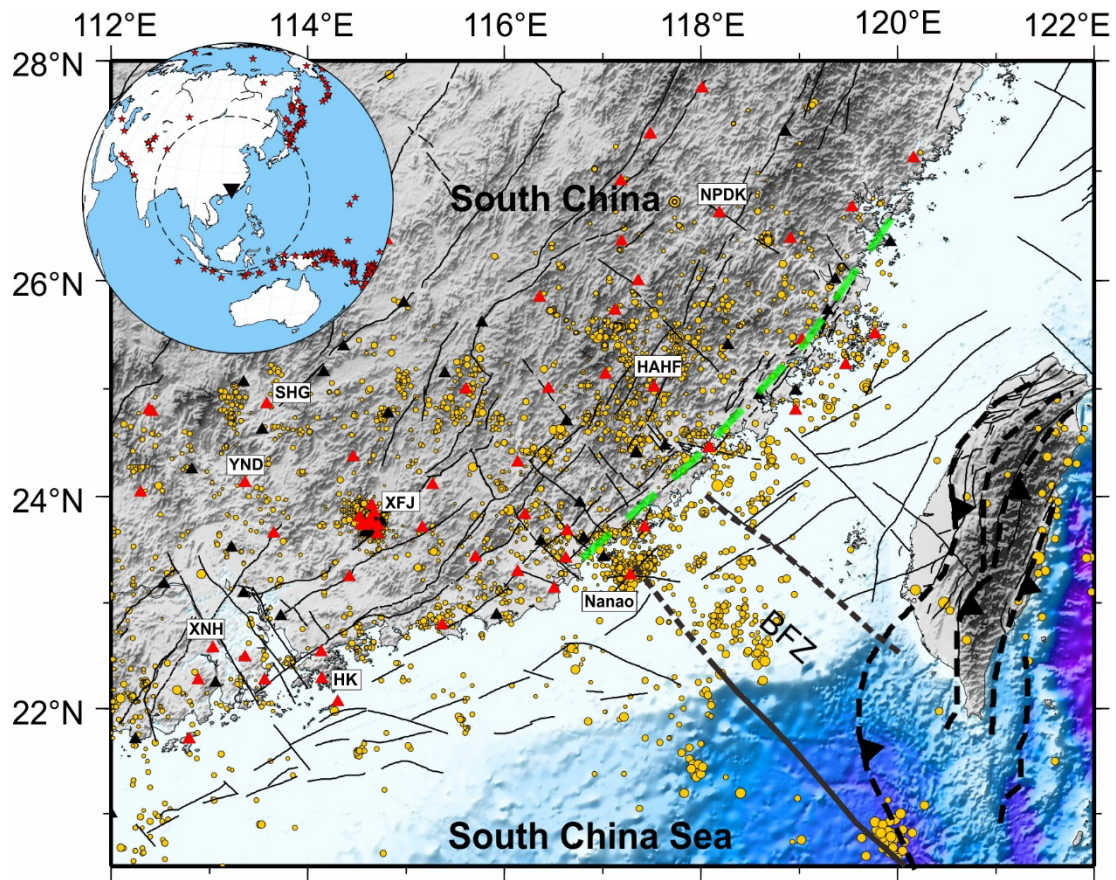
Figure. 6 Reliability test of the synthetic modeling of the RFs for GD_XNH. The top and bottom rows show the radial and transverse components, respectively. The blue boxes indicate the contribution of each model parameter to the RFs. The model parameters can be found in Supporting Information ([Table.S1](#) and [Table. S2](#)).

Figure.7 Maps of the inverted dipping direction shown in red arrows, the trend of the slow anisotropy axis shown in gray bars, and the fast axis in white bars. The background-colored map shows the crustal thickness (a) and V_p/V_s (b). The earthquakes are indicated by white circles, with strike-slip events shown in beach balls.

Figure.8 Sketch map illustrating the layered deformation and the mismatch evolution between GD and FJ. The regions of GD and FJ are shaded by different colors as the crusts in these areas show distinct characteristics of the thickness and V_p/V_s ratio. The red arrows in the upper and

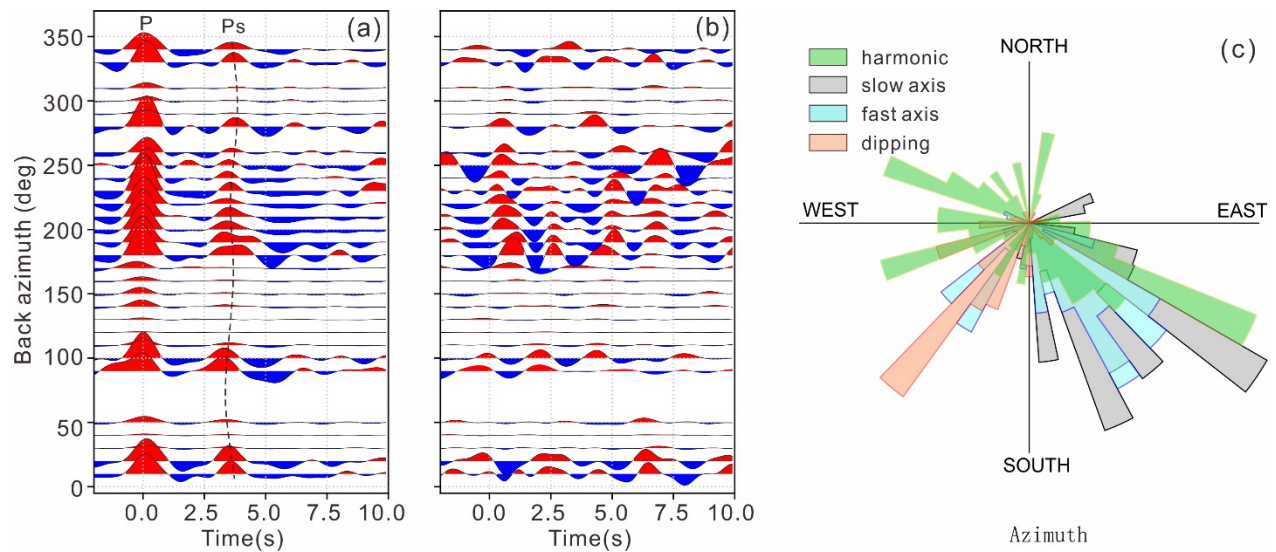
567 lower crust indicate the OPA and shearing-induced anisotropy due to the collision. The green
568 dashed lines show the shearing zone between the upper and lower crusts. Red stars show
569 devastating earthquakes located at the intersection of regional faults such as CNFZ and BFZ.

570 Figure.1



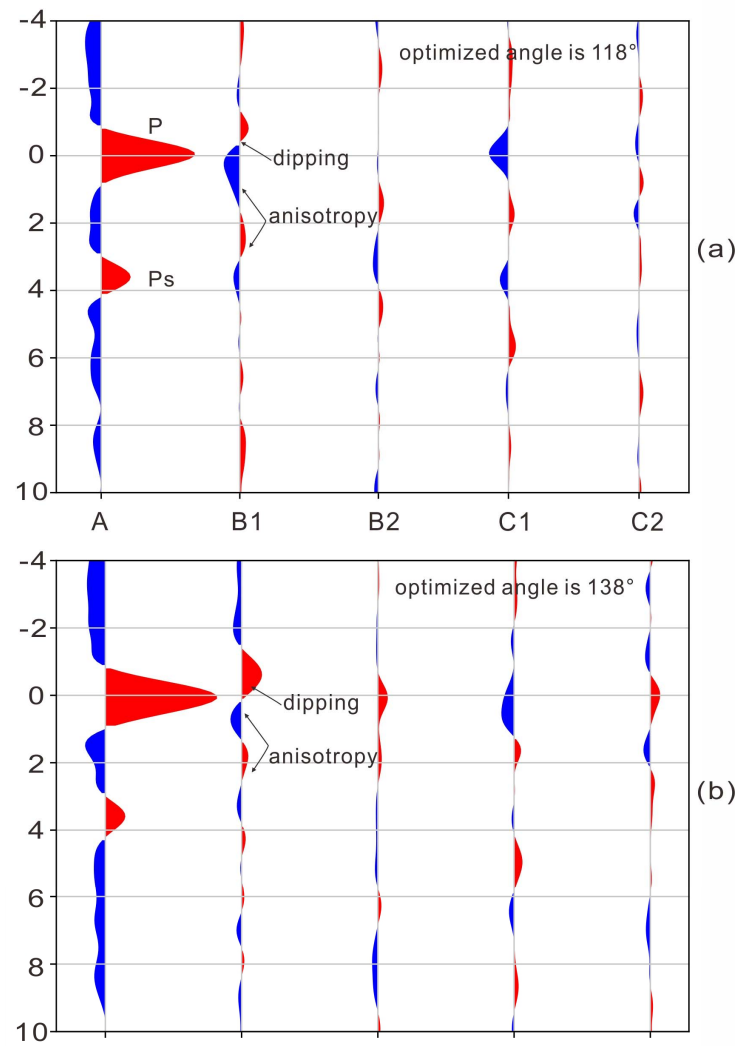
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572 Figure.2

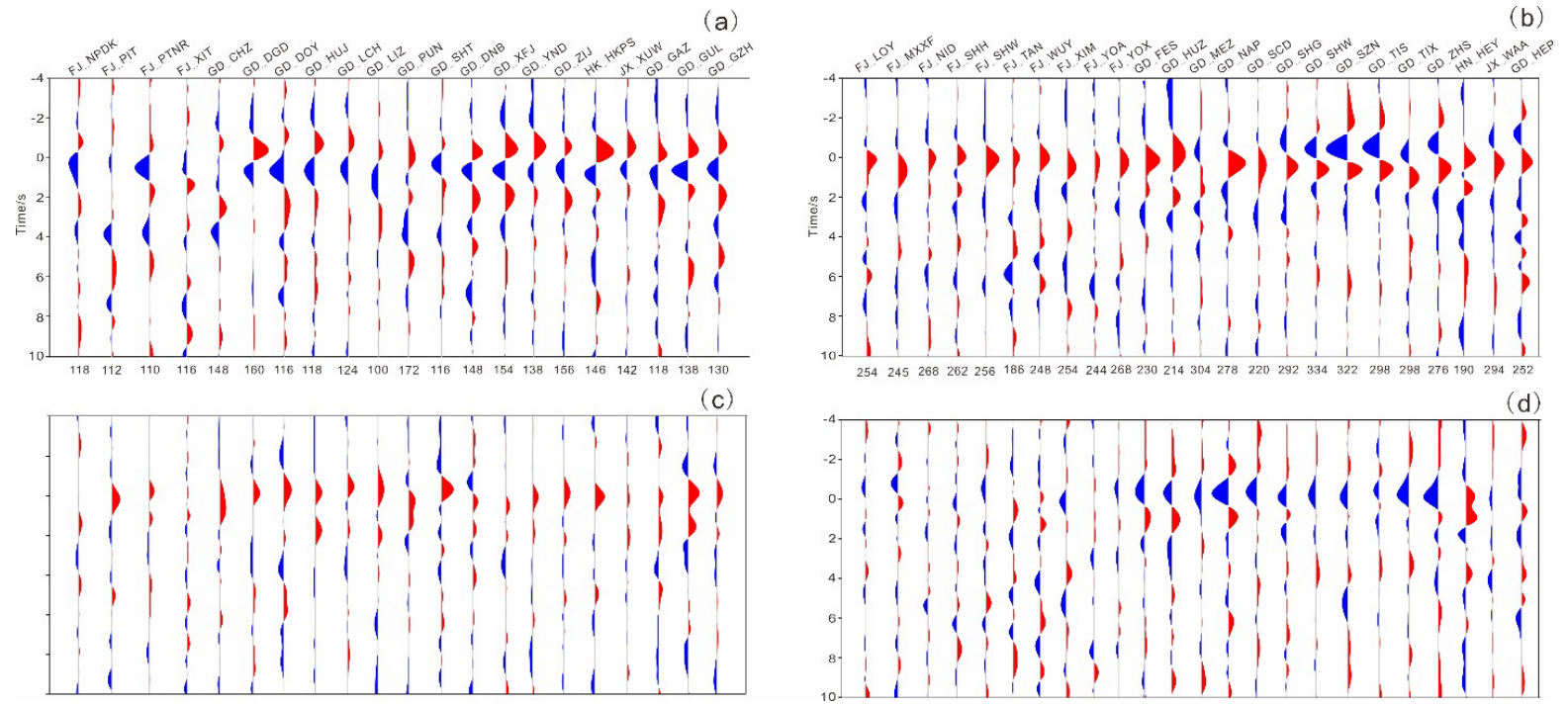


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574 Figure.3

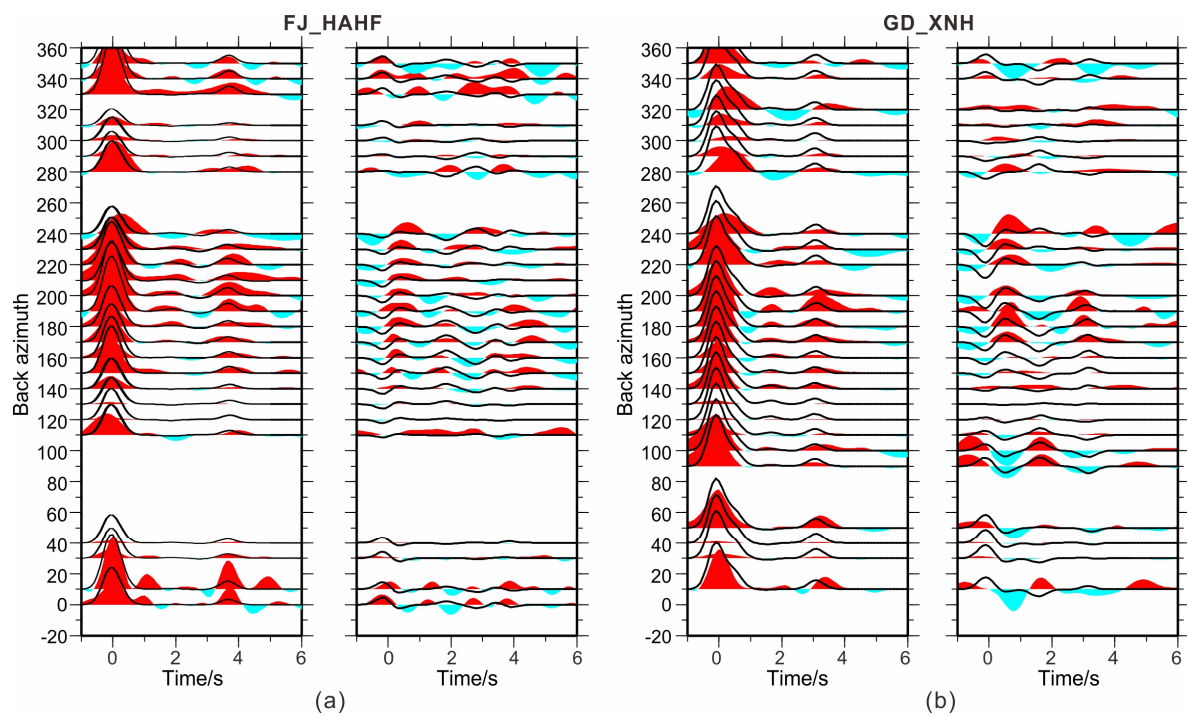


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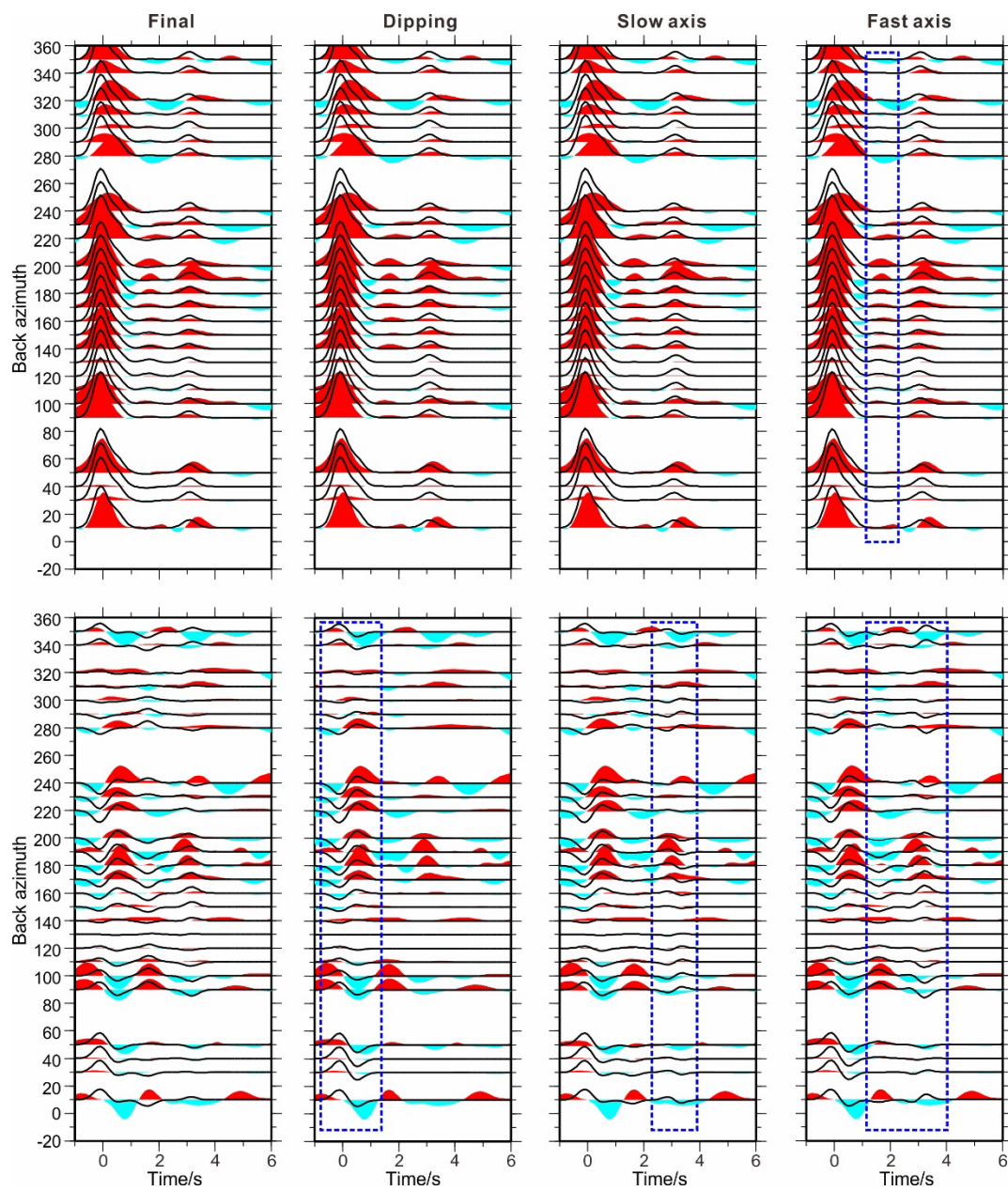
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578 Figure.5



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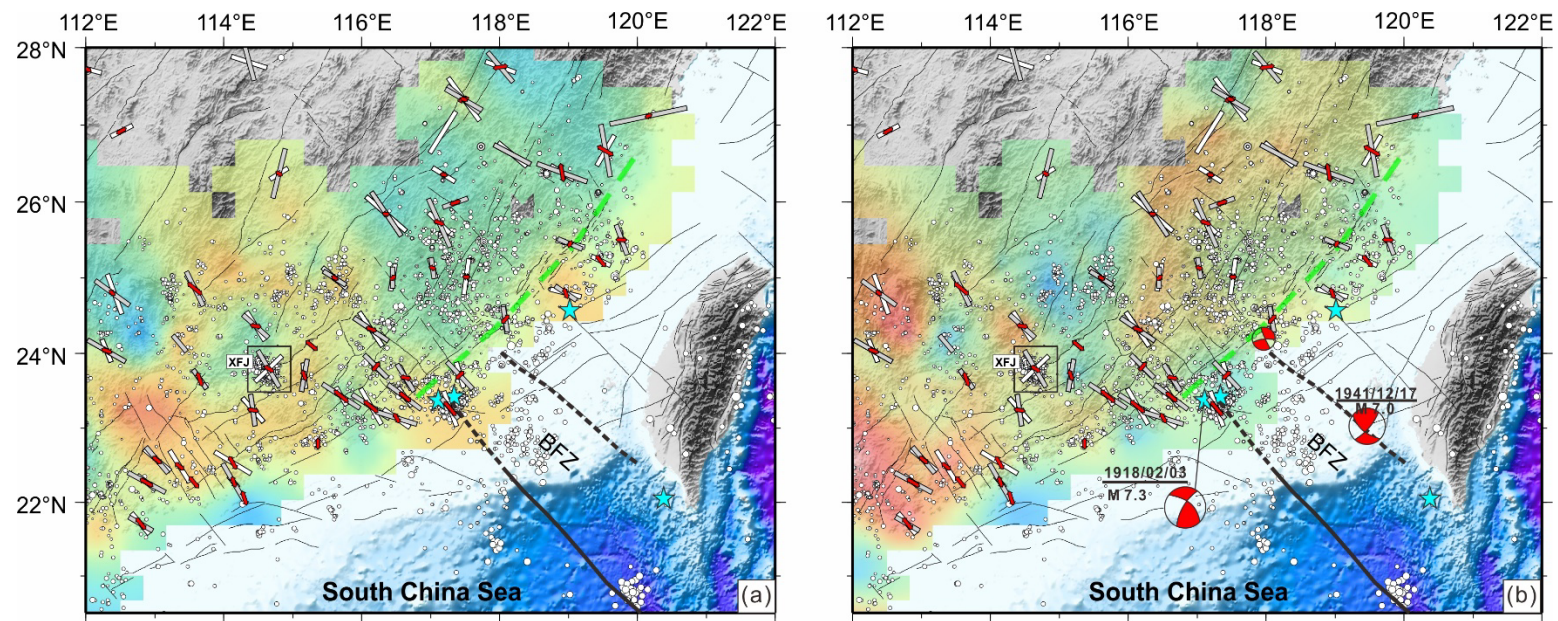
580 Figure.6



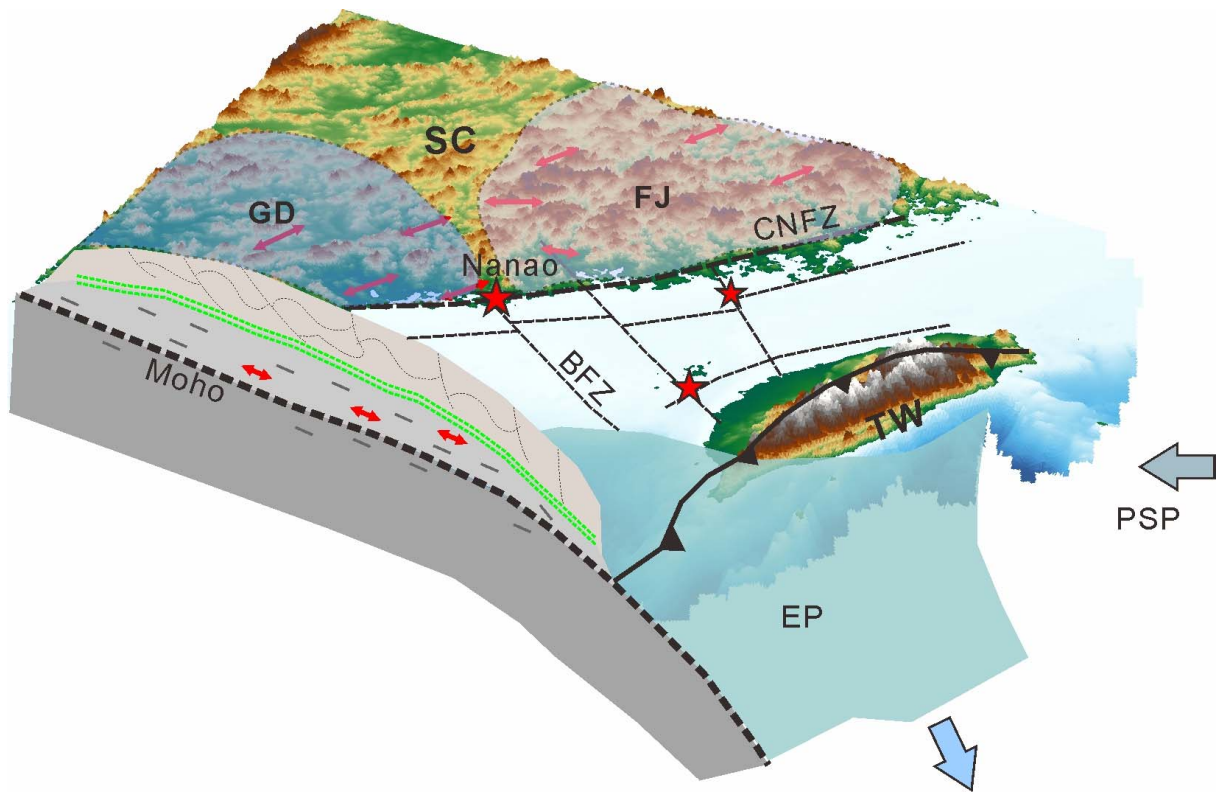
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582 Figure.7

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584 **Figure.8**



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Figure 1.

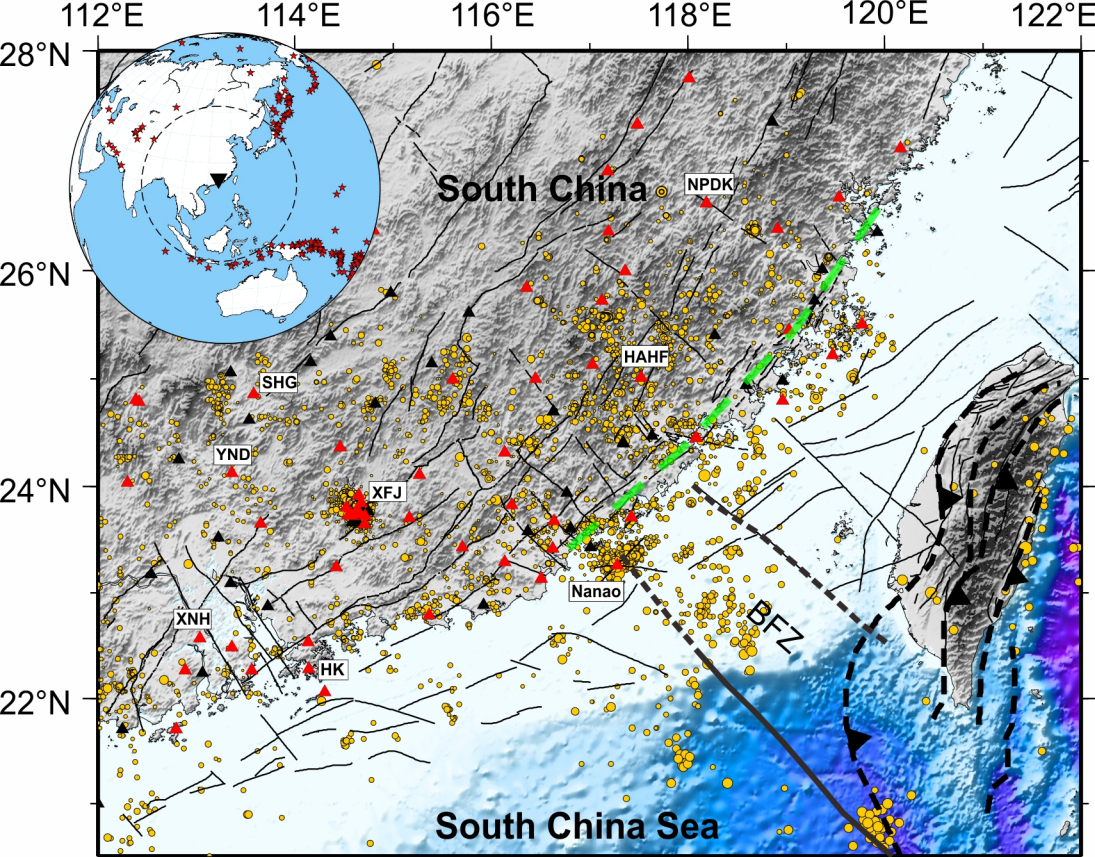


Figure 2.

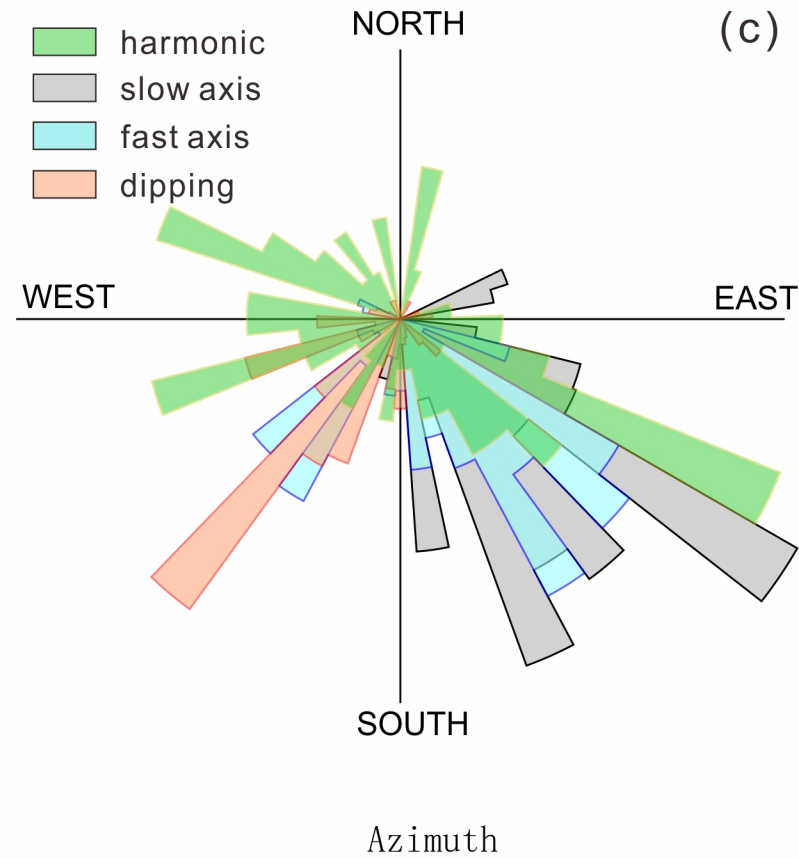
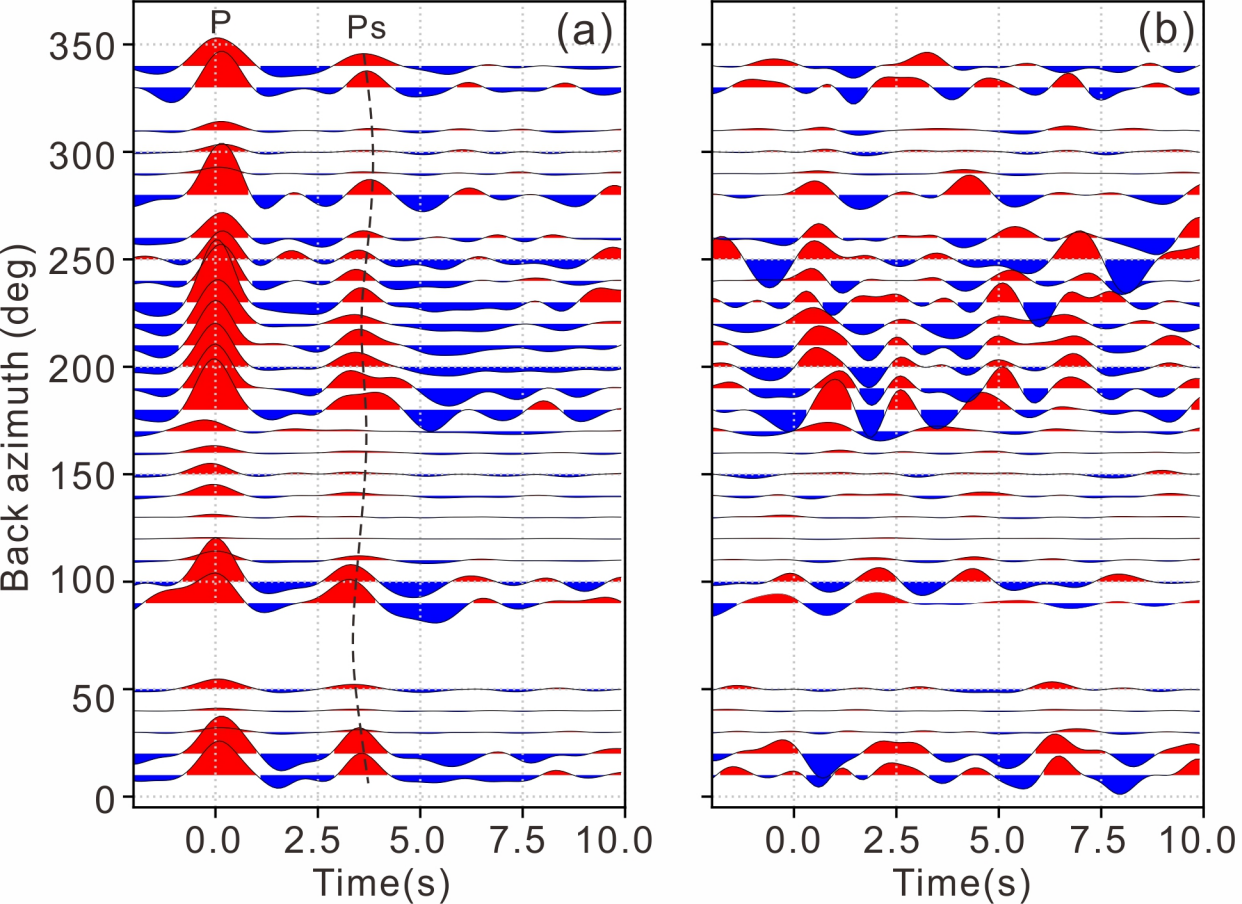


Figure 3.

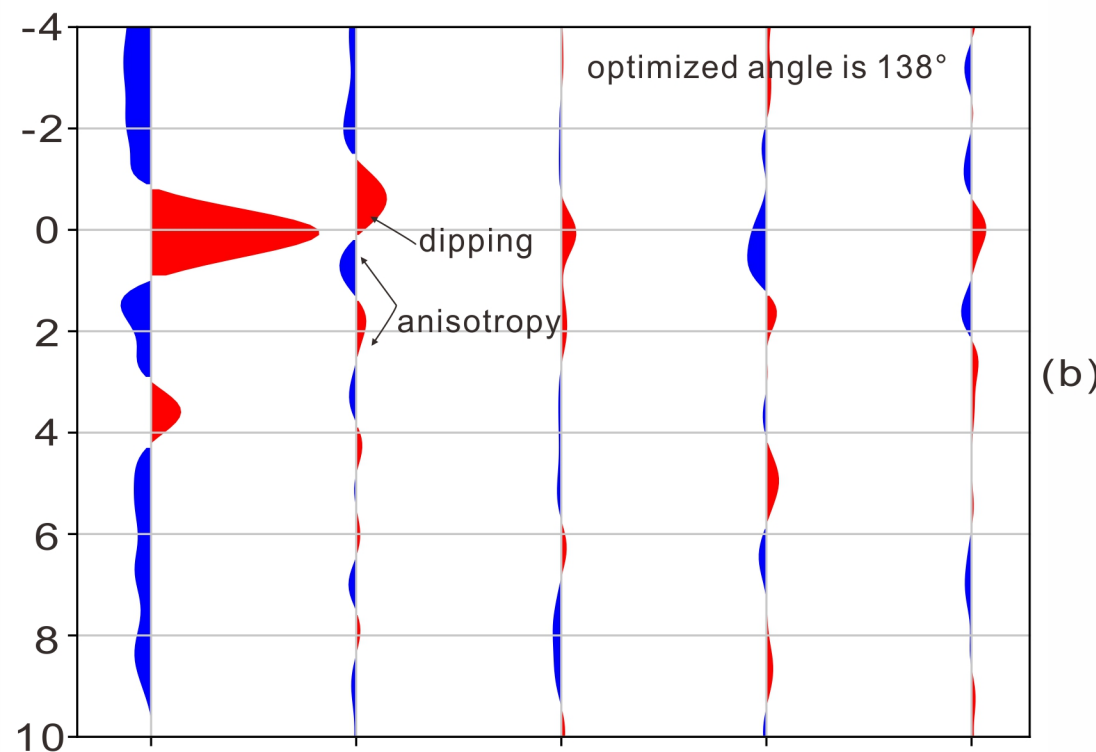
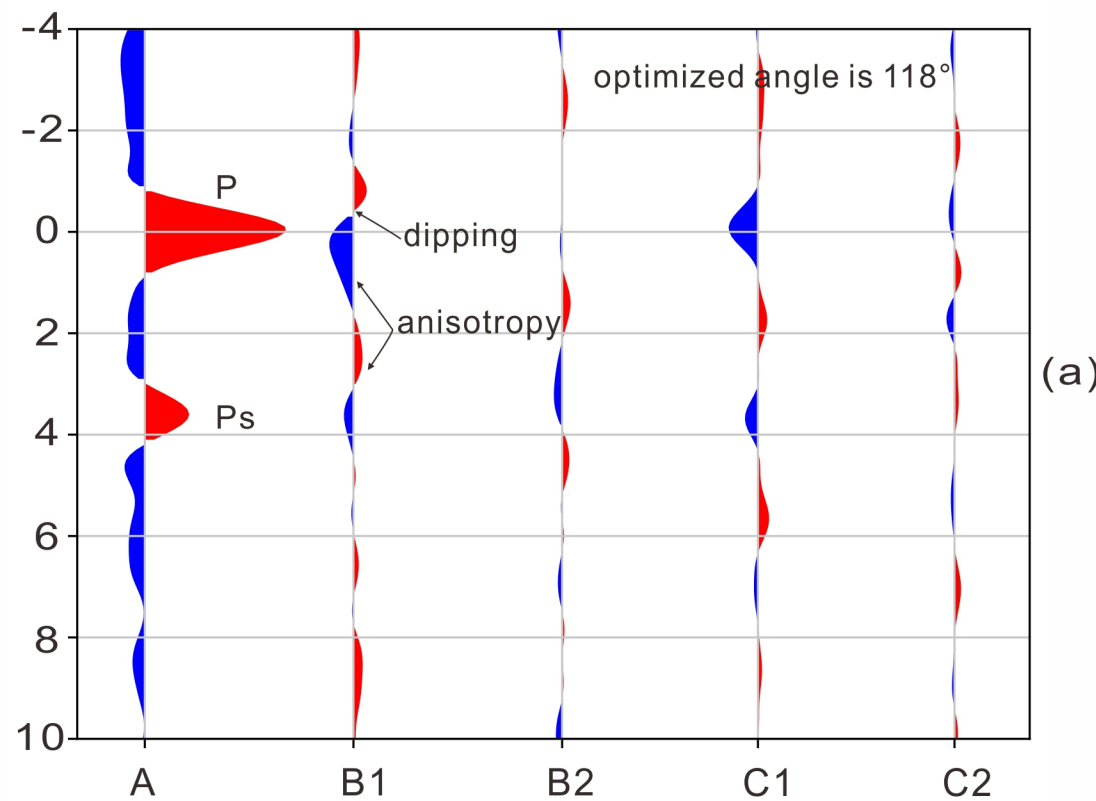


Figure 4.

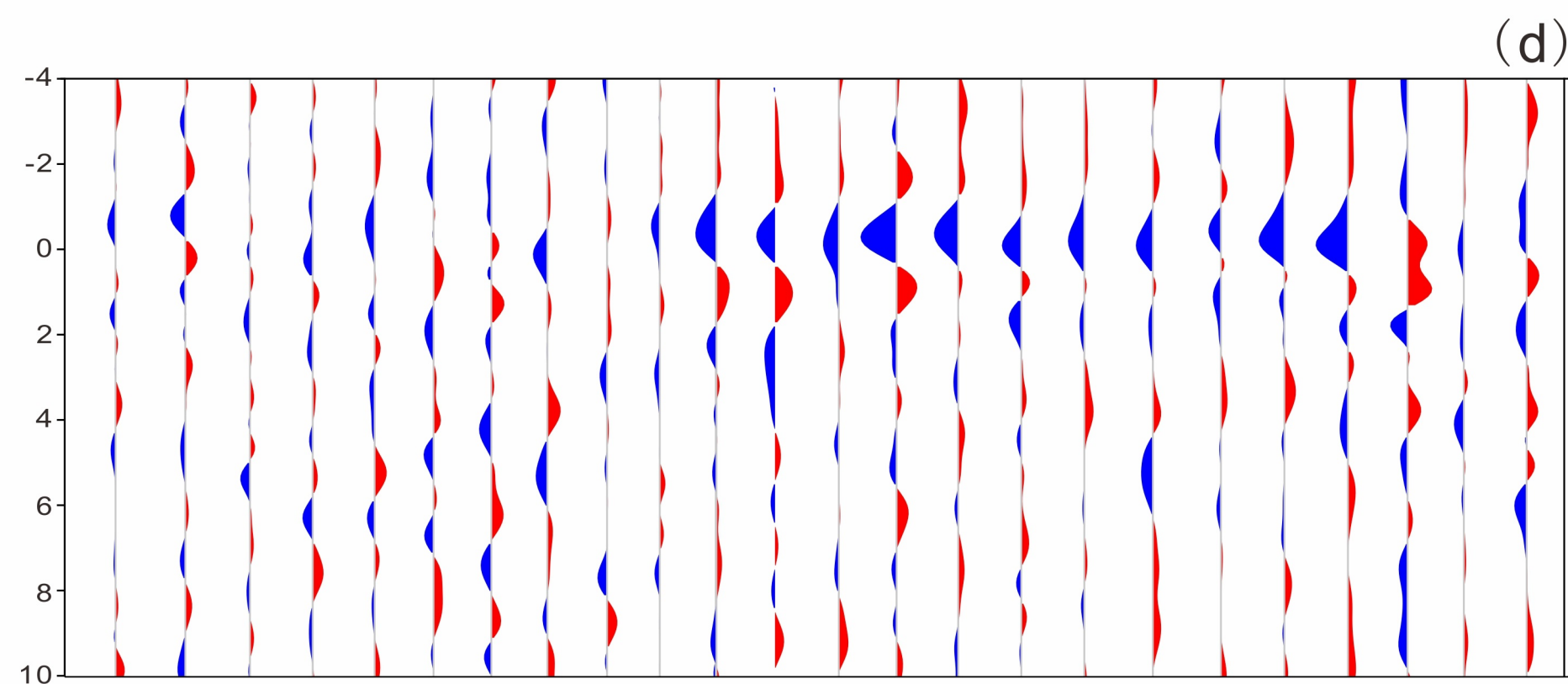
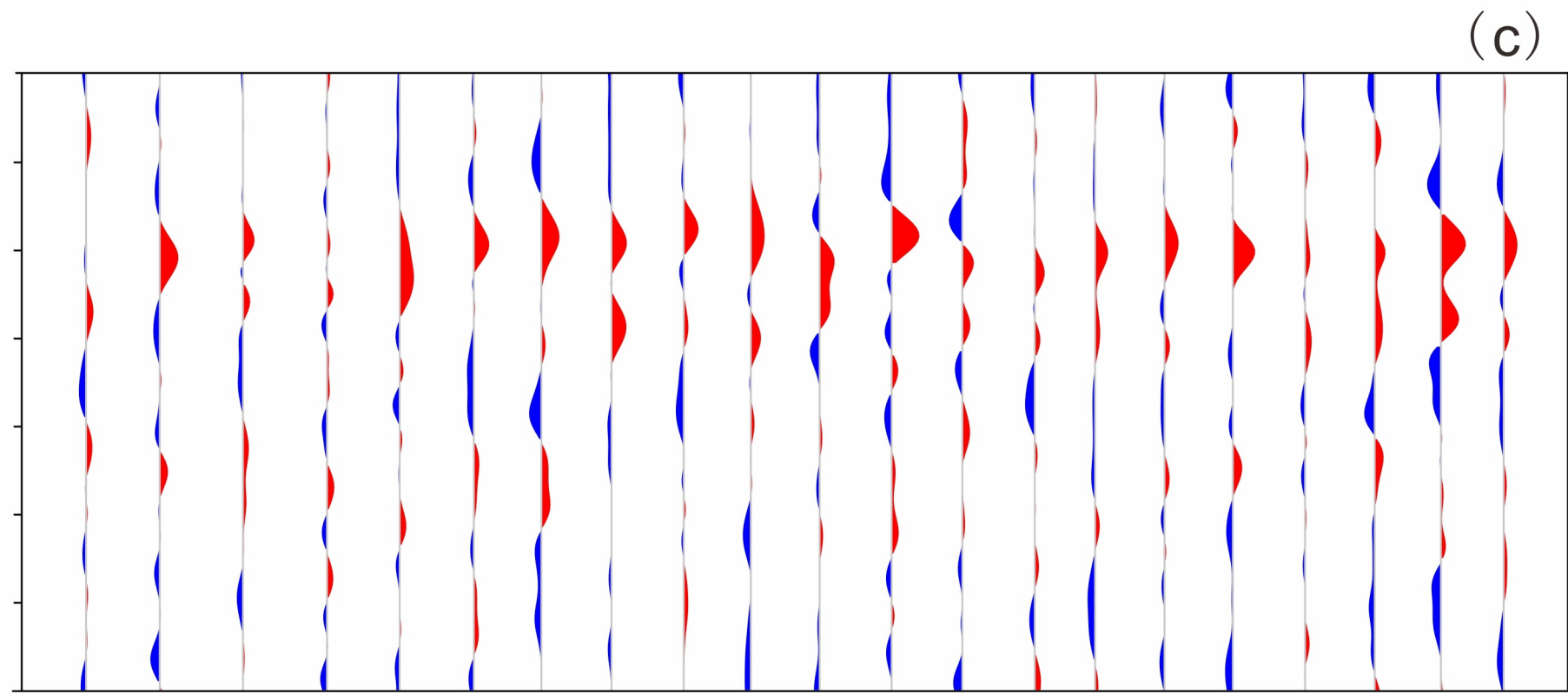
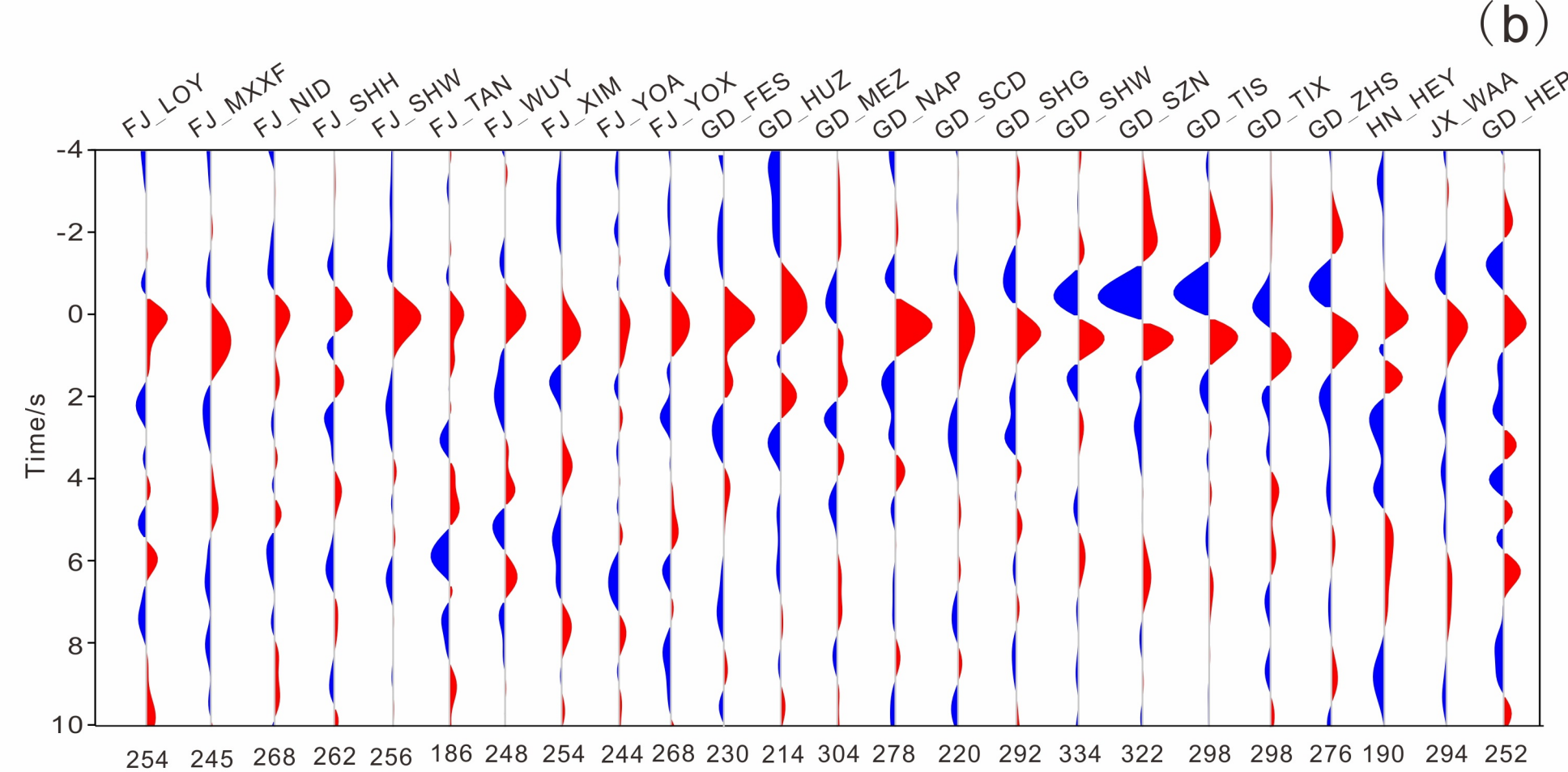
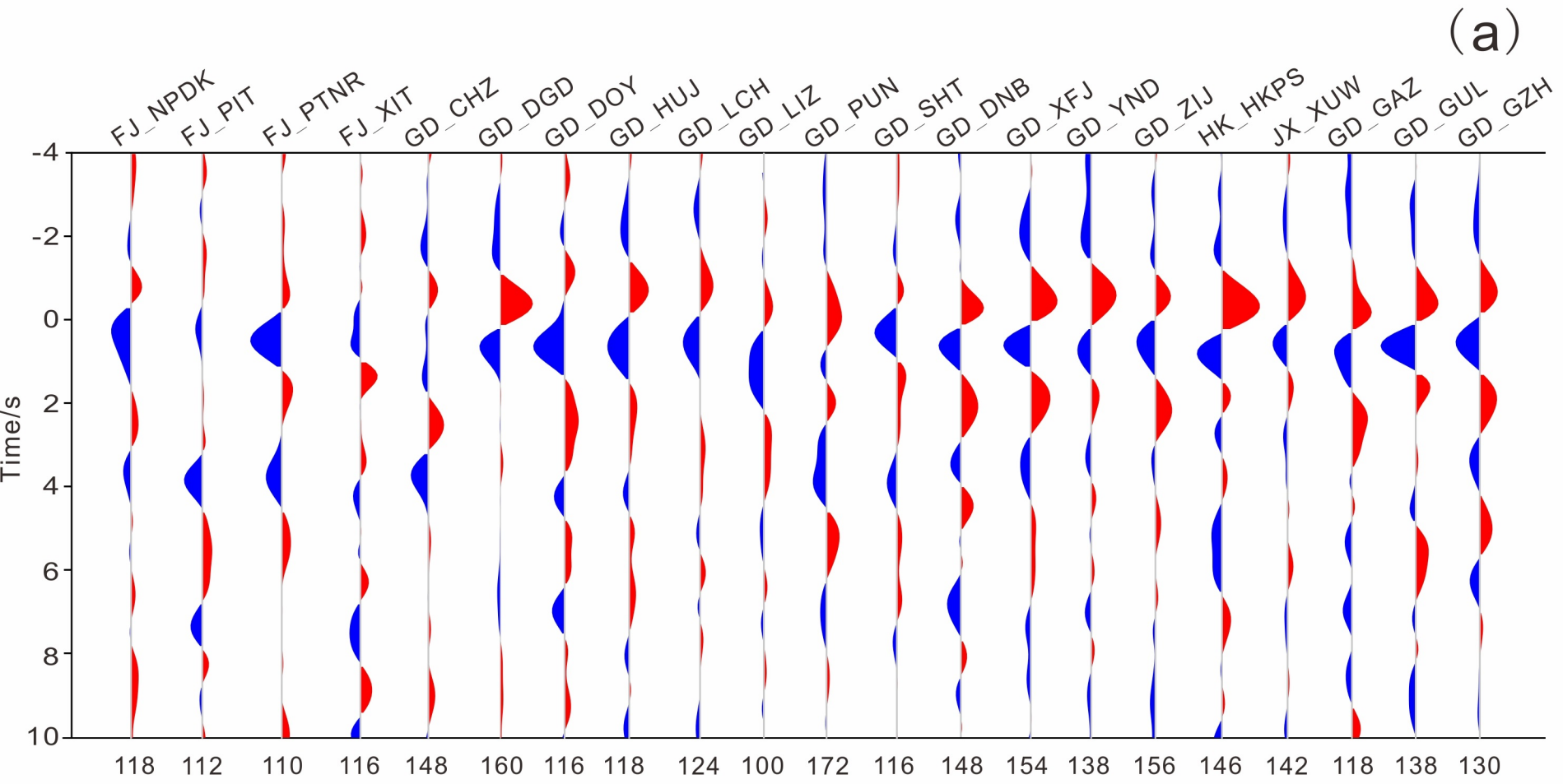


Figure 5.

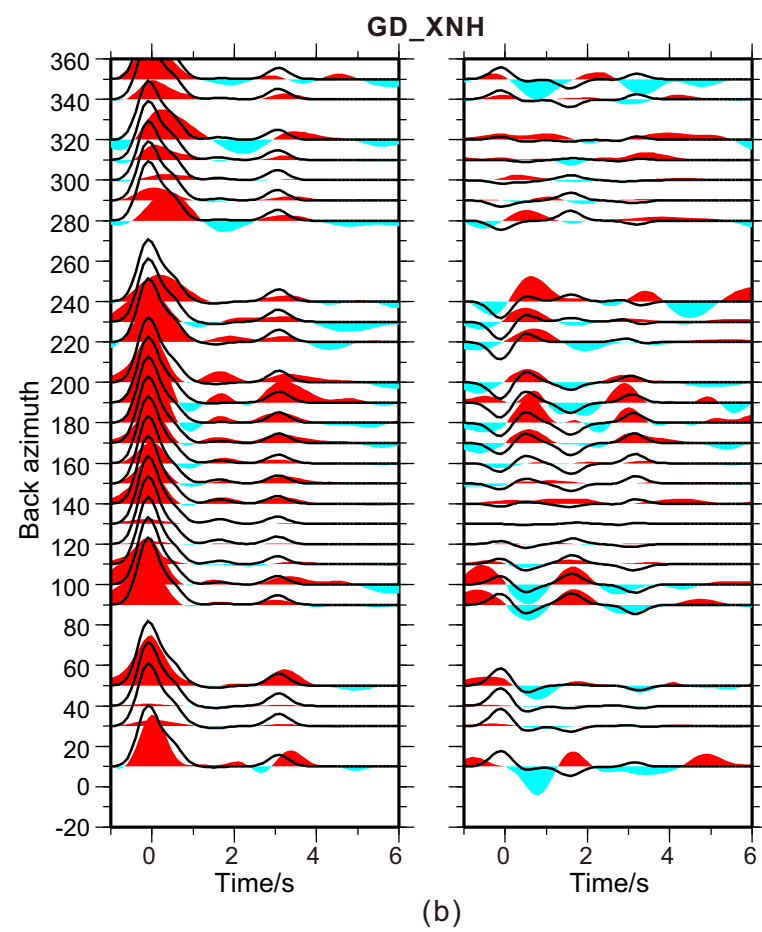
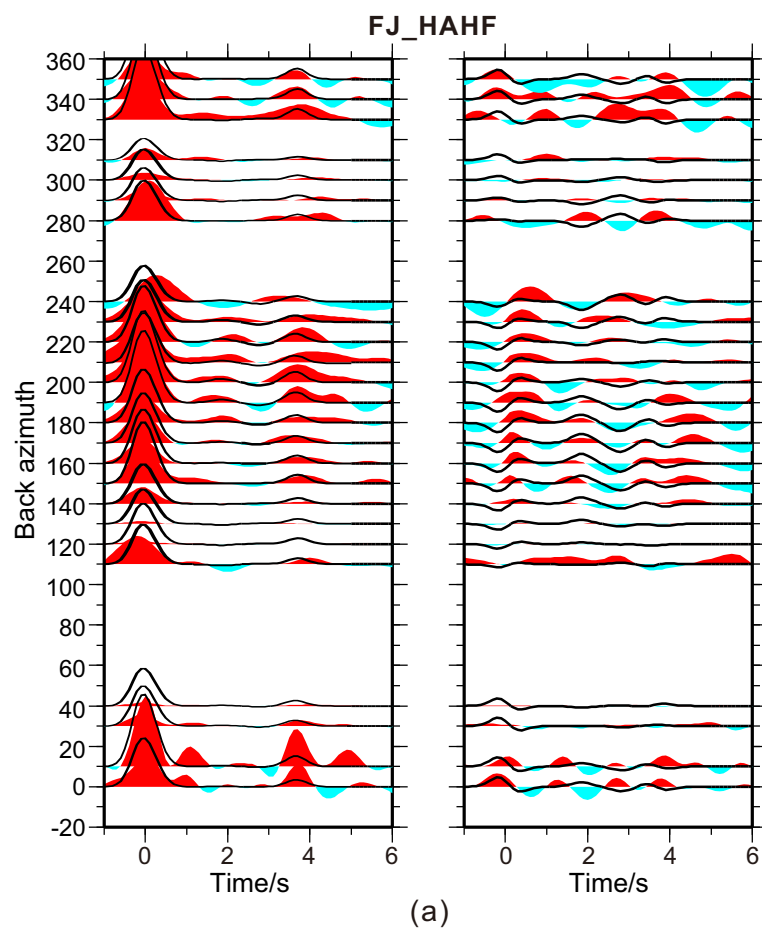


Figure 6.

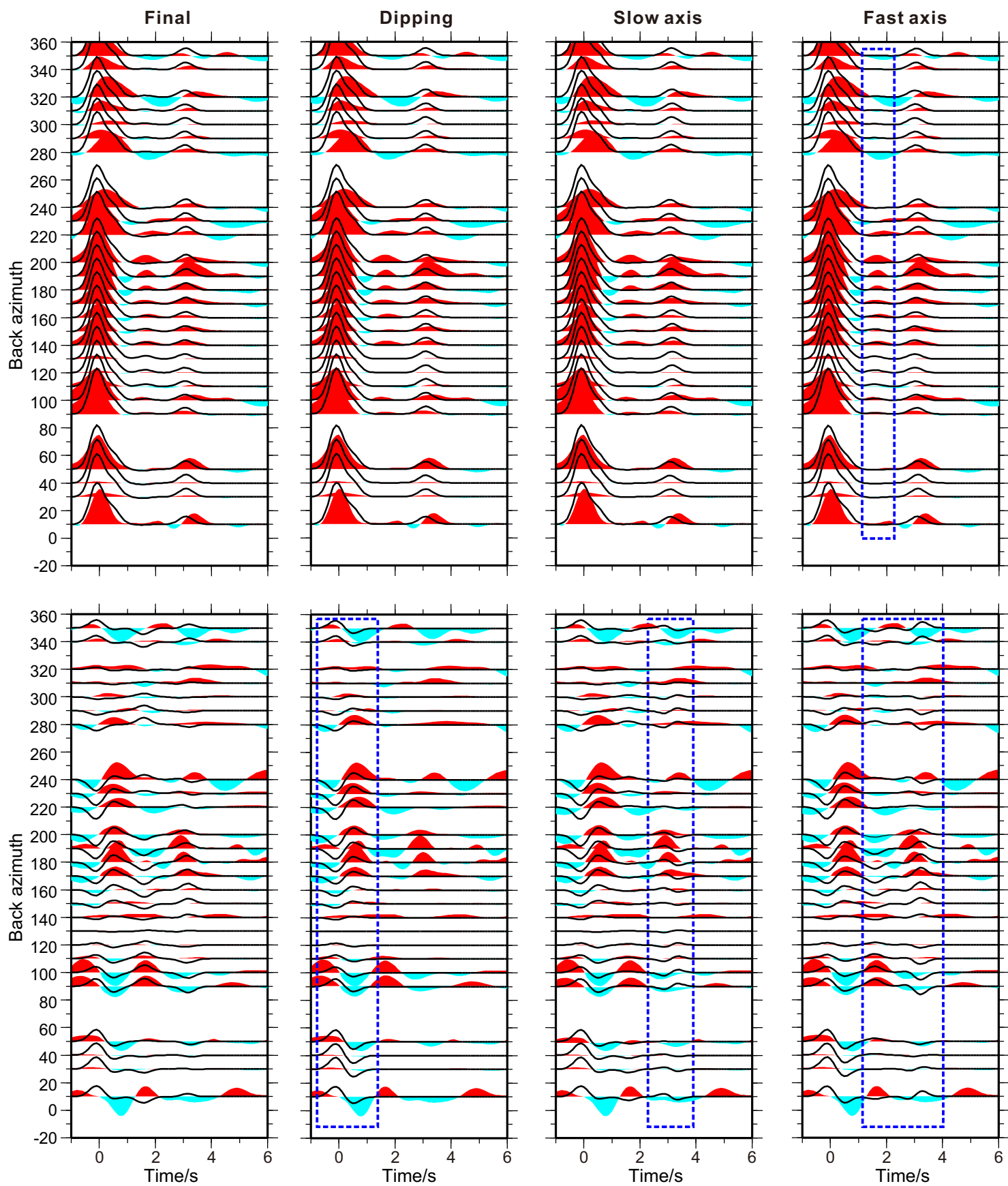


Figure 7.

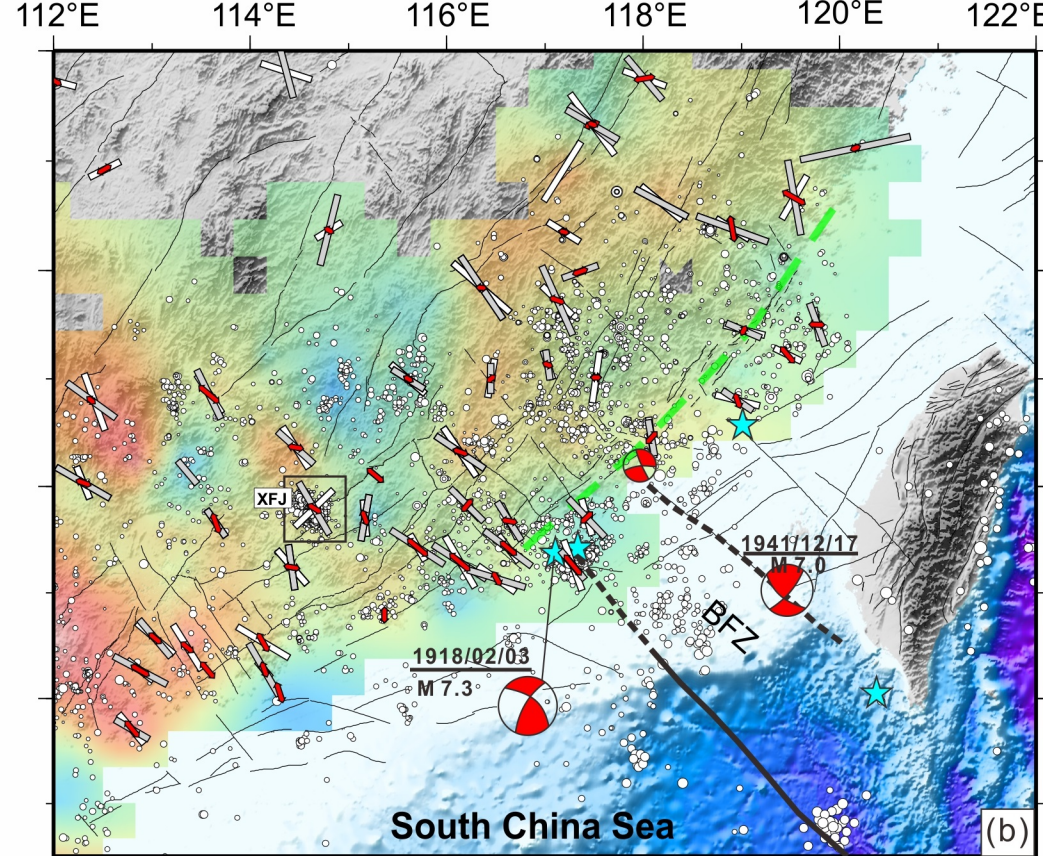
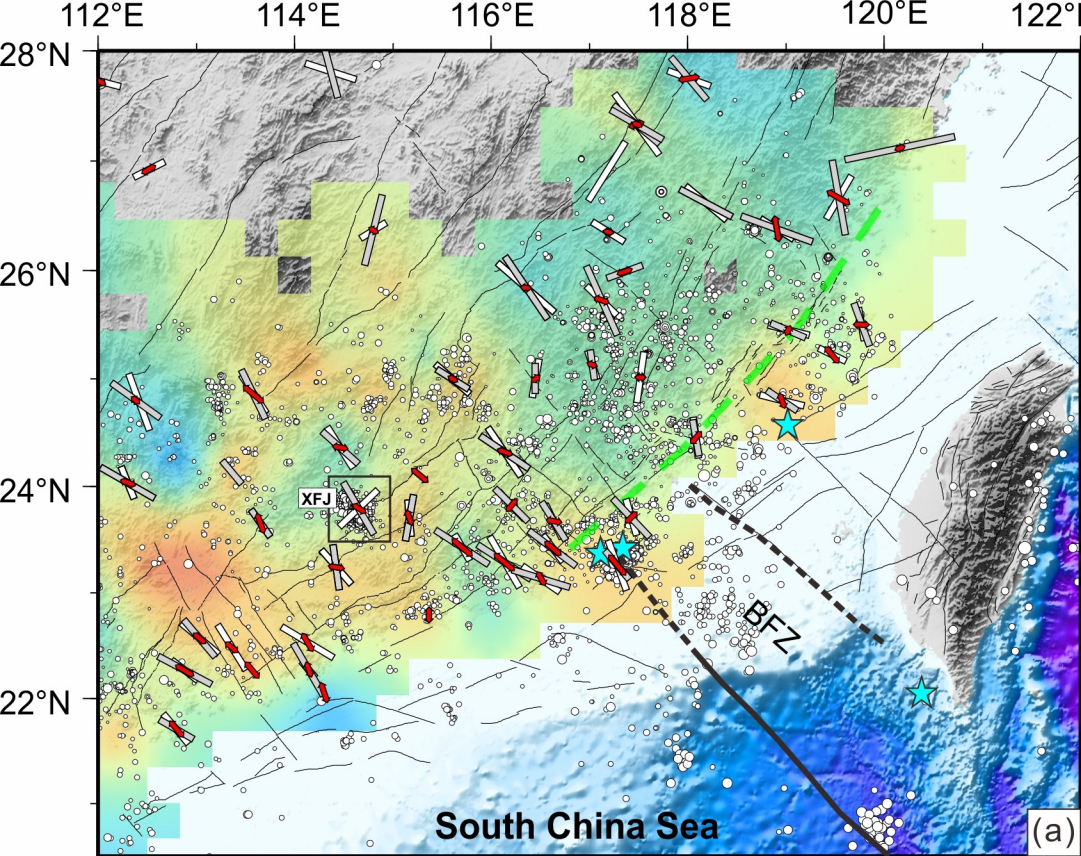


Figure 8.

