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Significant crustal structural variation across the Chaochou Fault, southern Taiwan: New tectonic implications for convergent plate boundary

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ABSTRACT

The Chaochou Fault, a major geological boundary in southern Taiwan is considered to be a part of the convergent plate boundary between the Eurasia Plate and the Philippine Sea Plate. We applied the Common Conversion Point stacking technique to teleseismic radial receiver functions and obtained Moho variation and crustal structure across the Chaochou Fault. In the Eurasia Plate to its west, the Moho depth is about 37 km and the crust is subducting to the east beneath the Philippine Sea Plate with a dip angle of about 30° between the Backbone Belt and the Tananao Schist. In the Philippine Sea Plate, the Moho depth is about 17 km. The Longitudinal Valley marks the collision boundary between the Eurasia Plate and the Philippine Sea Plate. The results suggest that the depth extent of the Chaochou Fault is about 30–35 km and the fault becomes a "shallow-angle" thrust fault at depth. The Common Conversion Point image also shows several bending interfaces of velocity contrast in the crust. We proposed a simple model to explain the Philippine Sea Plate and Eurasia Plate collision process and the observed crustal deformations.

1. Introduction

The Taiwan Island (TI) is a result of ongoing collision between the Philippine Sea Plate (PSP) and the Eurasia Plate (EP) (Fig. 1a) (Ho, 1986; Fitch, 1972; Teng, 1990). In the northeast of Taiwan, the PSP subducts northward beneath the EP along the Ryukyu Trench (Kao and Rau, 1999). South of Taiwan, the EP subducts eastward the PSP along the Manila Trench (Allen, 1962; Fitch, 1972). The current velocity vectors of the PSP at 124°E relative to south China is about 90 mm/yr (Sella et al., 2002; Yu et al., 1997, 1999). The rapid convergence generated several significant large-scale fault systems and geological units in Taiwan (Fig. 1b). They are, from west to east, the Coastal Plain (CP), the West Foothills, the Chaochou–Chuchih Fault, the Hsuehshan Belt, the Chaochou–Lishan fault, the Backbone Belt, the Tananao Schist, the Longitudinal Valley (LV), and the East Coastal Range (Fig. 1b) (Ho, 1986; Tillman and Byrne, 1995; Kao et al., 2000). Investigating the evolution of these large-scale fault systems and is essential for understanding the Taiwan orogeny and convergent process.

The Chaochou Fault (CF), a major geological boundary in southern Taiwan, is considered to be a part of the convergent plate boundary. It has existed since at least the early Pleistocene (Ho, 1975, 1982, 1986, 1988; Tillman and Byrne, 1995). On the surface, it separates the Backbone Belt to the east from the Coastal Plain and West Foothills to the west and can be traced from the southern coast of TI to the southern end of Chaochou–Chuchih fault and Choachou–Lishan fault (Ho, 1986; Teng, 1990). The CF is the beginning of the Chaochou–Chuchih fault and Chaochou–Lishan fault in southern Taiwan and plays a critical role in the development of these fault systems. From bathymetry data, the CF probably extends to the Manila trench-Luzon arc system in the south (Ho, 1986; Teng, 1990; Liu et al., 1997). Although the CF is known to be a high-angle (east-dipping 70–80°) thrust fault with a large left-lateral strike-slip component from geological survey, its depth extent and the crustal structure across the CF are not clear. For the depth extent, one scenario is that it cuts through the upper crust without affecting the lower crust. Another possibility is that the CF cuts through the entire crust and the deformation in the lower crust beneath it is concentrated in a narrow zone like beneath the San Andreas Fault as revealed by Zhu (2000). Based on metamorphic rocks exposed on the surface, we only know the shallow crustal structure (<10 km). A few efforts have been made to investigate the geometry of CF using geological measurements (Bonilla, 1975; Liao, 2002) and shallow seismic reflection surveys (Lin, 2008). In these studies, some features near the surface were revealed but

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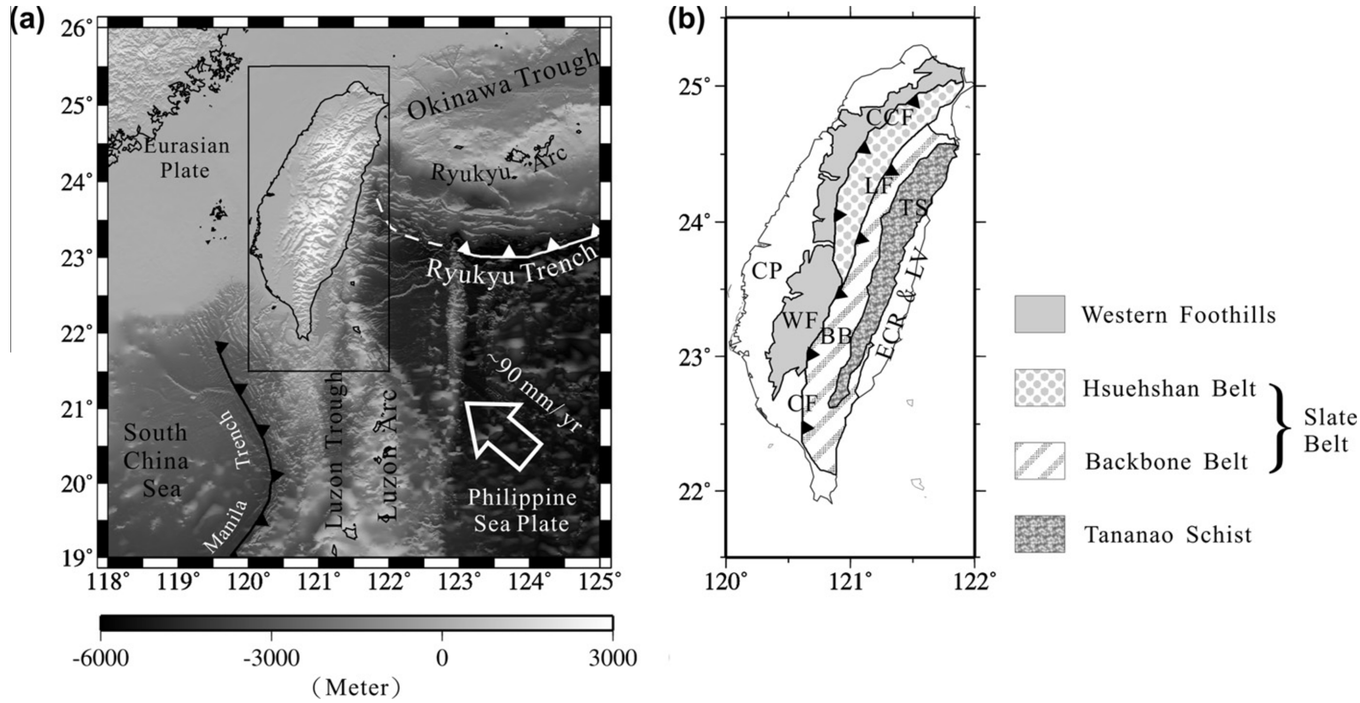

Fig. 1. (a) Topography and tectonic setting of Taiwan which was formed by the convergence of the Philippine Sea Plate (PSP) and the Eurasian Plate (EP). The current velocity vector of the PSP relative to south China at 124°E is about 90 mm/yr. (b) The major geological features and units in Taiwan. CF: the Chaochou Fault; CCF: the Chuchih Fault; LF: the Lishan Fault; LV: the Longitudinal Valley; CP: the Coastal Plain; ECR: the Eastern Coastal Range; WF: the West Foothills; BB: the Backbone Belt; TS: the Tananao Schist.

the crustal features including the Moho and the depth extent of CF remained obscure. Although large-scale seismic reflection experiments can produce a fine image of the entire crustal structure, such surveys are often expensive and hard to execute. A more effective technique is to use teleseismic earthquakes as a natural energy source to illuminate the crustal structure from below. Zhu (2000) introduced a method called Common Conversion Point (CCP) stacking, which is very useful to image crustal structure along a linear array. The method has been applied to the San Andreas Fault and yielded high-resolution results (Zhu, 2000). In this study, we will first image the crustal structure down to the Moho depth across the CF, using teleseismic waveform data from a dense linear array and the CCP stacking method. We will then discuss tectonic implications of the CCP image and proposed a new model to explain the PSP–EP collision process and crustal deformation in southern Taiwan.

2. Method and data analysis

The teleseismic receiver function (RF) method uses nearly vertically incident *P* wave to determine crustal structure beneath the receivers (Langston, 1977; Owens et al., 1984). The source time function in the *P* wave can be removed by deconvolving the vertical component from the radial and tangential components. RFs are very sensitive to velocity contrasts in the crust. In order to image the crustal structure across the CF, we calculated radial receiver functions (RRFs) and then applied the CCP stacking method. The method projects the energy of *P*-to-*S* converted phases on RRFs to their corresponding depths (Fig. 2) so that we can delineate Moho and velocity contrast interfaces in the crust. There are two steps in CCP stacking. First, we divided the crustal volume in the study area into certain size bins (Fig. 2a). We then calculated the ray-path of each RRF using a background velocity model. The amplitudes of the RRF were assigned to the corresponding bins where the *P*-to-*S* conversion occurred along the ray-path, by using the time delay of the converted phase with respect to the direct *P* (Fig. 2b). The amplitude is proportional to the velocity contrast of the medium at the conversion point. Next we summed all amplitudes in each bin to obtain average amplitude and variance. For details of CCP stacking method, see Zhu (2000). In this study, we were interested in 2D crustal structure beneath a linear seismic array across the CF. We used a bin size of 50 km perpendicular to the profile, 5 km along the profile and 1 km high. Neighboring bins overlap by 4 km along the profile so that a smooth 2-D image of 1 km horizontal grid spacing was produced. The resolution of the image depends on the ray coverage and wavelength of the receiver function signals. It is estimated to be about 10 km laterally using the Frenel Zone width and 2 km vertically using a quarter of the wavelength. Error of the CCP stacking image depends on the velocity model used, particularly the V_p/V_s ratio. In our procedure, we used a 1-D model derived from the tomographic results of Wu et al. (2007) for each station. From the checkerboard test of this velocity model (Wu et al., 2007), we believe that the uncertainty of our results is small enough to reveal significant crustal structural changes across the CF.

Data used in this study were recorded by the SS-Line stations of the Taiwan Integrated Geodynamics Research (TAIGER) Project (Fig. 3) (Okaya et al., 2009). A total of 39 broadband stations with digital three-component instruments were deployed between 26 March 2009 and 2 June 2009. We chose events with Mw ≧5.5 and epicentral distances from 30° to 90°. We removed mean of three components and then rotated the north–south and east–west seismograms to the radial and transverse components, respectively. For each earthquake, we aligned all vertical components of the records at the first *P* arrival using a waveform cross-correlation technique. The *P* waveforms were cut from continuous recordings using a 60-s time window, starting at 10 s before the *P* arrival, and were band-pass filtered between 0.01 and 2.0 Hz. We used a