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Tectonophysics 466 (2009) 162–169
TECTONOPHYSICS
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# Plate convergence at the westernmost Philippine Sea Plate

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Available online 21 November 2007

**Abstract**

To understand the convergent characteristics of the westernmost plate boundary between the Philippine Sea Plate (PSP) and Eurasian Plate (EP), we have calculated the stress states of plate motion by focal mechanisms. Cataloged by the Harvard centroid moment tensor solutions (Harvard CMT) and the Broadband Array in Taiwan (BATS) moment tensor, 251 focal mechanisms are used to determine the azimuths of the principal stress axes. We first used all the data to derive the mean stress tensor of the study area. The inversion result shows that the stress regime has a maximum compression along the direction of azimuth N299°. This result is consistent with the general direction of the rigid plate motion between the PSP and EP in the study area. In order to understand the spatial variation of the regional stress pattern, we divided the study area into six sub-areas (blocks A to F) based on the feature of the free-air gravity anomaly. We compare the compressive directions obtained from the stress inversion with the plate motions calculated by the Euler pole and the Global Positioning System (GPS) analysis. As a result, the azimuth of the maximum stress axis, $\sigma_1$, generally agrees with the directions of the theoretical plate motion and GPS velocity vectors except block C (Lanhsu region) and block F (Ilan plain region). The discrepancy of convergent direction near the Ilan plain region is probably caused by the rifting of the Okinawa Trough. The deviation of the $\sigma_1$ azimuth in the Lanhsu region could be attributed to a southwestward extrusion of the Luzon Arc (LA) block between 21°N and 22°N whose northern boundary may be associated with the right-lateral NE–SW trending fault (i.e. Huatung Fault, HF) along the Taitung Canyon. Comparing the $\sigma_1$ stress patterns between block C and block D, great strain energy along HF may not be completely released yet. Alternatively, the upper crust of block C may significantly have decoupled from its lower crust or uppermost mantle.


*Keywords:* Stress inversion; Luzon Arc; Philippine Sea Plate; Focal mechanism

## 1. Introduction

The westernmost Philippine Sea Plate (PSP) is converging toward the Eurasian Plate (EP) in the direction N310° (Seno et al., 1993) (Fig. 1). The associated westernmost plate boundary is located at the zone along the Luzon Arc (LA), which gradually evolves from normal subduction in the south to a mountain building collision in the north. The Taiwan orogen is generally considered as a result of the oblique collision between the LA and EP (e.g. Teng, 1987; Hsu and Sibuet, 1995; Wu et al., 1997; Sibuet and Hsu, 2004) (Fig. 1). With high-angle oblique thrust and left-lateral strike–slip components, the Longitudinal Valley fault in eastern Taiwan is considered as the plate suture zone (Yu and Kuo, 2001), or at least the Longitudinal Valley fault has consumed half of the convergent rate. Composed of the strato-volcanoes and trending approximately in the N–S direction, the 1200 km long LA has been formed due to the east-dipping subduction of the South China Sea basin along the Manila Trench.

Yu et al. (1999) have processed the Global Positioning System (GPS) data to study the crustal deformation and motion of the LA with respect to Eurasia and found that there is a significant southward increase in crustal motion along the N–S trend of the LA. Kao et al. (2000) used the bathymetry, seismicity, and source parameters of earthquakes to characterize the transition from oblique subduction to regional collision. To the south of 21°N, the feature of a subduction zone is clearly marked by both bathymetry and seismicity, while to the north of 23°N, the collision is the major mechanism with strong deformation on both sides of the suture. In between, the transition is accommodated by a distributed thrust deformation zone.

To date, the relationship among spatial distribution of the tectonic stress filed, GPS velocity vectors and plate motion model of the westernmost PSP is still not clear. In this study, we

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0040-1951/$ - see front matter 
doi:10.1016/j.tecto.2007.11.011

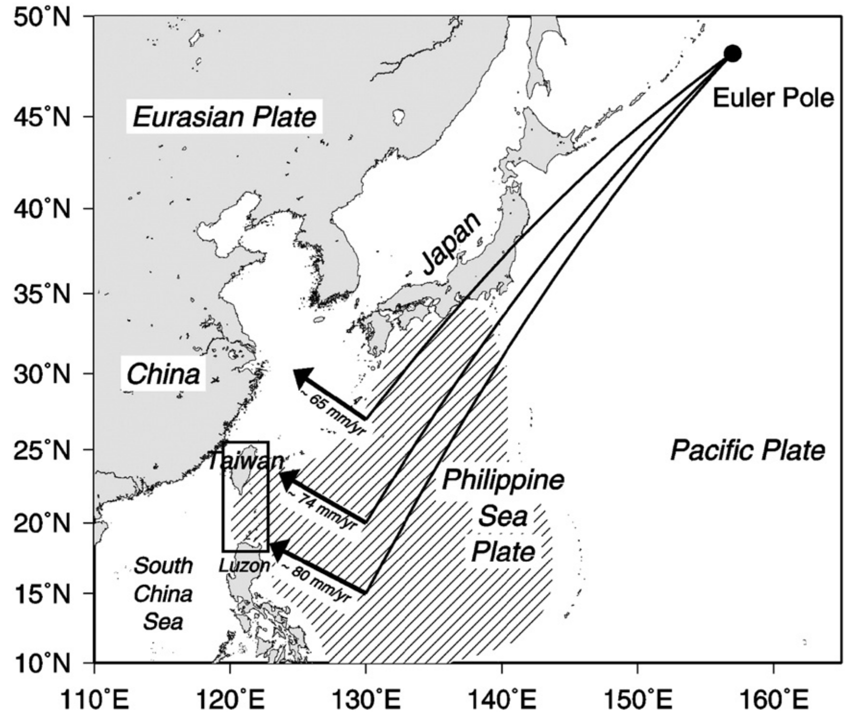


Fig. 1. The tectonic setting of Taiwan and Luzon region. The study area is marked by the rectangle. The Euler vectors (black arrows) show the plate motion of the PSP relative to the EP. Results were calculated from the Euler pole published by Seno et al. (1993).

attempt to investigate the variation of stress and the plate convergent characteristics of the westernmost PSP relative to the EP.

## 2. Method and data

### 2.1. Stress inversion method

Studying the state of stress in the Earth's crust and upper mantle is useful to understand the plate motion and regional deformation (Hardebeck and Hauksson, 2001; Xu, 2004). Earthquakes are indicators of stress; thus, we will use earthquake focal mechanisms to detect the stress state of convergent boundary which cannot be directly measured. Several authors have proposed methods to determine the orientations of stress axes of seismotectonic regime in spite of complicated tectonic settings (e.g. Gephart and Forsyth, 1984; Michael, 1984; Angelier, 1989; Horiuchi et al., 1995). In this study, we use the Focal Mechanisms Stress Inversion (FMSI) method of Gephart and Forsyth (1984) to determine the orientations of the principal stress axes between the westernmost PSP and EP.

FMSI method has three basic assumptions (Gephart and Forsyth, 1984; Gephart, 1990; Lu et al., 1997): (1) slip on the fault plane occurs in the direction of resolved shear stress; (2) the stress orientation is uniform in the calculated area; and (3) earthquakes are due to shear dislocations and can occur on preexisting faults. The FMSI method uses a grid search over stress field parameter space to find the best-fitting model that minimizes the average of the individual misfits between possible models and data (Gephart and Forsyth, 1984; Gephart, 1990).

The individual misfit calculated for each earthquake is defined as the smallest rotation angle about an axis of any orientation that would bring the slip direction into alignment with the resolved shear stress on the faults plane (Gephart and Forsyth, 1984). Fault plane ambiguity is addressed by using the nodal plane with the smaller misfit. In addition, the 95% confidence region is used to evaluate the quality of inversion (e.g. Gephart and Forsyth, 1984; Gillard et al., 1996; Lu et al., 1997). We obtained the azimuths and plunges of the three principal stresses axes $\sigma_1$, $\sigma_2$ and $\sigma_3$ ($\sigma_1 \geqq \sigma_2 \geqq \sigma_3$) and the ratio $R=(\sigma_2-\sigma_1)/(\sigma_3-\sigma_1)$ $(0 \leqq R \leqq 1)$ by the best-fitting model. The value of $R$ is a magnitude ratio of the intermediate principal stress ($\sigma_2$) relative to the maximum ($\sigma_1$) and minimum ($\sigma_3$) principal stresses, and this may help us to distinguish the stress filed type.

There are four stress parameters ($\sigma_1$, $\sigma_2$, $\sigma_3$ and $R$) in the inversion algorithm, and the minimum number of events used to inversion is four. Moreover, diverse data set can give better constrains to find out the stress tensor orientation. For above reasons, we used all the earthquake focal mechanisms within each data set to obtain an average local stress field without separating the fault types in a region.

The procedure to determine best-fitting stress model is as follows. We first perform a coarse initial grid search (10° spacing in stress orientations) covering the whole range of possible models for each data set by the approximate method FMSIA (Gephart and Forsyth, 1984). We then take the best resulting stress model as a starting stress model to perform a fine