Spatial and Temporal Variation of Tectonic Stress Pattern at the Westernmost Plate Boundary in Taiwan

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To understand the convergent characteristics of the westernmost plate boundary between the Philippine Sea Plate (PSP) and Eurasian Plate (EP), we calculated the stress states of plate motion by damped stress inversion methods. 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 derive mean stress tensor in the Taiwan orogenic belt from all available dataset and shows that the maximum compressive axis ($\sigma_1$) is mainly along the direction of azimuth N299$^\circ$. The result is consistent with the general direction of the rigid plate motion between the PSP and EP in Taiwan. The spatial variation of the regional stress pattern is further investigated by dividing 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 $\sigma_1$ 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 (OT). 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$^\circ$N and 22$^\circ$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.

Base on the best fitting stress model, we also determined the direction of maximum horizontal compressive stress ($S_H$) and the tectonic stress regimes. The directions of $S_H$ are almost the same as the directions of the $\sigma_1$ and consistent with the stress trajectories derived from the other constraints. In Taiwan-Ryukyu junction area, a significant NW-SE trending stress boundary, $T$, is identified and it may correspond to the location of a tear fault or strong crustal deformation separating the stress fields of the Taiwan orogenic region in the southwest and the Southern Ryukyu Subduction Zone (SRSZ) in the northeast. Furthermore, the direction of $\sigma_1$ in the Lanyu-Lutao forearc region turns into E-W, which may be affected by the trending of the Taitung Canyon/Huatung Fault. In middle Taiwan, just in front of the LMH, a thrust faulting regime is observed, whereas to the north and the south of the LMH, the stress regimes are of strike-slip faulting. This may reflect the crustal thickening and uplifting in the middle Taiwan and lateral extrusions induced by collision. The direction of extensional stress axis ($\sigma_3$) of the SRSZ gradually changes from NNW-SSE direction in the westernmost OT to E-W direction in the Nanao Basin. Because of different...
direction of $\sigma_1$ in the Nanao Basin and in the OT, the stress field of the SRSZ can be further divided into two sub-systems. The OT stress system, including the OT and the Hoping Basin, is probably associated with the rifting of the OT, while the Ryukyu forearc stress system is related to the northward subduction of the PSP.

We also discover a high magnetization zone, the Lukang Magnetization High (LMH), from the spatial variation of the stress filed in the mid-west Taiwan. However, the $\sigma_1$ azimuth in the northeast side of the LMH deviates clockwise from the theoretical plate motion direction, while in the eastern and southern sides of the LMH the $\sigma_1$ azimuth deviates counterclockwise. In contrast, the $\sigma_1$ azimuth around the Paikang High (PKH) does not change significantly. Besides, the state of stress in the northeastern side of the LMH is more heterogeneous and may relate to the existence of the Sanyi transform fault zone, while the influence of pre-exiting faults on the local stress field in the south side of the LMH is minor. Such significant change of stress orientation may be induced by the existence of the LMH, a rigid structural barrier.

To understand the temporal evolution of stress state within the seismogenic zone associate with the Chi-Chi earthquake, two groups of data separate by the main shock were investigated. The result indicates that the direction of the $\sigma_1$ axis prior to the main shock is N122° and becomes N302° after. The detection of the temporal variation of the $\sigma_1$ axis soon after the Chi-Chi earthquake is carried out by examining its cumulative stress orientation of aftershock sequences as a function of time. Overall, the direction of $\sigma_1$ stress changes instantly and returns to its regional normal stress state prior to the Chi-Chi main shock in about 300 days. Relatively short recurrence interval mark its uniqueness of the largest earthquake related to the Chelungpu fault in Taiwan over last century. Moreover, we analyzed the 245 fault plane solutions of Chi-Chi aftershocks through a non-overlapping, equal event number window, and found that the temporal variation of $\sigma_1$ is a significantly oscillatory, rather than smoothly varying as reported by Zhao (1997).

Keywords: stress inversion; Lukang magnetization high; the Luzon Arc; Philippine Sea Plate; focal mechanism; southern Ryukyu subduction zone, Chi-Chi earthquake