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Focal mechanisms and seismotectonic stress in North Central Taiwan in relation with the Chi-Chi earthquake

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Abstract

The aftershock sequence of the 1999 Chi-Chi earthquake (M_w =7.6) provided a large number of focal mechanisms recorded with BATS Centroïde Moment Tensors (CMT) which allowed us to perform reliable stress tensor inversions in North Central Taiwan. These inversions were done for three time-periods corresponding to the post-seismic phase of the 1999 Chi-Chi earthquake (M_w 7.6). In the last period the 2003 Chengkung earthquake (M_w=6.5) occurred on the vicinity of our study area and its influence is also examined. For comparison between seismotectonic regimes of the pre- and post- Chi-Chi periods, we also carried out stress inversion using published focal mech of the pre Chi-Chi period.

For each period, we delineated seismogenic domains with relatively homogeneous stress regimes in agreement with the local structures. The boundaries of these domains vary during the whole post Chi-Chi period as seismic activity decays. A 25° clockwise rotation of the main compressive stress σ_1 is observed between the pre and the post Chi-Chi periods in the domain located near the northern termination of the Chi-Chi rupture. A stress perturbation related to the Chengkung earthquake could be detected in the eastern part of the Central Range. We present an interpretation of the determined stress regimes in terms of changes in mechanical behaviour of the Sanyi–Puli transfer zone.

Keywords: Seismotectonics; Focal mechanisms; Stress tensor; North Central Taiwan

1. Introduction

An earthquake alters the shear and normal stress on surrounding faults. Nowadays, computing Coulomb stress change, accompanying a major earthquake is a classical way to try forecasting the next rupture probability in the region of earthquake (Stein, 1999). The Coulomb criterion allows the evaluation of the intensity of stress change. However, evidencing a change in the regional stress field direction after a major earthquake can afford additional analysis for the seismicity rate and the future seismic behaviour of the region. For example, Angelier et al. (in press) show a stress rotation in South Iceland, after the M_w=6.5 shock of June, 2000. The present paper focuses on the influence of the (M_w=7.6) Chi-Chi earthquake, which occurred near the town of Chi-Chi in central Taiwan, on September 20th, 1999, as the largest inland earthquake of the past 100 years in Taiwan. The Chi-Chi earthquake reactivated the Chelungpu fault, a major thrust near the front of the Taiwan mountain belt. On December 10th, 2003, another strong earthquake (M_w=6.5) occurred in the eastern part of Taiwan, near the city of Chengkung. This Chengkung earthquake reactivated the Chihshang fault of the Longitudinal Valley in eastern Taiwan (Fig. 1a).

In this paper, we take advantage of the numerous focal mechanisms provided by the BATS's CMTs (Centroid Moment Tensor solutions form the Broadband Array in Taiwan for Seismology) (Kao et al., 1998), notably for the Chi-Chi aftershock sequence. We thus determine the stress field in the northern

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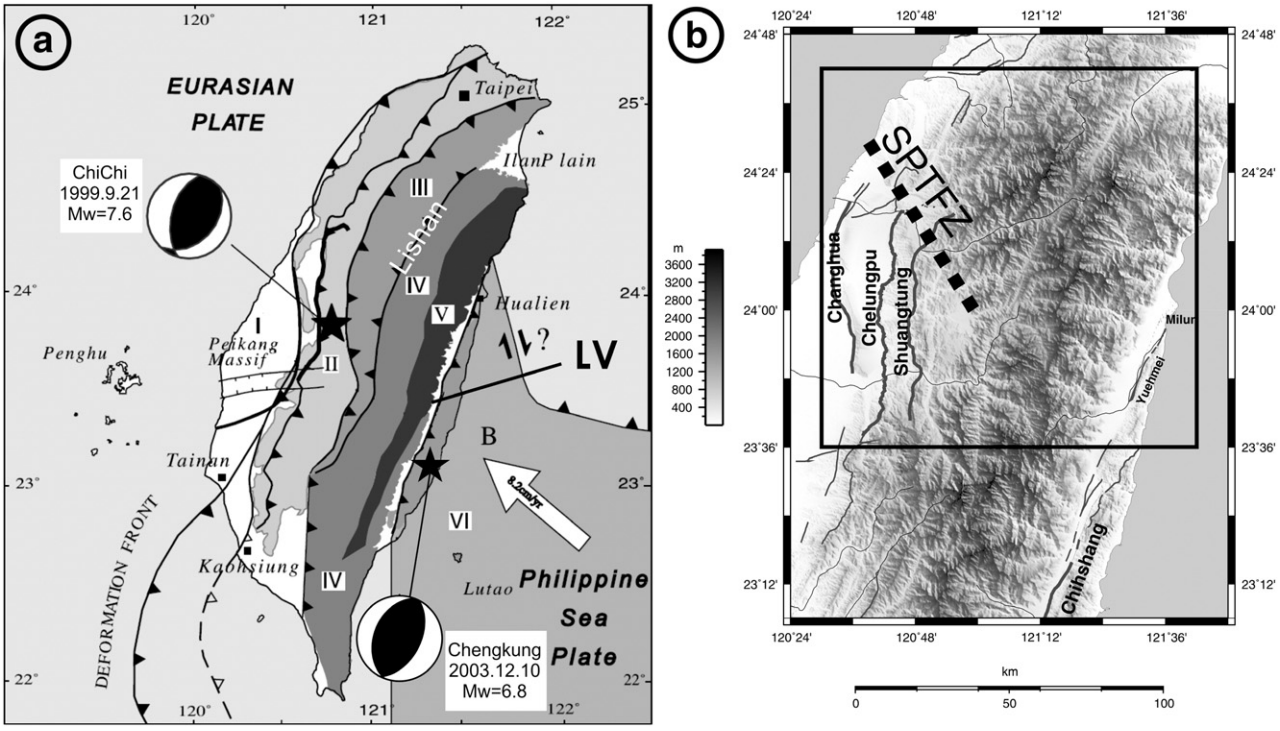

Fig. 1. a: Location of the study area, from (Lee et al., 2001). Map of Taiwan with dominant structures and faults. I: Coastal Plain; II: Foothills; III: Hsuehshang Range; IV: Backbone Range; V: Tanao metamorphic basement. Two focal mechanisms of major earthquakes are shown: the Chi-Chi earthquake (September 21st, 1999); The Chengkung earthquake (December 10th, 2003). Broad line: surface rupture of the Chi-Chi earthquake. Lishan: the Lishan fault. LV: Longitudinal Valley b: relief map with faults considered active. Frame: studied area. SFTZ: Sanyi–Puli Transfer Fault Zone (Deffontaines et al., 1994; 1997).

central part of Taiwan (frame of Fig. 1b). The BATS CMT catalogue started in 1995, and for the pre Chi-Chi period contains only two solutions located in the study area. Thus, our analysis concentrates on the period extending from the end of 1999 to the end of 2005. It includes the post-seismic period of the Chi-Chi earthquake crisis as well as the pre- and post- seismic periods of the Chengkung earthquake. However, we also took into consideration another source of data providing focal mechanisms for the pre-Chi-Chi period (Wu and Rau, 1998). These data cover only part of our study area and involve events of lower magnitude, as compared with the post Chi-Chi catalogue. Because of these differences, direct comparisons between the two subsets, pre- and post- Chi-Chi, should be handled with caution.

We also carried out a waveform inversion, testing a different approach working with a reduced number of seismic stations. Based on a grid search, this technique allowed us to determine whether the focal mechanism solution was unique or not. For the examined sample, we obtained a result very similar to that of the BATS catalogue and we adopted the BATS database as the main source of information, because of its relatively high quality and technical homogeneity.

The goals of this study are to delineate the major seismotectonic units, determine the corresponding stress regimes and investigate the possible stress field variations in space and time in northern Central Taiwan, taking into account the presence of a major transfer zone, the Sanyi–Puli transfer zone (Deffontaines et al., 1994), located at the northern tip of the thrust zone activated during the Chi-Chi earthquake, the Chelungpu Fault Zone (CGS, 1999).

2. Geodynamic setting

2.1. Major geological units

The Taiwan orogeny is the result of the convergence between the Philippine Sea and Eurasian Plates, with a relative movement of the Philippine Sea Plate of about 8.2 cm/yr in the direction N309°E (Yu et al., 1997).

Fig. 1a shows the main units of the collision belt, which can be divided in two major domains (Ho, 1986, 1988):

- the Eurasian margin to the West with the large metamorphic units of the Central Range and the sedimentary fold and thrust units of the Foothills Range;
- the Coastal Range to the East, corresponding to the deformed Luzon volcanic arc.

Our study area (Fig. 1a) includes these two domains and contains two major fault zones where significant displacement occurs: the deformation front thrust to the West and the Longitudinal Valley to the East. However, most of the data analysed herein correspond to the crust beneath the Central Range, west of the Longitudinal Valley active boundary.

2.2. North Central part of Taiwan: the front thrust and the 1999 Chi-Chi earthquake

The deformation front is marked by large thrusts (Fig. 1), developing along pre-existing structures (continental shelf