Deep electrical structure of the southern Taiwan orogeny and its tectonic implications by MT data

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SUMMARY

The Taiwan orogen has formed as a result of the arc-continent collision between the Eurasian continental margin and the Luzon island arc over the last 3 million years. It is the type example of an arc-continent collision. However, scientists are mainly debating the tectonics setting beneath Taiwan, which can be interpreted as a thin-skinned tectonics model or lithospheric collision model and its plate boundary. In 2004, the Taiwan Integrated Geodynamical Research (TAIGER) project was formed and began a systematic investigation of the crustal and upper mantle structure beneath Taiwan. This included new magnetotelluric (MT) data collection to study the geo-electrical structure beneath Taiwan. In order to fully understand the tectonic processes associated with the collision and compared with previous researches, it is necessary to study other parts of the orogenesis such as deep structure of southern Taiwan. We deployed 16 stations of board-band MT to image the electrical structure beneath southern Taiwan orogeny along 100 km of profile. Two-dimensional inversion and tensor decomposition were used in the study. A series of conductive anomalies have been imaged located in the shallow and mid crust that are strongly related to fluids distribution. The electrical model shows a resistive anomaly at depth of southeastern Taiwan that is a significantly evidence of the subducting forearc sliver. This result implies that the Philippine Sea plate has been converging into southeastern Taiwan over the Eurasia slab. Base on number of recent models, we present a different model that is called thin-skinned subduction model for the tectonics implications beneath southern Taiwan.

Keywords: Taiwan, Magnetotellurics, Thin-skinned subduction model, Arc-Continent Collision

INTRODUCTION

The island of Taiwan was created by oceanic-continental collision between the Luzon volcanic arc along the western margin of the Philippine Sea plate and the passive continental margin of southeastern China 5 Ma ago (Suppe, 1981; Ho, 1986). At this location, the Philippine Sea plate is subducting northward under the Eurasian plate, and a portion of the Eurasia Plate is subducting eastward under the oceanic plate (Tasi, 1989; Seno, 1993; Kao, 2000). This is a young active orogeny and unique natural laboratory for studying arc-continental collisional processes around the world. Since the unique collisional tectonics issues had been proposed, various physics and simulation models have been suggested (e.g. Suppe, 1981; Wu et al., 1997; Ding et al., 2001; Wang, 2006; Wu et al., 2007; Cheng, 2008). However, scientists are mainly debating the tectonics setting beneath Taiwan, which can be interpreted as a thin-skinned tectonics model (Suppe, 1981) or lithospheric collision model (Wu et al., 1997) and its plate boundary. Although no deep crustal information was available when the thin-skinned model has been suggested, and also limited resolution of deep structure for the lithospheric collision model due to lacked of telsismic data. However, to fully understand the tectonic processes associated with the collision and compared with previous researches, it is necessary to study other parts of the orogenesis such as deep structure of southern Taiwan. Since 2007, the TAiwan Integrated GEodynamics Research project (TAIGER) has been dedicated to investigating the existence of tectonics issues in Taiwan. This project combines seismology,
magnetotellurics (MT), geology, and other fields of study. The project is mainly supported by National Science Council (NSC) of Taiwan, and National Science Foundation (NSF) of Unite State. There are five national universities and Academia Sinica at Taiwan; six institutes from U.S., as well as one from a Canadian university (Wu, 2007). In the MT study, National Central University of Taiwan and University of Alberta, Canada are cooperating to collect data, and preliminary data processed at the end of 2007 (Chiang et al., 2007). In this paper, we will describe more details of the electrical model and its tectonic implications beneath southern Taiwan.

Figure 1. (a) The map of Taiwan is shown with the topography and the study area (solid squire). (b) The dominated electrical strike (N29°E) is plotted with rose diagram; the local electrical strikes is indicated by black lines and simplified tectonostratigraphic boundaries (Ho, 1986), I: Costal Plane (CP), II: Western Foothills (WF), III: Hsuehshan Range (HR), IV: Backbone Range (BR), V: Eastern Central Range (ECR), VI: Costal Range (CR), VII: Longitudinal Valley (LV).

MT DATA COLLECTION AND ANALYSIS

We used two systems to record MT data: five-component commercial V5-2000 wideband systems designed by Phoenix Geophysics Ltd. for shallow probing, and five-component NIMS recording systems designed by Narod Geophysics Ltd. for deeper penetration. The time series data acquired at each site was calculated using two robust statistics algorithms (Egbert and Booker, 1986; Jones, 1989) with remote-reference (Gamble et al., 1979) to estimate the response of transfer functions over 0.0026–10,000 seconds from variations in the Earth’s natural electromagnetic field at 16 MT stations. For doing the remote reference technique, remote station was deployed on Penghu island approximately 50 km away from Taiwan (Figure 1).

Before MT data can be converted to subsurface resistivity models, dimensionality analysis is required to understand and determine its in full 3D environment.

A 2D analysis assumption of the real case is simpler than 3D analysis (Unsworth et al., 2007). Therefore, the extended GB technique (McNeice and Jones, 2001) was applied for all the data sets to reduced subsurface electric distortion. The dominant electric strike was well-defined at N29°E with multi-stations parallel to the tectonic setting (Figure 1b), and single site decomposition extracts the local strikes that were also parallel to major geological provinces for the period range from 13 to 7,447 seconds (Figure 1b) except eastern profile. For the dimensional analysis of twist and shear were presented (Chiang et al., 2007), and the mostly skew values were below 0.3. These are appropriate for the 2D model assumption.

Converting the apparent resistivity and phase data variations to depth information requires an inversion algorithm. Therefore, we applied NLCG method (Rodi and Makie, 2001) to convert the MT data into apparent resistivity, phase curves and projected with induction vectors. The conductivity of seawater was fixed with 0.3 ohm-m for both the Taiwan Strait and Pacific Ocean beside Taiwan according to the bathymetry. Inversion began form a 100 ohm-m half-space with error floor of 20%, 15%, 0.1 were used on the apparent resistivity, phase and transfer functions respectively. The high value of the error floors in order to down-weight the influence of 3D effects (Booker, 2005 et al.) and decreased static-shift effects of the apparent resistivity. Moreover, this study also manually set the static shift parameters to reduce the effects. The responses for both resistivity and phase are in good agreement with measured data, but the phase poor fitting at long periods of TM mode (Figure 2) that is probably influence by strong 3D effects (Chen and Chen, 2002), and the root-mean-square (r.m.s.) misfit is 1.69.

Figure 2. Pseudo-sections of MT resistivity and phase model response for both TE and TM polarization modes, here the currents flow alone (TE) and cross (TM) the geological strike.
RESULT AND INTERPRETATION

Figure 3 shows the electrical model and earthquake events for $M_w \geq 3$, from 1973 to 2006, within a $\pm 15$ km profile. Note that a sequence of shallow conductive anomalies appears in the electrical model, which coincide with earthquakes and geology at shallow depth ($0 \sim -10$ km). It means that the conductive anomalies are related with fracture zone of seismicity. In the west (0~20 km along profile, Figure 3), the conductive anomaly is associated with the fluids saturated at sedimentary sequence that corresponding to seismic models (e.g. Kim, 2005; Wu et al., 2007); in central (30~70 km along profile), we interpret the conductive anomaly is related to fracture zone of seismicity with fluids. This phenomenon supports the hypothesis that conductive anomaly was located in the oceanic-continental subduction system (Kurtz, et al., 1990; Soyer and Unsworth, 2006). In this study, the conductive anomaly also imply that a dehydration beneath 10-20 km of mountain range as initially presented by Chen and Chen (1998); The eastern conductive anomaly is presumably the result of interconnected fluids related with the surface evidence of hot springs (~80km) between the BR and ECR boundary; Farther east (95~110 km along profile), the conductivity is probably related to the convergence boundary with seismicity zone and fluids. These results correspond to previous studies giving an important validation of the data analysis.

An interesting feature apparent a resistive anomaly located below the far eastern conductive anomaly between -20 to -50 km at depth, and 70 to 110 km at horizontal is shown in figure 3. The high resistive anomaly indicates that a material difference exists between the Philippine Sea plate and fundamental base of the Eurasian continental plate. This result has been suggested by Cheng (2008) from joint analysis of seismic arrival time and gravity anomaly data. The physical and numerical modeling implies that high P-wave velocity could be associated with a subducting Luzon fore-arc sliver (e.g. Chemenda, 1997). Cheng’s model (2008) found the crustal anomalies of two prominent high velocity and high poison’s ratio anomalies in the mid and lower crust of southeastern Taiwan. Otherwise, the seismic evidence of Wang et al. (2006) demonstrates that the Eurasian slab is subducting with the Philippine Sea plate beneath southern Taiwan at a 2% high P-wave velocity perturbation extrusion. Due to Ding et al. (2001) demonstrated that suture zone of the plate collisional Longitudinal Valley should be included into the basic thin-skinned tectonics model, and must affects mountain building to fit with the GPS data.

According to the both models of Ding et al. (2001) at shallow and Wang et al. (2006) at depth can help us to interpret with the electrical model as illustrated in figure 3. This electrical model shows well fitting with the lower bound of Eurasian slab at depth of 70 km dipped toward to the eastern, but unclear in the upper bound of Eurasian slab, refer to Wang’s (2006) model. However, base on the thin-skinned collisional model (Ding, et al., 2001), the authors opining the resistive anomaly is a slab over thrusting into southern Taiwan on the Eurasian plate if upper bound slab is existed as a decollement at southeastern Taiwan. This subducted slab has not been considerate to Ding’s (2001) model, but has shown in lithospheric collision model.

To fully understand the electrical model will be influenced by the resistive anomaly, a simulation model is needed. The forward modelling shows that the resistive anomaly is needed to be located in this area for best fitting. The response curves will be influenced between the periods of 10-10,000s both TE and TM mode, if exchange with the resistor to conductor. Therefore the resistive anomaly is more convinced, and could be related with the subducting forearc sliver beneath southeastern Taiwan at mid crust.

Figure 3. The electrical model and earthquake events ($M\geq3$) within a $\pm 15$ km profile is shown in the figure, and the topography is sketched on the top with the geological boundary, CP- Costal Plan, WF-Western Foothills, BR-Backbone Range, ECR-Eastern Central Range, LV-Longitudinal Valley, CR-Costal Range. The faults location indicated by red words, CKF-Chuko Fault, CF-Chuichih Fault, CERF-Central Range Fault, LVF-Longitudinal Valley Fault, CRF-Costal Range Fault. The arrow directions  are indicated the blocks movement modified from (Ding et al., 2001). The upper and lower bound of the Eurasian slab were defined by Wang’s (2006) model.
CONCLUSIONS

The shallow conductive anomalies beneath the southern Taiwan are strongly related with the collisional plates and fluids distribution. However, the significant evidence of the forearc sliver has clearly been extracted by MT imaging beneath southeastern Taiwan. This study sufficiently supports the thin-skinned subduction model for the tectonic implication at southern Taiwan. The thin-skin with subduction model beneath southern Taiwan should be considered for the other models.

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REFERENCES


Ho, C. S., 1986, A synthesis of the geologic evolution of Taiwan. Tectonophysics, 125, 1-16.


Tsai, Y. B., 1986, Seismotectonics of Taiwan, Tectonophysics, 125, 17-38.


Wu, F. T. and U.S./Taiwan TAIGER teams, 2007, TAIGER (TAiwan Integrated GEodynamics Research) project for testing models of Taiwan orogeny, Geophysical Research Abstracts, 9, 02135.