An Electric Resistivity Study of the Chelungpu Fault in the Taichung Area, Taiwan

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ABSTRACT

We conducted an electric resistivity survey in the Taichung area to investigate the subsurface structures of the Chelungpu fault, where the surface ruptures of the 1999 Chi-Chi earthquake diverged eastwardly from the foot of the hills for most part of the Chelungpu fault to the slope of the hills. Six profiles of resistivity image profiling with pole-pole array were carried out. The data were interpreted by the 2-D inversion method. Based on the formation sequence and the resistivity measured on the outcrops of rocks in and around the study area, the interpretative resistivity layers are correlated to the strata, the resistivity spectra of the rock formations are obtained and the geological structures are deduced.

The results indicate that the Chelungpu fault is a complex fault system consisting of two major thrust faults, several minor faults and a strike-slip fault in the Taichung area. The two major thrust faults are the basal fault in the west and the Chi-Chi fault in the east of the fault system. The basal fault dips 30°-60° eastwardly and is the main fault of the Chelungpu fault system, which has a cumulate throw of 2000 m or more. The Chi-Chi fault is a branch of the Chelungpu fault which was developed on the hanging wall after a strike-slip fault had formed in the south of the study area. The Chi-Chi fault dips 40°-60° eastwardly and has a cumulate throw of several tens meters. It is very active recently, and may become the dominantly active fault zone in the northern section of the Chelungpu fault system. In the south of the study area, the basal and the Chi-Chi faults are coincident.

(Key words: Resistivity structures, Chelungpu fault, Active fault)

INTRODUCTION

The Taichung area is located in west-central Taiwan where the buildings were seriously destroyed and the ground was greatly disturbed by the 1999 Chi-Chi earthquake. This earthquake was generated by the reactivation of the Chelungpu fault which was suggested to be a thrust fault with the east Pliocene Chinshui Formation ridding on the west Pleistocene Toukoshan Formation along the foot of the hills in west-central Taiwan (Pan 1967; Chang 1971). Before the Chi-Chi earthquake, only a few outcrops of the fault were found and most part of the fault line could not be traced due to weathering, collapsing and debries coverage. During the Chi-Chi earthquake, this fault was reactivated with the hanging wall lifted about 1-4 meters above the footwall generally (Lee et al 1999; Lin et al 2000; Huang et al 2000). The surface ruptures showed that the fault is more complex than the previously suggested model. It has a wide fault zone consisting of several ruptures and fractures. In some places, it is accompanied with folds and a back thrust. A large portion of the major surface ruptures appeared along the foot of the hills where the Pliocene Chinshui Formation westwardly thrusted on the Quaternary formations as the model suggested previously. It is said that the boundary between the Chinshui Formation and the Quaternary formations is a typical contact of the Chelungpu fault. But in the Taichung area, the Chi-Chi surface ruptures appeared in the Late Pliocene Cholan Formation on the slope of the hills located to the east of the foot of the hills. No visible displacement were found along the foot of the hills, except in the southern part of the study area where the Chinshui Formation thrusted westwardly on the alluvium. Two cores were drilled at Fengyuan where is 4 km north of the study area for studies of the Chelungpu fault. The cores indicated that the rock formations are the Quaternary terrace deposits, the Pliocene Chinshui Shale and the Mio-Pliocene Kueichulin Formation from top to bottom. Several fracture zones existed in the latter two formations. The major Chelungpu fault zone was interpreted to be located at the bottom of the Chinshui Shale which was underlain by the older Kueichulin Formation at a depth of 172 m (Tanaka et al 2002; Huang et al 2002). This fault contact is different from the typical model of the Chelungpu fault, an older formation ridding on younger ones. The core drilled from the site of TCDP showed that the Kueichulin Formation was underlain by the Cholan Formation indicative of a thrust fault at a depth of 1707 m. Two questions are then arised: (1) where is the outcrop of the fault found at 1707 m deep under the TCDP site? (2) is there any geological structure beneath the foot of the hills? The authors intend to find the answers to these questions by using geoelectric resistivity structures.

GEOLOGICAL SETTING

The study area is covered with the Quaternary and the Neogene formations with boundaries in a general trend of N-S direction. From west to east, they are the alluvium, the lateritic terrace deposits, and the Cholan Formation. A small portion of the Chinshui Formation outcrops in the south of the study area. The alluvium is composed of clay, silt, sand, and gravel. The Late Pleistocene lateritic terrace deposits are composed largely of unconsolidated gravel with flat-lying sandy or silty lenses. The Late Pliocene Cholan Formation is composed of sandstone, shale, and mudstone dominantly. The Pliocene Chinshui Formation is composed largely of shale and a few siltstone and mudstone layers (Ho, 1975).

The boundary between the alluvium and the lateritic terrace deposits is also a topographic boundary, the eastern side is the area of terrace and hills but the western side is the area of plain. The outcrops of the strata show that the alluvium is undisturbed or little disturbed in the plain area. The lateritic terrace deposits have been tilted, folded and dragged near the foot of the hills. The Cholan Formation dips eastwardly at an angle of 20° - 40° in the area of hills. To the east of the study area, the Cholan Formation is overlain by the Toukoshan Formation which is a Pleistocene formation of massive conglomerate containing a few thin sandy beds.

METHOD

The technique of electric resistivity image profiling (RIP) with the pole-pole electrode configuration was used in this study because it has a high data density for high resolution interpretation. Basically, it is a four-electrode configuration with one current electrode and one potential electrode, called the sounding electrodes, are set on the surface of the profile to be investigated, and the other two electrodes including one current electrode and one potential electrode, called the remote electrodes, are fixed at distant places. The remote electrodes are far from the profile and are far from each other.

The RIP data were interpreted following the 2-D inversion method because a fault can be regarded as a 2-D structure. The forward part of the 2-D inversion program used in this study is based on the finite element method and the inverse part is based on the least-squares optimization technique (deGroot-Hedlin and Constable, 1990；Loke and Barker, 1996；Tong and Yang, 1990)

RESULTS and DISCUSSIONS

Six RIP data sets of A-A’, B-B’, C-C’, D-D’, E-E’ and F-F’ profiles were obtained in the Taichung area. The locations of these profiles are shown in Fig.1.

1. Geological Structures beneath the Foot of the Hills

The interpretative geological section of Profiles A-A’, C-C’ and E-E’ show that the younger Toukoshan Formation is overlain by the older Chinshui Formation with an east dipping boundary at an angle of 30°-60° beneath the foot of the hills. It means that the boundary is a thrust fault. In normal sequence, the Chinshui Formation is conformably overlain by the Cholan Formation of about 2000 m thick and then by the Toukoshan Formation successively in the study area (Ho and Chen 2000). So that the hanging wall of the fault should have a cumulate vertical displacement of 2000 m or more relative to the footwall. Since the fault has the typical contact of the Chelungpu fault, that is the Quaternary formations are overlain by the westwardly thrusted Pliocene formations, the fault beneath the foot of the hills should be the major fault zone of the Chelungpu fault. It is called the basal fault zone because the strata to the west of the fault are undisturbed. The gravel layer of the lateritic terrace deposits appears on the top of eastern side and underlies the alluvium on the western side of the fault indicating that the fault has cut through the layer of the lateritic terrace deposits. In other words, the faulting still occurred after the layer of the lateritic terrace deposits had been formed in Late Pleistocene.

2. Chi-Chi Fault Zone

The subsurface rupture of the Chi-Chi fault was found in Profiles A-A', B-B' and D-D'. At the place of Profile A-A', it has the typical form and contact of the Chelungpu fault, that is, the Chinshui Formation overlies the Toukoshan Formation with an east dipping boundary. It indicates that the Chi-Chi fault coincided with the basal fault of the Chelungpu fault system. But at the places of Profiles B-B' and D-D', the rupture associated with the Chi-Chi earthquake was developed in the Cholan Formation on the former hanging wall of the Chelungpu fault.

In Profiles B-B' and D-D', the lateritic terrace gravel layer borders the Chi-Chi fault in the east. The forming of the lateritic terrace deposits is suggested to be related with the relative uplift of the eastern hanging wall of the Chi-Chi fault. The terrace gravel layer is about 70 m and 30 m thick at the places of Profiles B-B' and D-D', respectively. It implies that the relative uplift is about 70 m at the place of Profile B-B' in the south and is about 30 m at the place of Profile D-D' in the north. This difference in magnitude of relative uplift might be caused by differential uplifting of the fault at different segments, or by different sharing of the uplift into several blocks.

If a faulting event resulted in an average throw of 2 m, an approximate to the magnitude of the Chi-Chi faulting (Chang et al. 1999), then more than fifteen faulting events of the Chi-Chi magnitude had occurred along the Chi-Chi fault prior to the 1999 Chi-Chi earthquake. In other words, the Chi-Chi fault is an active fault where many times of faulting have occurred since the lateritic terrace gravel layer was formed in Late Pleistocene.

The position of the Chi-Chi fault is consistent with the basal fault zone of the Chelungpu fault in the south of the study area. Therefore the Chi-Chi fault is a branch of the Chelungpu fault system. The Chi-Chi fault has a cumulate throw of several tens meters which is much smaller than the basal fault, but it is very active recently and may become the dominant active fault in the northern segment of the Chelungpu fault system.

3. Minor Faults and Transverse Strike-slip Fault

The gravel layer of the lateritic terrace deposits has several notches in resistivity contours and a step-like bottom. They indicate that the gravel layer has been cut into several blocks by parallel fractures and minor faults, and has been undergone differential uplifts since the stratum was deposited. It implies that the ruptures associated with the earthquakes prior to the Chi-Chi earthquake consisted of minor faults, and fractures, in addition to major faults as that associated with the Chi-Chi earthquake appeared in the Tsaotun area to the south of the Taichung area (Chang et al. 1999; Cheng et al. 2002).

A west-east departure of about 800 m of the basal fault of the Chelungpu fault system is found between the places of Profile A-A' and Profile C-C'. In order to explain the departure of the basal fault, a west-east transverse strike-slip fault adjacent to the north of Profile A-A' labled G-G' in Fig.1 is inferred. The location and the direction of the geoelectrically inferred strike-slip fault are slightly different from that of the geologically inferred strike-slip fault (Ho and Chen 2000).

CONCLUSION

Based on the formation sequence and the resistivity measured on the outcrops of the rocks in and around the study area, the resistivity spectra of the rock formations are obtained. The alluvial gravel layer, the alluvial sand layer and the lateritic terrace gravel beds have a dominant resistivity of 200-600 Ω-m, 30-150 Ω-m, and 300-1200 Ω-m, respectively. The Toukoshan Formation, the Cholan Formation, and the Chinshui Formation have a main resistivity of 150-500 Ω-m, 40-100 Ω-m, and 8-40 Ω-m respectively. The interpretative results of the profiles show that the Chelungpu fault is a complex fault system consisting of two major thrust faults, several minor faults accompanied with fractures and a strike-slip fault in the Taichung area. The two major thrust faults are called the basal fault and the Chi-Chi fault temporarily. They are 300-800 m apart on the ground and trend in a N-S direction. The basal fault lies in the west and the Chi-Chi fault lies in the east of the fault zone with the minor faults in the middle. The strike-slip fault is suggested to be transverse to the major faults located in the southern part of the study area. To the south of the strike-slip fault, the basal fault and the Chi-Chi fault are coincident in location.

The basal fault dips eastwardly at an angle of 30°-60° beneath the foot of the hills. It has a cumulate throw of 2000 m or more showing its greatness and is the main fault of the Chelungpu fault system. Within a depth of 150 m, the Pliocene Chinshui Formation thrusted westwardly on the Toukoshan Formation. In the west of the basal fault, the Toukoshan Formation is overlain by the lateritic terrace gravel beds and the alluvium successively, where the alluvium and the terrace gravel beds are about 3-10 m and 40-60 m thick, respectively. But at the place of Profile A-A’, the flood-plain of the Talihsi stream in the south of the study area, the alluvium is about 70 m thick. In the east of the basal fault, the Chinshui Formation is overlain by the Cholan Formation. The Chinshui Formation and a portion of the Cholan Formation are overlain unconformably by the lateritic gravel beds of thickness 15-70 m on the top.

The Chi-Chi fault is a branch of the Chelungpu fault which was developed in weak layers of the Pliocene formations on the hanging wall in the Taichung area. Within a depth of 150 m, the Chi-Chi fault was formed in the Cholan Formation with an east dipping angle of 40°-60°. It has a cumulate throw of several tens meters implying that the fault was formed earlier than the 1999 Chi-Chi earthquake and many times of thrusting events had occurred there. Although the Chi-Chi fault is much smaller than the basal fault, it is very active recently and may become the dominantly active fault zone in the northern segment of Chelungpu fault.

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REFERENCES

Chang, H. C., C. W. Lin, and S. T. Lu, 1999：The report of a field survey of the 921 earthquake, Central Geological Survey, MOEA., R.O.C., Taiwan, (in Chinese)

Cheng P. H., C. H. Yang, J. I. You, J. S. Shieh, 2002: An electric resistivity study of the Chelungpu fault in the Tsaotun area, central Taiwan. TAO, 13, 375-386.

deGroot-Hedlin, C., and S. Constable, 1990：Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data. *Geophysics*,55, 1613-1624.

Ho, C. S., 1975: An introduction to the geology of Taiwan explanatory text of the geologic map of Taiwan, MOEA, Taiwan, 153pp.

Ho, H. C. and M. M. Chen, 2000: Explanatory text of the geologic map of Taiwan, sheet Taichung. Central Geological Survey, Taiwan, 65pp.

Huang, S. T., J. C. Wu, J. H. Hung, and H. Tanaka, 2002: Studies of sedimentary facies, stratigraphy, and deformation structures of the Chelungpu fault zone on cores from drilled wells in Fengyuan and Nantou, central Taiwan. TAO, 13, 253-278.

Huang, W. J., Z. Y. Chen, S. Y. Liu, Y. H. Lin, C. W. Lin, and H. C. Chang, 2000: Surface deformation models of the 1999 Chi-Chi earthquake between Tachichi and Toupienkengchi, central Taiwan. Special issue for the Chi-Chi earthquake, 1999, Central Geological Survey, MOEA, Taiwan, 63-87.

Lee, J. F., C. S. Hou, C. C. Lin, and T. C. Lai, 1999：The Chelungpu fault and the 921 Chi-Chi large earthquake. Special issue of the Chi-Chi large earthquake, Central Weather Bureau and the Geophysical Soc. of China, Taiwan, 7-36. (in Chinese)

Lin, C. W., H. C. Chang, S. T. Lu, T. S. Shin, and W. J. Huang, 2000：An introduction to the active faults of Taiwan,2nd ed., Central Geological Survey, MOEA., R.O.C., Taiwan, 129pp. (in chinese)

Pan, Y. S., 1967：Interpretation and seismic coordination of the Bouguer gravity anomalies over west-central Taiwan. *Petrol. Geol. Taiwan*, 4, 287-301.

Tanaka, H., C. Y. Wang, W. M. Chen, A. Sakaguchi, K. Ujiie, H. Ito, and M. Ando, 2002: Initial science report of shallow drilling penetrating into the Chelungpu fault zone, Taiwan. TAO, 13, 227-251.

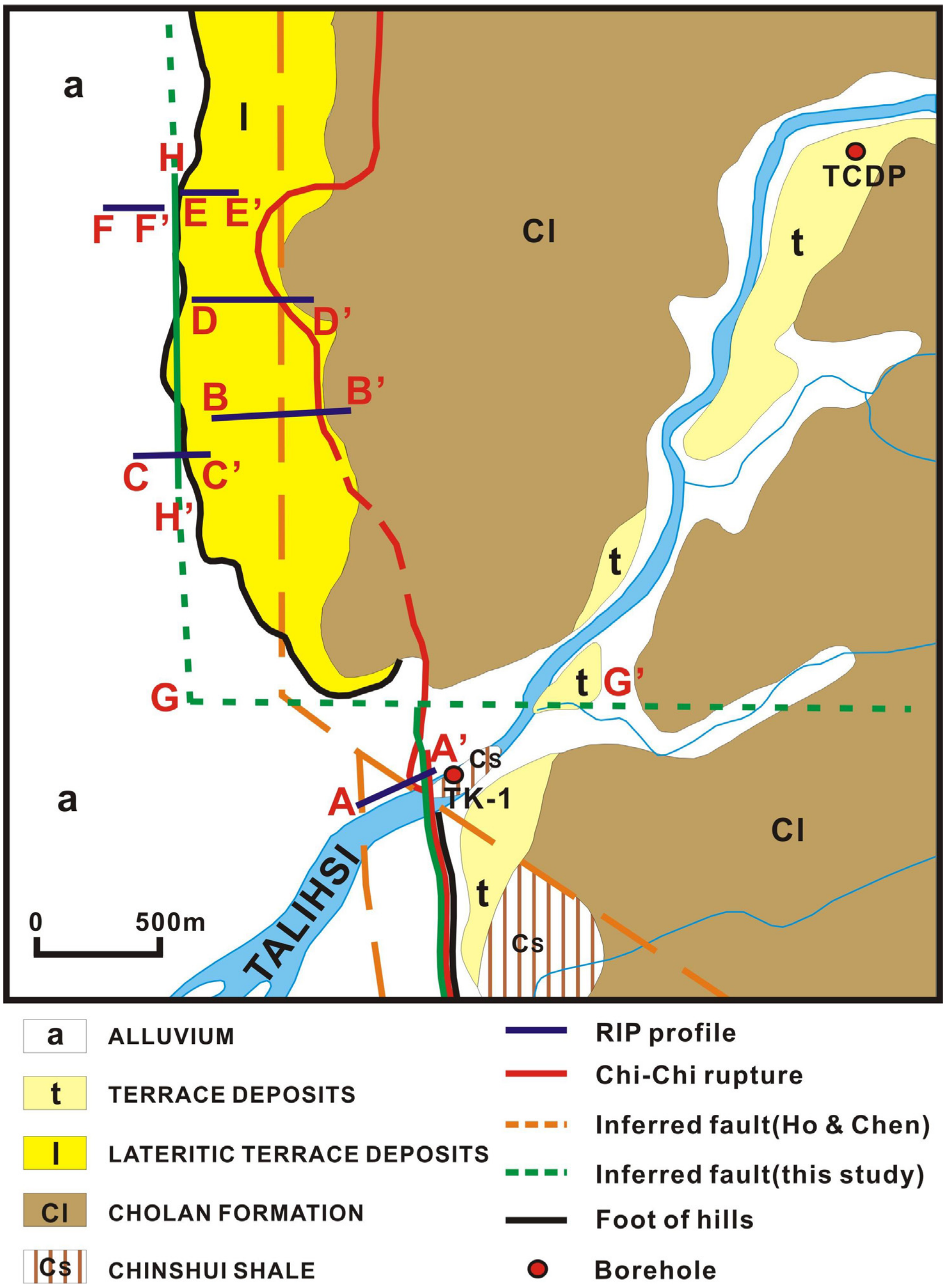

Fig.1. Geological map of the study area (modified from Ho and Chen 2000) and the locations of the RIP profiles. G-G' is the location of an inferred strike-slip fault ; H-H' is the inferred basal fault of the Chelungpu fault system.