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# DEFORMATION AND AGE OF FLUVIAL TERRACES SOUTH OF THE CHOUSHUI RIVER, CENTRAL TAIWAN, AND THEIR TECTONIC IMPLICATIONS

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## ABSTRACT

**A flight of four progressively eastward-tilted fluvial terraces appear on the south side of the westward-flowing Choushui River, central Taiwan. A radiocarbon dating on peat constrains the age of emergence of the second oldest terrace, B, to be about 30 ka. Assuming the rate of tilting has been constant, the age of the oldest terrace, A would be about 90 ka, 3 times as old as the age of terrace B. The two younger terraces, C and D, are least tilted and may be Holocene in age. The tilted terraces appear to be the result of slip on a southern extension of the Changhua fault, which dips eastward beneath the tilted Pakua Tableland north of the Choushui River. The Changhua and Chelungpu faults appear to merge about 10km south of the terraces.**

**Key words: Changhua Fault, Chelungpu fault, central Taiwan, fluvial terraces, $^{14}$C dating**

## INTRODUCTION

The Pakua Tableland, up to 400 m in altitude, is located in central Taiwan, north of the Choushui River, the largest river of the island (Fig.1). This tableland consists of a series of very wide tilted fluvial terraces, which appear to have been formed by the Choushui River and its tributaries (Shih and Yang, 1985) (Fig. 2). Slip on the Changhua fault beneath the tableland appears to have caused the tableland to tilt (e.g. Shih and Yang, 1985). The trace of the fault west of the tableland is unclear, however, at least in part because of the thick cover of colluvial deposits along the western edge of the tableland. It has been extended south of the tableland along the western margin of the Touliu Hills by the Central Petroleum Company (CPC) on their 1:100,000 geological maps (CPC, 1982). The active fault maps published by Central Geological


Figure 1. Map showing the location of the study area.

Survey, however, do not extend the fault trace south of the Choushui River (Chang *et al*., 1998; Lin *et al*., 2000). Thus, different opinions exist about the southward extension of the Changhua fault. Shyu (1994), who studied fluvial terraces south of the Pakua Tableland, suggested that the Changhua fault may extend along the east side of the Chinshui River valley, a northward-flowing tributary of the Choushui River (Fig. 2). In this paper, we present arguments that favor this interpretation and discuss its implications.

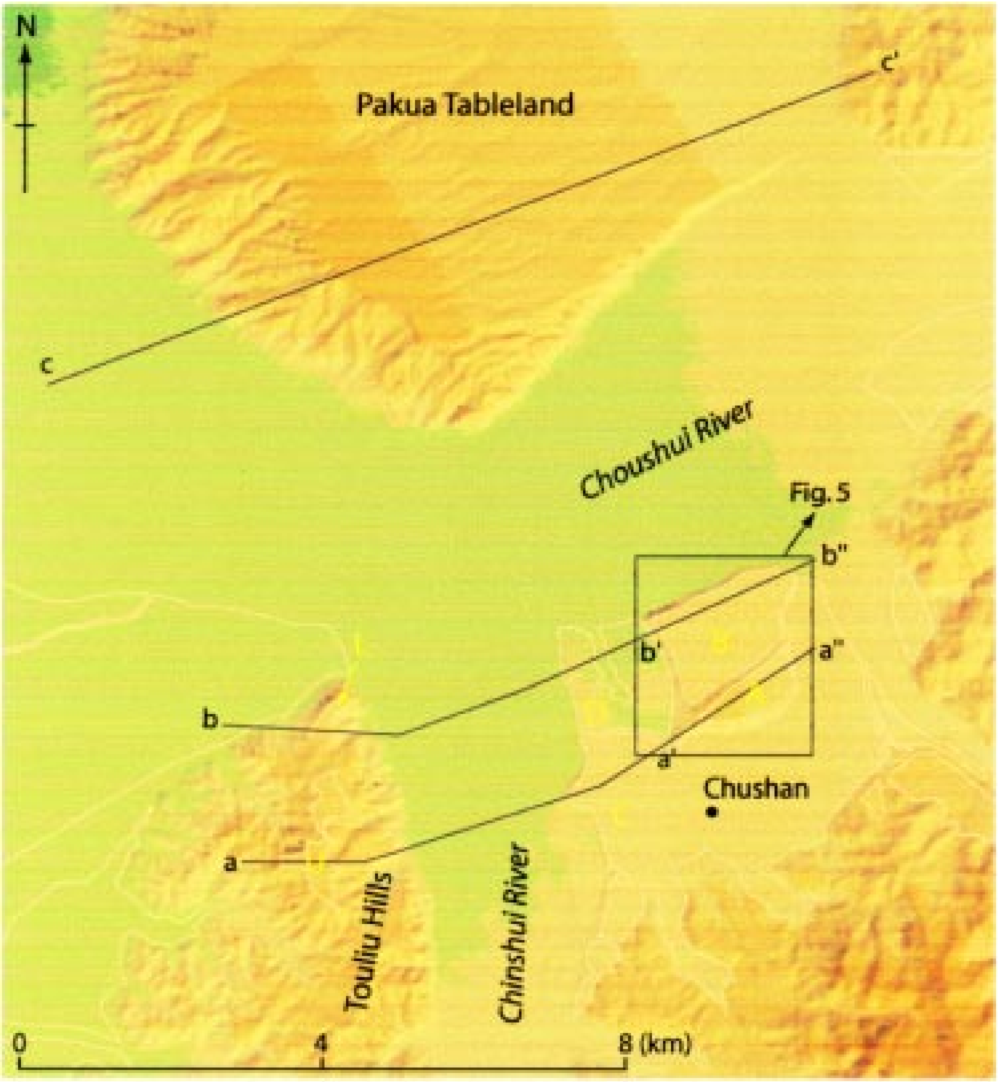


Figure 2. Annotated relief map of the study area constructed from 40-m-resolution DEM. The light source is from the southeast (135°) at a 45° inclination. Several terraces south of the Choushui River in the Chushan area clearly show eastward tilting. Lines a-a", b-b" and c-c' indicate the location of profiles shown in Figures 3 and 5. Capital letters indicate various fluvial surfaces.

Our work is based upon interpretation of aerial photographs (scale about 1:20,000), examination of shaded-relief maps constructed from a 40-meter-resolution DEM, field observations and radiocarbon dates from the tilted terraces.

## FLUVIAL TERRACES IN THE STUDY AREA

### Distribution of terraces

A flight of well-preserved fluvial terraces exists north of Chushan, near the junction of the Choushui and Chinshui Rivers (Fig.2). Height difference and Progressive tilt of these terraces allows us to divide them into four distinct levels, A to D. The surface height of terraces ranges from 250-160 m for terrace A, 190-150 m for terrace B, 170-150 m for terrace C, and 140-130 m for terrace D (Figs.2 and 3). The highest terrace A has a thick layer of lateritic soil on the surface. Lateritic soil is thin and only locally seen on terrace B, and does not exist on terraces C and D. Thus, both the tilt and degree of soil development indicate that terrace A is the oldest and D is the youngest.

Along the eastern bank of the Chinshui River, a very narrow terrace, which probably corresponds to terrace C, also exists south of the region shown in Figure 2. Two wide terraces also exist on the top of the Touliu Hills west of the Chinshui River (Fig. 2). The height of the upper terrace (U) is 330-280 m, and the height of the lower terrace (L) is 240-230 m (Fig. 3). The presence of lateritic soil on the terrace U (Shyu, 1994) suggests that its age is similar to that of terrace A.

### Age of terraces

A large outcrop produced by the construction of a new freeway revealed gravel beds more than 30 m thick underlying terrace B. The terrace surface is conformable with the gravel beds, and thus appears to be a depositional surface. The gravels consist of unweathered rounded to sub-rounded gravel, up to 50 cm in diameter. Many of the gravel clasts consist of slate derived from the Central Range (Shyu, 1994). Therefore, terrace B is a depositional terrace of the Choushui River, which drains the Central Range. A distinctive 85-cm-thick peat bed (Fig. 4) overlies the gravel beds. The abundance of organic material decreases downward. This peat bed is overlain by gray colored silt. The silt and peat are evidence that the terrace B became an area of slack water and organic deposition soon after high-energy fluvial deposition ended. Thus, the age of this peat probably is a close minimum limit to the date of the emergence of terrace B above the active riverbed.

We collected two samples from the upper part of the peat. Their conventional $^{14}C$ ages of 30400 ± 200 yr BP (NTU-3279) and 30950 ± 290 yr BP (NTU-3509) are identical. These radiocarbon ages indicate that terrace B formed about 31 ka ago. Age of the formation of terrace A should be significantly older than ca. 31 ka, since it is much more tilted and has a much more developed soil. Using the same argument, terraces C and D are much younger, probably Holocene in age.

### Deformation of terraces

A characteristic feature of the terraces in the Chushan area is their eastward tilting. Since these are terraces of the west-flowing Choushui River, the tilt is upstreamward (Figure 3, and

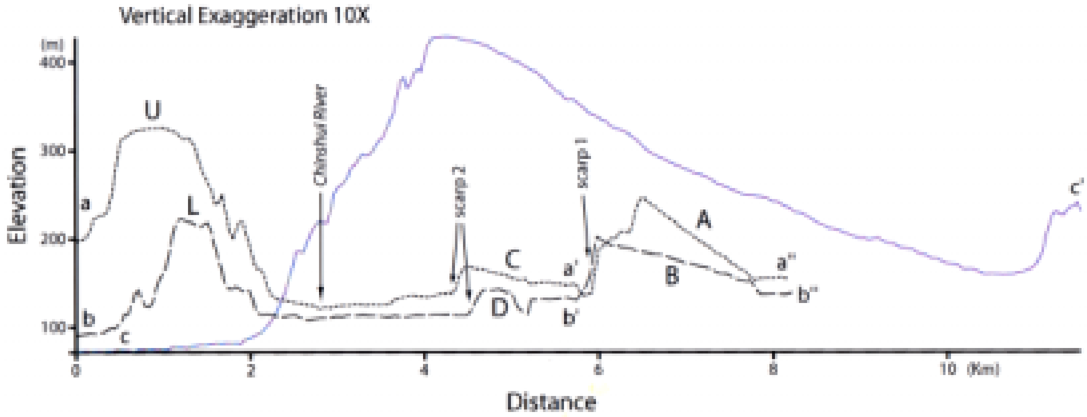


Figure 3. Profiles across the deformed terraces. Profiles a-a" and b-b" show that terraces A, B, C and D east of the Chinshui River tilt progressively eastward, in contrast to the nearly horizontal surface of the higher terrace (U) west of the Chinshui River. The amount of tilting on the Pakua Tableland (profile c-c') is similar to that of terrace A.

Figure 4. Photograph of the sample site on terrace B. An 85-cm thick peat layer overlies the terrace gravel (not shown on the photograph) in the outcrop. Dated samples are collected from the upper black part by the handle of a hammer. Lower part of the peat layer is also black when scraped.

Figure 5, Profiles a'-a'' and b'-b''). The tilt is greater for terrace A (37m/1000m) than for terrace B (12m/1000m). This implies that tilting has been progressive since at least the time of the emergence of terrace A.

The average tilting rate of terrace B, based on the radiocarbon dates and the amount of

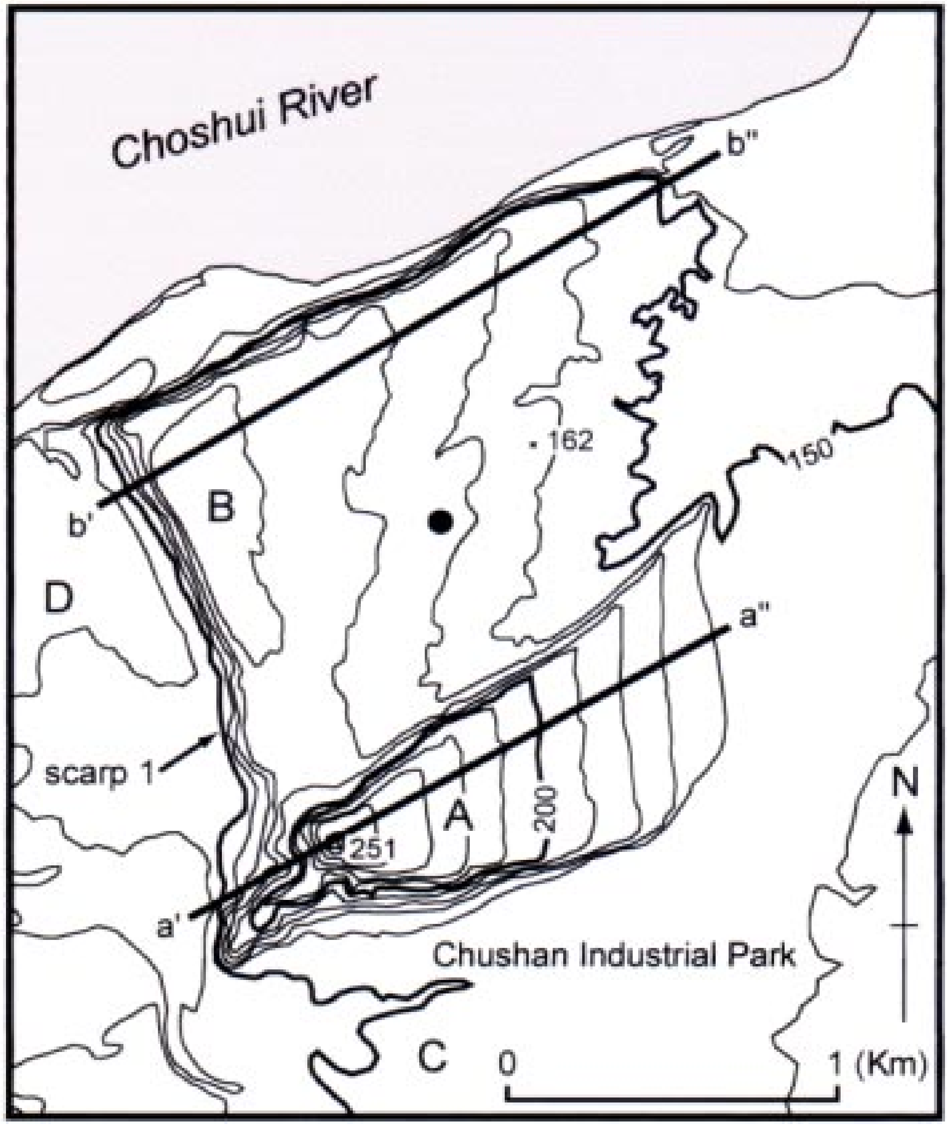


Figure 5. Contour map of the tilted terraces A and B. The contour interval is 10 m (after the 1:25,000 topographic map; Chushan sheet, 9520-IV-SE; published by the Ministry of Interior Affairs, 1987). Terraces C and D are also shown in the map. The black dot on terrace B indicates the location of the dating sample.

tilting, is 0.4m/km/kyr. Assuming a constant tilting rate, the age of terrace A can be estimated to be ca. 92,000 years old. Although we have not yet acquired any datable material from terrace A, the estimate above can serve as a reasonable constraint for the age of terrace A.

Although much more gentle, terraces C and D, situated immediately to the west of terraces A and B, also show eastward tilting. Terrace C drops from 170 m to 151 m (11m/1000m) eastward and terrace D falls from 144 m to 130 m (7m/1000m) (Fig. 3). Thus, progressive eastward tilting is also apparent for these younger terraces.

Eastward tilting is not observed on the narrow terrace along the eastern bank of the Chinshui River, probably because the terrace is too narrow to show any tilting. It is not clear if terrace L on the Touliu Hills is tilted. However, terrace U is clearly free from eastward tilting.

## CAUSATIVE FAULT FOR EASTWARD TILTING AND ORIGIN OF SCARP

The eastward tilting described above is in reverse sense to the original slope, which was formed by westward-flowing Choushui River and its tributaries. Therefore, we need to consider that a causative fault should be located west of the tilted terraces. Following Shyu (1994), we propose that the southern extension of the Changhua fault is the causative fault, based on the

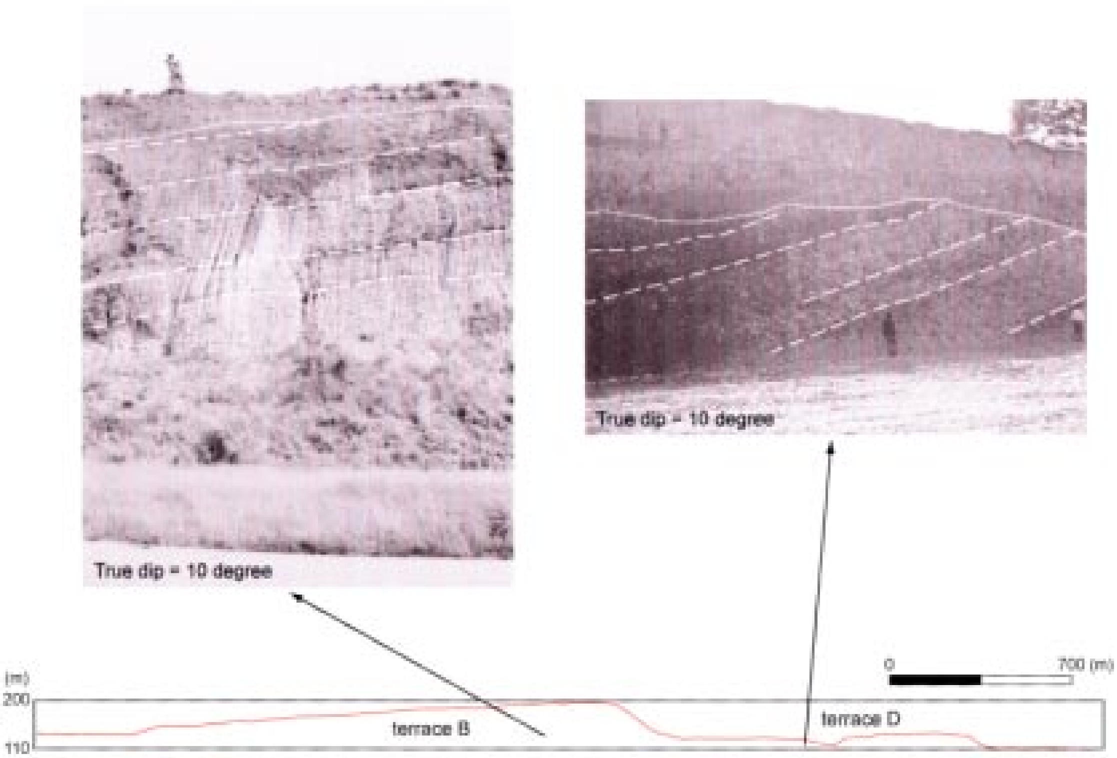


Figure 6. The similar dip of bedding beneath terrace surfaces B and D suggests that scarp 1 (Fig. 2) is an erosional scarp rather than tectonic.

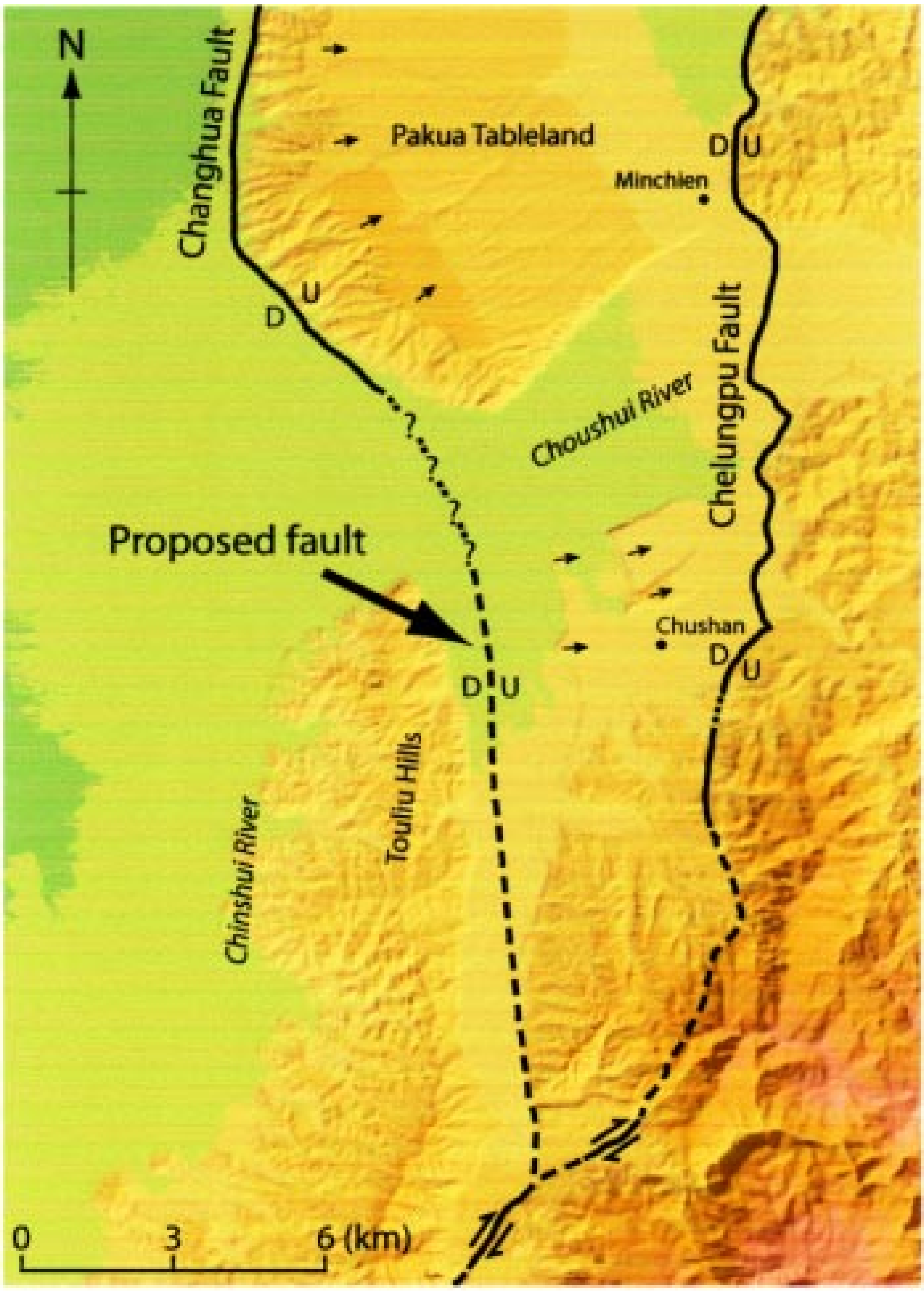


Figure 7. Interpretive map of the terraces in the study area and their relationships to the Changhua fault and Chelungpu fault. Arrows indicate the direction of tilting of the terraces. The tilting of the terraces appears to result from displacement on the Changhua fault.

similarity in terms of direction and amount of tilting for the top surface of the Pakua Tableland and terrace A of the study area.

The extension of the Changhua fault should be located between the tilted terraces (A-D) and relatively flat terraces on the Touliu Hills. These two areas certainly belong to different tectonic units, judging from the patterns of terrace deformation. North of Chushan, there are two north-south trending scarps. Scarp 1 forms the western boundary of terraces A and B, and scarp 2 forms the western margin of terraces C and D (Fig. 3). Both of these two scarps can be the geomorphic expression of the causative fault. However, there is no difference in bedrock dips across scarp 1 (Fig. 6). This indicates that scarp 1 itself is probably an erosional scarp produced by northward flow of the Chinshui River. Scarp 2 is more likely to be a fault scarp, although we found no exposure of faulting there, and there exists the possibility of scarp modification due to stream erosion, especially on the west margin of Terrace C. We have no data to determine the nature of the structure responsible for the uplifting of terraces U and L on the Touliu Hills.

On the geological maps of CPC (No.3 and No.4), the Changhua fault appears along the west side of the Touliu Hills. This implies that the Pakua Tableland and Touliu Hills are similar geomorphic features that have resulted from slip along the same underlying fault. However, detailed comparison of the Pakua Tableland and Touliu Hills shows that they are very different. The Pakua Tableland is an asymmetric anticline, with a very gentle (less than $10^{o}$) east limb and relatively steep ($10\text{-}25^{o}$) west limb. The Touliu Hills, on the other hand, is a relatively symmetrical anticline, with much tighter ($30\text{-}50^{o}$) limbs. Moreover, the anticline underlying the Touliu Hills is plunging to the north. These structural differences make the extension of the Changhua fault along the west side of the Touliu Hills very unlikely.

In contrast to other interpretations, we argue that the Changhua fault does not continue southward along the west side of the Touliu Hills. Rather it likely continues to the south along the Chinshui River, and merges with the Chelungpu fault near the southern end of its 1999 rupture (Fig. 7). This marks the southern boundary of the Taichung Domain of Shyu *et al*. (2001), a tectonic domain dominated by these two sub-parallel reverse faults. However, we are still uncertain about the exact location of the Changhua fault trace within the channel of the Chinshui River. Further structural and geomorphic investigations are still needed in order to understand the tectonic characteristics and potential seismic hazard in this region.

## ACKNOWLEDGMENT

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