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南部活動斷層之長期滑移速率及其相關之構造地形

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摘要

旗山斷層與高屏溪斷層位於台灣西南部構造活躍區域，本研究利用構造地形學方法對此兩條斷層於晚第四紀以來的活動性進行調查，更進而探討其斷層運動機制。

東北走向之旗山斷層為南台灣主要活動斷層之一。本研究檢視旗山斷層沿線之相關構造地形，發現多處晚第四紀之階地與沉積層產生變形的現象，這些變形之階地於空間分部上並非呈現單一之斷層軌跡，可能暗示旗山斷層是由數條互相平行的活動斷層所組成之較寬廣的斷層滑動帶。

南北走向之高屏溪斷層於高屏溪西側北部之階地造成明顯的東傾拱曲構造地形，指示高屏溪斷層應為一斷層面西傾之活動斷層。而高屏溪西側南部之階地並未呈現如北部階地之拱曲構造地形，推測這現象應該是高屏溪的侵蝕作用之結果。本研究認為高屏溪斷層的持續性活動，可能是造成目前高屏溪東西兩側地形上差異的主因，同時也可能是台灣南部主要發震斷層之一。

關鍵字：旗山斷層、高屏溪斷層、活動斷層、階地變形、南台灣。

Abstract

This paper intends to provide geomorphic evidences as a key for the identification of late Quaternary activities of the Chishan Fault and Kaoping River Fault in the tectonically active southern Taiwan, and discusses their nature and their relationship. The Chishan Fault with roughly NE-SW strike has been regarded as one of the major faults in southern Taiwan. We examined the distribution of lineament along the Chishan Fault and the location of the fault exposures. The Chishan Fault is the active fault which deforms the late Quaternary fluvial terraces or deposits, but these sites are not necessary located on the major single lineament, suggesting that the Chishan Fault is relatively wide fault zone, consisted of several traces, and some traces were activated at different time. Several subparallel lineaments to the Chishan Fault in the Chungliao Mountains represent a structural relief reflecting lithological control within the easterly dipping Tertiary strata. The N-S trending Kaoping River Fault has better geomorphic expression as an active fault. We propose that in the northern area, the fault plane of Kaoping River Fault dips westward and deforms late Quaternary fluvial terraces into east-facing flexural scarp. In the southern area, however, flexural scarp is now removed and changed to erosional scarp cut by the Kaoping River. We also confirmed the progressive deformation by this faulting during the late Quaternary, but the Holocene activity was not found by the present study. Even though, the Kaoping River Fault has contributed to the differentiation of major morphology between the terraced area to the west and Pingtung Plain to the east, and can be capable seismogenetic fault. Unsolved problems are determination of slip rate for these two faults due to lack of datable material, and their relationship.

Keywords: Chishan Fault, Kaoping River Fault, active reverse fault, deformed terraces, structural relief, southern Taiwan

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I. Introduction

I-1. Geological and tectonic setting and previous works

Taiwan is known as a tectonically very active island along the boundary between the Eurasian plate and Philippine Sea plate. To the south, including this study area, young Eurasian plate is subducting beneath the Philippine Sea plate with a rate of 82mm/yr (Yu et al., 1997,1999 ; Inset of Fig.1) .

Two major faults are known as the active faults in southern Taiwan (Lin et al., 2000; Shyu et al., 2005; Fig. 1). One is the Chaochou Fault, which marks the western boundary of the Central Range, and the other is the Chishan Fault striking slightly oblique to the Chaochu Fault and cutting the Chungliao Mountains. In addition, the Kaoping River Fault, which is further studied in this paper, is inferred on the west of the Pingtung Plain (Fig. 1; Shyu et al., 2005). Deformation of terraces as an indicator for the active fault by the Chaochou Fault has been reported by Shih et al (1983, 1984). Yang (1986) proposed that late Quaternary activity of the Chaochou Fault is taken place by an active fault, branched from the main Chaochou Fault. However, late Quaternary activities on other two faults (Chishan and Kouping River) are not well understood. Therefore, this study focuses to establish geomorphic evidence as the active fault for the Chishan and Kaoping River faults. The study area covers the Chungliao Mountain and Linkou Mountains located west of the Kaoping River. It also covers the foot of the Yuehkuang Mountains across the Kaoping River (Fig. 2). This study area belongs to “Western Hills of Kaoping Domain” where several faults and folds are developed (Shyu et al., 2005).

The Chishan Fault, 85 km long, strikes NNE to SSE. It controls the direction of the Chungliao and the Yueguang Mountains, which are underlain mostly by late Miocene to early Pliocene sedimentary rocks (Fig. 1, Wu and Mei, 1992; Wu, 1993; Lin, 1991). The Chishan Fault has been studied since 1930's and recently is noticed as a possible active fault, because of the presence of cracks and mud volcanoes along the fault (e.g. Sung, et al., 2004; Chen, et al., 2005), even it is regarded as “suspect (reverse) fault” by Lin et al.(2000). Chen et al. (2005) summarized the previous geological works on the Chishan Fault, and showed a trace of the Chishan Fault on the relief map based on DEM. They divided the Chishan Fault into two, the southern Chishan Fault on west of the Kaoping River and the northern Chishan fault, east of the Kaoping River. On the southern part, the shale bed of late Miocene to early Pliocene thrust toward the west upon the late Pliocene strata. In contrast, the Linkou Mountains runs NNE-SSW, nearly parallel to the south-flowing Kaoping River. Although the western boundary of the Linkou Mountains is sharply defined (Fig. 2), no fault was mapped.

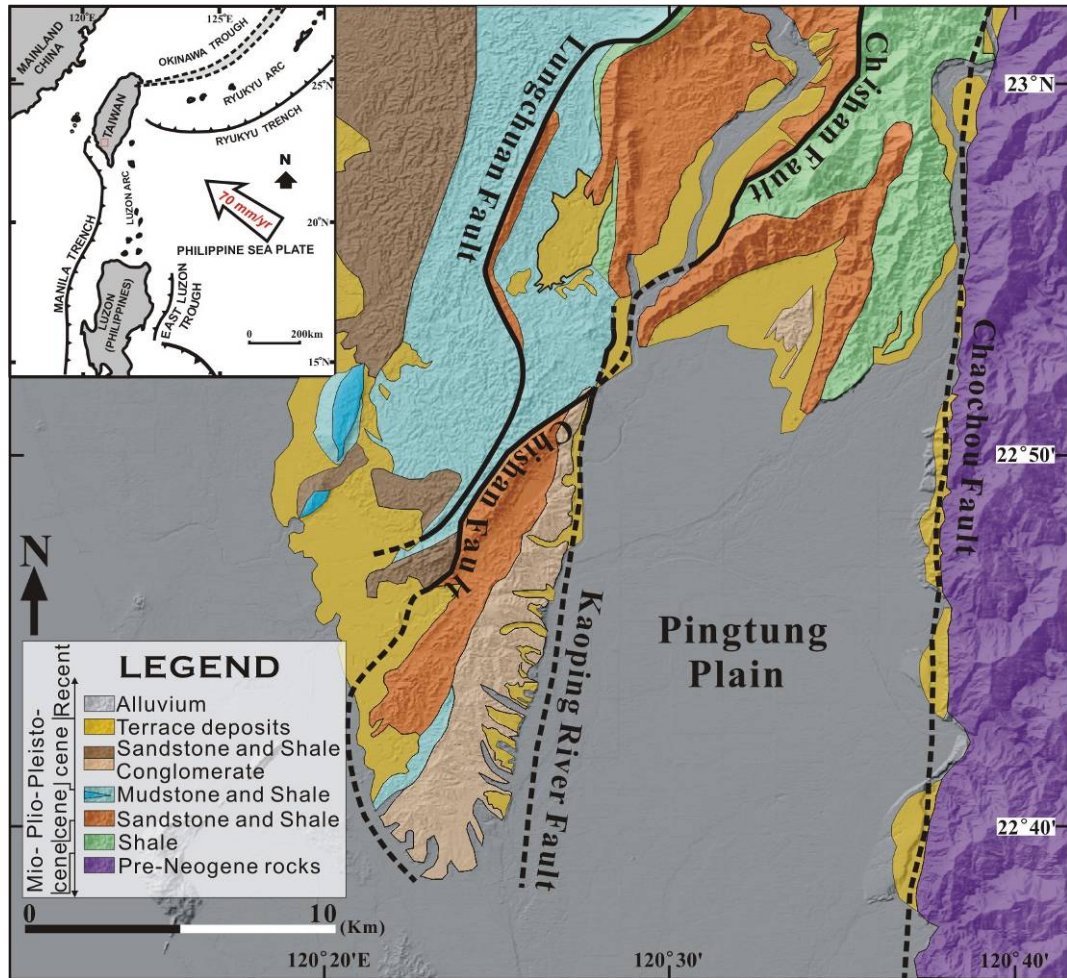


Figure 1. Tectonic and geologic setting of the study area. Tectonic setting is after Yu et al. (1999). Geological map is on shaded relief map simplified and modified from CPC, (1989). The Chishan Fault is geologically confirmed fault (solid line) and dashed lines are estimated faults

Recent discovery of fault exposures cutting Holocene and late Pleistocene deposits (Chen et al., 2005) confirms the late Quaternary or Holocene activity of the Chishan Fault. Shyu et al. (2005) mapped the Chishan Fault as an echelon right lateral strike fault. They also mapped an inferred fault on the west bank of Kaoping River, and estimated that this inferred fault is a left-lateral strike slip with vertical dip and called it as West-Pingtung Plain Fault or Kaoping River Fault (Fig. 1). They concluded the southward extrusion of western foot hill area, judged by those fault arrangement. GPS data also support the deformation along these two faults: that is, the Chishan Fault is dominated by right-lateral motion with a fault slip rate ~ 7 mm/yr in a N50°W direction and the Kaoping River Fault is dominated by left-lateral motion with a ~ 4 mm/yr in a N-S direction (Shen et al., 2003; Hu et al., 2007). However, none of these works provided the basis for the identification of surface expression as active faults for these faults, and their detailed features and nature.

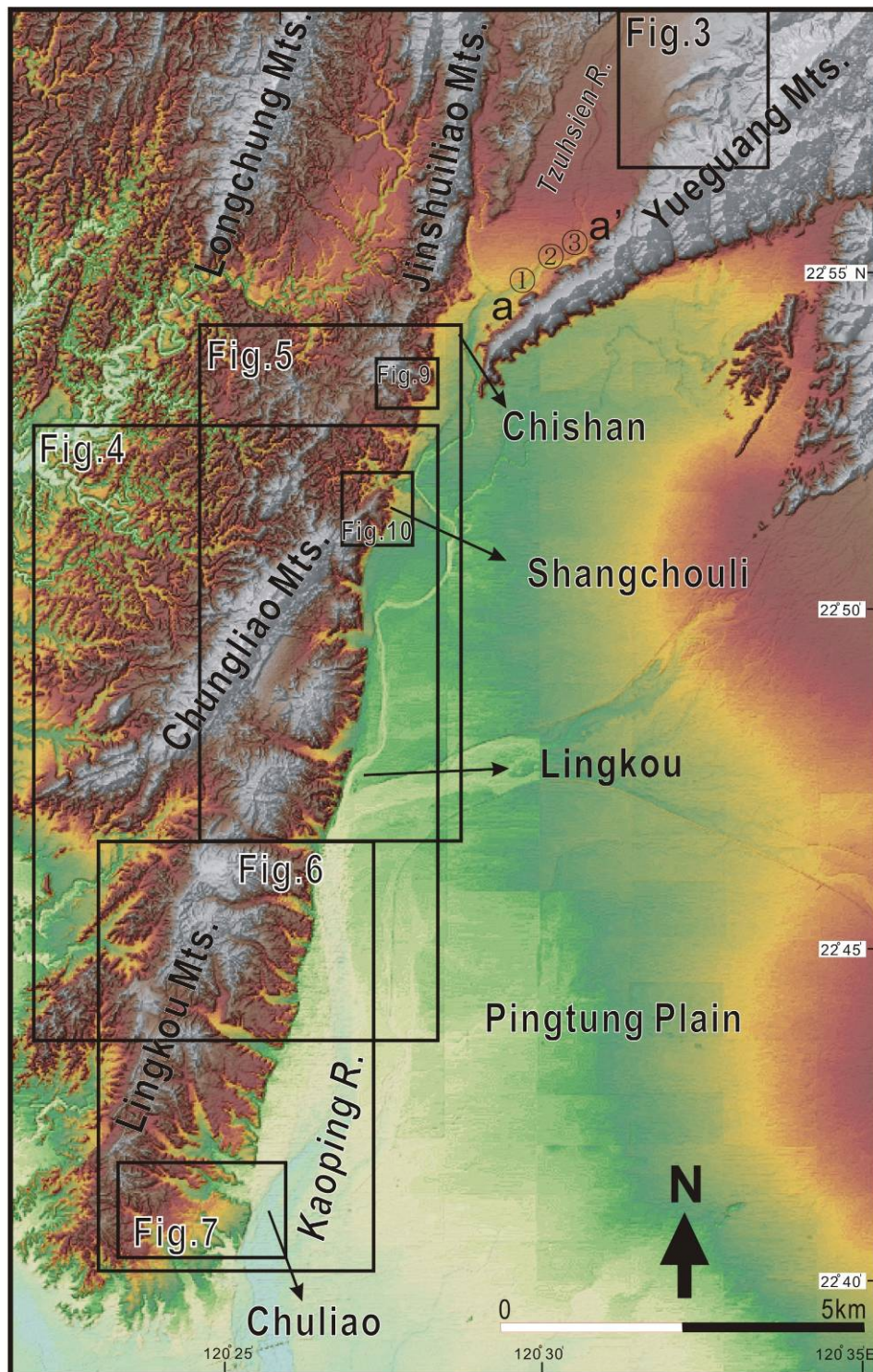


Figure 2. Shaded relief map of the study area based on 40 m grid DEM with locations of detailed maps shown in the text and major place names.

I-2. Purpose of the study

As mentioned above, geomorphic evidences to prove the late Quaternary activity of the Chishan Fault and Kaoping River Fault were not provided before. We believe that deformed landforms should be a key for understanding the recent activity

and evolution of these faults. Therefore, we intend to solve the following problems in this paper: 1) to identify and map the geomorphic data such as fluvial terraces and their deformation due to faulting, and other lineaments which have a possibility of tectonic origin, 2) to understand the characteristics of these faults, and 3) to discuss the tectonic relationship between the Chishan Fault and Kaoping River Fault.

I-3. Study methods

We have mapped terraces and their deformation, active faults and lineaments based on the interpretation of aerial photographs of ca. 1:20,000 in scale over the entire areas. We selected possible deformation sites and examined them in the field. Exposures were examined for understanding of terrace deposits and nature of bedrock. We used shaded relief map based on 20 and 40 m-DEM in order to draw detailed contour maps and profiles for important deformed terraces. 1:5,000 photo maps are also used in order to provide the longitudinal profiles of terraces.

II. Geomorphic observation on the Chishan Fault

We found many subparallel lineaments that strike generally NE-SW along the western margin or cutting through the Chungliiao and Lingkou Mountains on the west of the Kaoping River. On the east of the river, a straight lineament limits the northwestern foot of the Yuehkuang Mountains. Some lineaments are 10 km long and some are only less than 2 km long. A-J are given for the major lineaments (Figs. 2 and 4), in addition to a-a' in Fig. 2.

II-1. Chishan Fault on the Western foot of the Yuehkuang Mountains

A straight lineament a-a' (Fig. 2) limits the northwestern foot of the Yuehkuang Mountains (maximum height is 649 m at Mt. Yuehkuang), mostly underlain by late Miocene sedimentary rocks and striking NNE-SSW on the north and NE-SW on the south. Several lineaments parallel to the lineament a-a' are present on the southern part of the Yuehkuang Mountains (Fig. 2), but they also seem to be structural relief due to lithologic control, because no deformed terraces or alluvial lowland are observed.

We found one positive evidence for the deformation of terrace on the northeastern extension of this lineament a-a', where at least three steps of fluvial terraces (TI to TIII in descending order) are preserved (Fig. 3). TI (202 m above sea level, TII (150 m) and TIII group (lower than 120 m). Most terraces gently slope down westward toward the main river (Tzuhsien River, Fig. 2). However, TI at Kuanyin Mt slopes eastwards from 202 m at the western margin to 180 m at the eastern margin (Fig. 3, profile a-a'). Such an eastward dip of the terrace is abnormal,

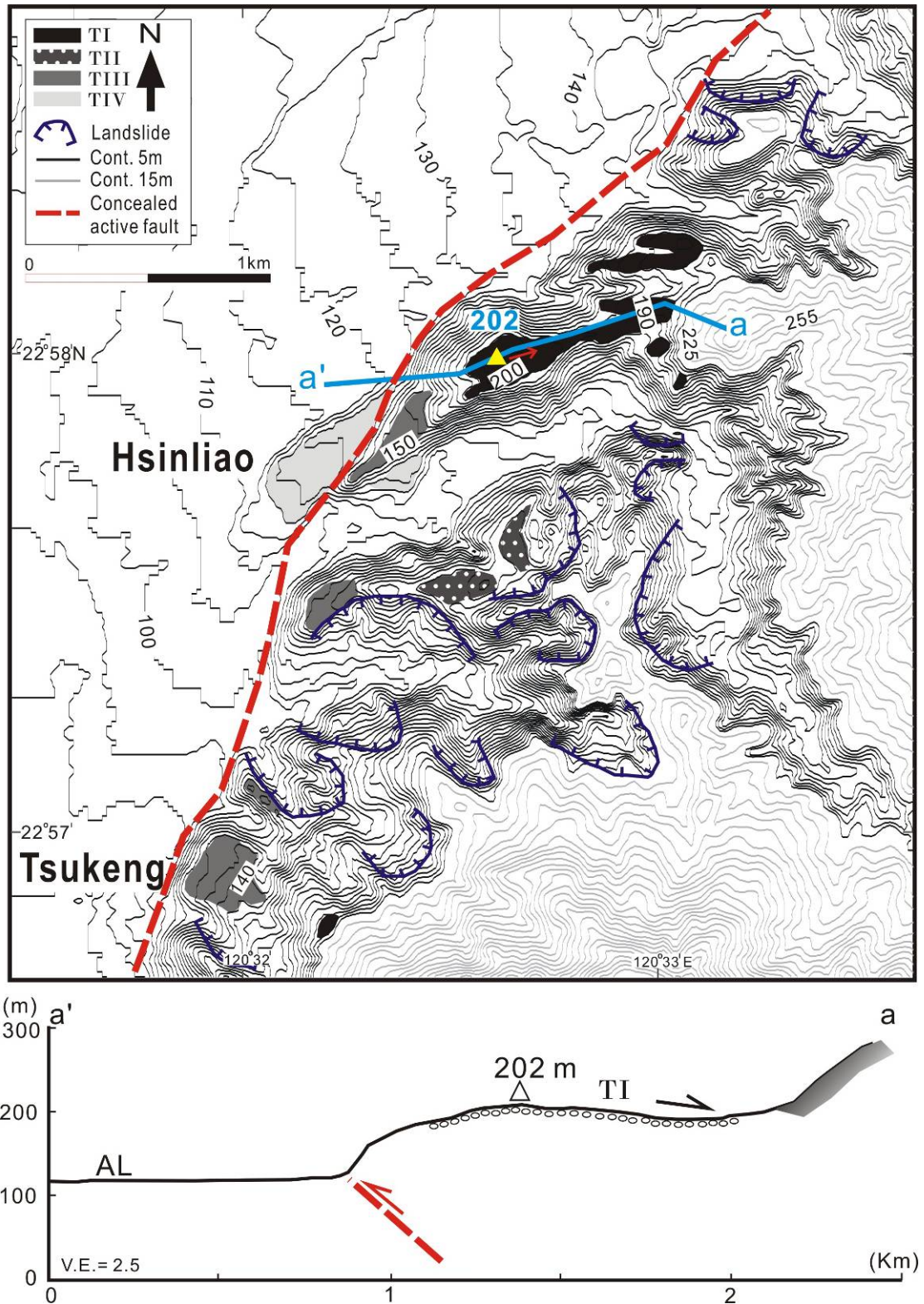


Figure 3. Terrace and fault map of western part of the Yuehkuang Mountains . Dashed line at the base of the terrace scarp is estimated location of the Chishan Fault as a buried reverse fault. Profile a-a' across Terrace I shows eastward back tilting, and possible location of a buried Chishan Fault.

considering the origin of the terrace, which is located east side of the south-flowing

Tzuhsien River. We interpret that this eastward dip represents a back tilting resulted from a buried reverse fault with east-dipping fault plane (part of the Chishan Fault). The height of supposed fault scarp on the western margin of TI is ca. 100 m, but probably smaller than this value, taking the back tilting and down cutting by the river into account. Even so, such a high scarp still suggests repeated activities of faulting. The profile of TII at Tsukeng (location in shown in Fig. 3) is rather horizontal, except for the inner edge, which is covered by talus deposits. Such a nearly horizontal slope of TII may show some effect of back tilting, but it is difficult to confirm because of too much artificial modification. For the lower TIII group, we could not observe the evidence of deformation.

It is certain that this part of the Chishan Fault has activated after the formation of TI, and possibly after that of Terrace II during the late Quaternary. However, since we have no age control for terraces, it is difficult to estimate slip rate and establish progressive deformation.

On the southwestern end of lineament a-a' (Fig. 2), three hills (1,2,3) make a series of cols between these hills and the main part of the Yuehkuang Mountains. It may reflect the location of the Chishan Fault, but no direct evidence of recent deformation is found. Thus, we conclude that this part of lineament a-a' follows the Chishan Fault, but the present morphology is a structural relief, reflecting the non-resistant weak shattered zone on the fault.

The southern margin of Yuehkuang Mountains may be also structurally controlled, with some submerged morphologies. No evidence of active deformation is found (Fig. 2).

II-2. Chishan Fault and Lineaments in the Chungliao Mountains and Lingkou Mountains

There are several subparallel straight lineaments, nearly parallel to the trend of the mountains, in the Chungliao and Lingkou Mountains areas (A-J in Fig.4). Dotted zones A, B and C represent the relatively wide (less than 500 m) summit of the both mountains, where Miocene (is it correct?) sandstone layers are exposed. The top of Chungliao Mountains (the highest point is 421 m at Mt. Chungliao) is a flat summit making a remarkable topographic high, corresponds to the hanging wall of the Chishan Fault, which is represented by lineament G. Similarly, C corresponds to the top of the Lingkou Mountains (maximum height is 261 m at Kaoshiung Mt.). Top of the Lingkou Mountains is prominent, but no fault origin was proposed. It seems that the ridge coincides with the presence of hard sandstone and represents structural relief. A series of short, sharp and NEE-SWW striking ridges (D) are also sandstone ridges, which alternate with straight linear depressions, corresponding to the presence

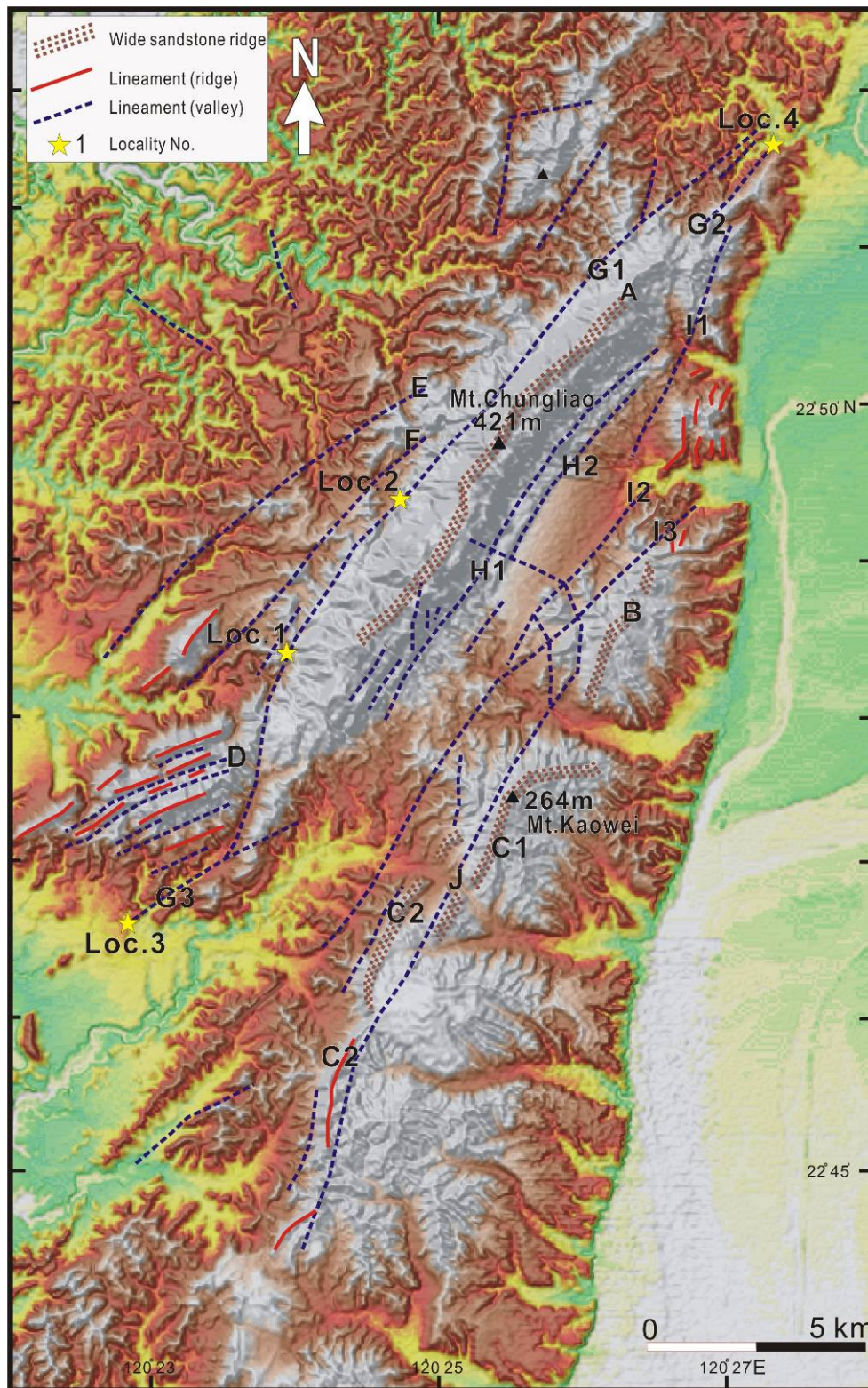


Figure 4. Distribution of lineaments in the Chungliiao and Lingkou Mountains, interpreted from aerial photographs and superimposed on shaded relief map based on DEM. Dotted zones (A-C) are topographical high (corresponding to the presence of sandstone), and solid lines (D) are narrow sandstone ridges. Dashed lines (E-J) are lineaments, expressed as depression or valleys, mostly correspond to the presence of mudstone. G1 coincides with the known trace of the Chishan Fault. Locs.1-4 are fault sites described in the text

of mudstone. Thus, ridges of D group and depression in between are clearly structural relief. The presence of sandstone contributes to the formation of high summit or ridges, although their scale is variable depending on the thickness of sandstone.

In contrast, lineaments E to J (Fig. 4) are valleys or depressions between sandstone ridges. Their length is also variable from ca. 10 km to only 1 km or less. Among them, G1 is the longest, extending with nearly NE to SW direction. It slightly bends however, at both ends. This trace is surprisingly coincident with the known Chishan Fault trace, although we traced this lineament just connecting topographic low based on the aerial photo interpretation. Thus, lineament G1 is certainly a topographic expression of the Chishan Fault.

There are at least two confirmed fault exposures on this lineament G1. A very wide and extensively sheared fault zone cutting bedrock is exposed at Loc.1. Fault appeared in the tunnel at Loc. 2 (Sung et al., 2004). However, the following two fault exposures, discovered by Chen et al. (2005), are not located on this lineament G1. At Loc. 3 on lineament G3, Holocene alluvial deposits of 7189 ± 160 yrs BP is thrust up by early Pleistocene sediments (Chen et al, 2005), indicating the Holocene activity of the Chishan Fault. The upper part of the Holocene deposits with unknown age is not deformed at this locality, however. It is a question if Loc. 3 is actually located on G1, or on G3. If the former is the case, the Chishan Fault trace extremely bends southward and again changes its strike to NE to SW. If the latter is the case, a short lineament G3 is an active portion of the Chishan Fault during the Holocene. As the third case, it is possible that the G1 and G3 join together. We cannot decide which one is the probable interpretation at this stage. Certain thing is that the fault exposure of Loc. 3 is not located on the direct southwestward extension of G1. At Loc. 4 on the northern end of G2. Lingkou conglomerate is faulted, showing Quaternary faulting (Chen et al., 2005). Almost the same problem as Loc. 3 occurs at Loc. 4, where the fault exposure is not located on the main part of G1, but on short lineament of G2.

Lineament G1 exactly coincides with the geologically identified location of the Chishan Fault, but at its both ends, the fault exposures may be located not exactly on lineament G1, but on lineament G2 and G3, slightly away from old fault trace (G1). Then the Chishan Fault may not be a simple and single trace, but is composed of multiple traces, making a fault zone. Also, we cannot identify the deformed terrace or alluvial lowland on the lineaments shown in Fig. 4 as the key for the recent faulting. Because of intensive erosion, the Chishan Fault is expressed as only depression along the shattered zone, without clear morphologic evidence of recent faulting. In this sense, lineament G1 may be still tectonically controlled structural relief. Two lineaments on the northwest of lineament E and F are also just structural relief.

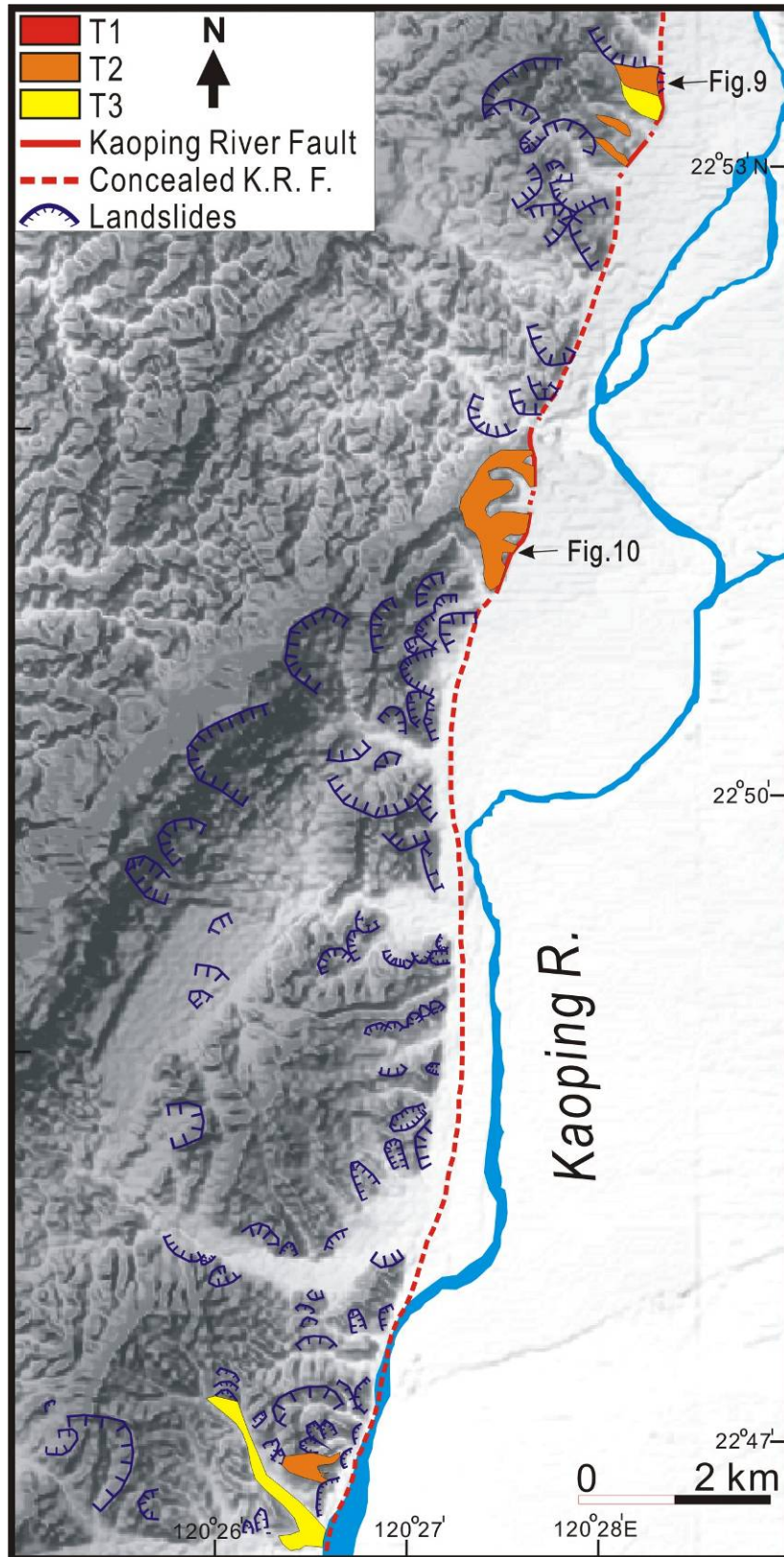


Figure 5. Terrace and fault map on shaded relief map based on DEM in the northern area of west of the Kaoping River. Terrace distribution is limited in this area. Landslide removed terraces on the south of this figure. Flexural scarp is identified in the areas shown in Fig. 9 and 10.

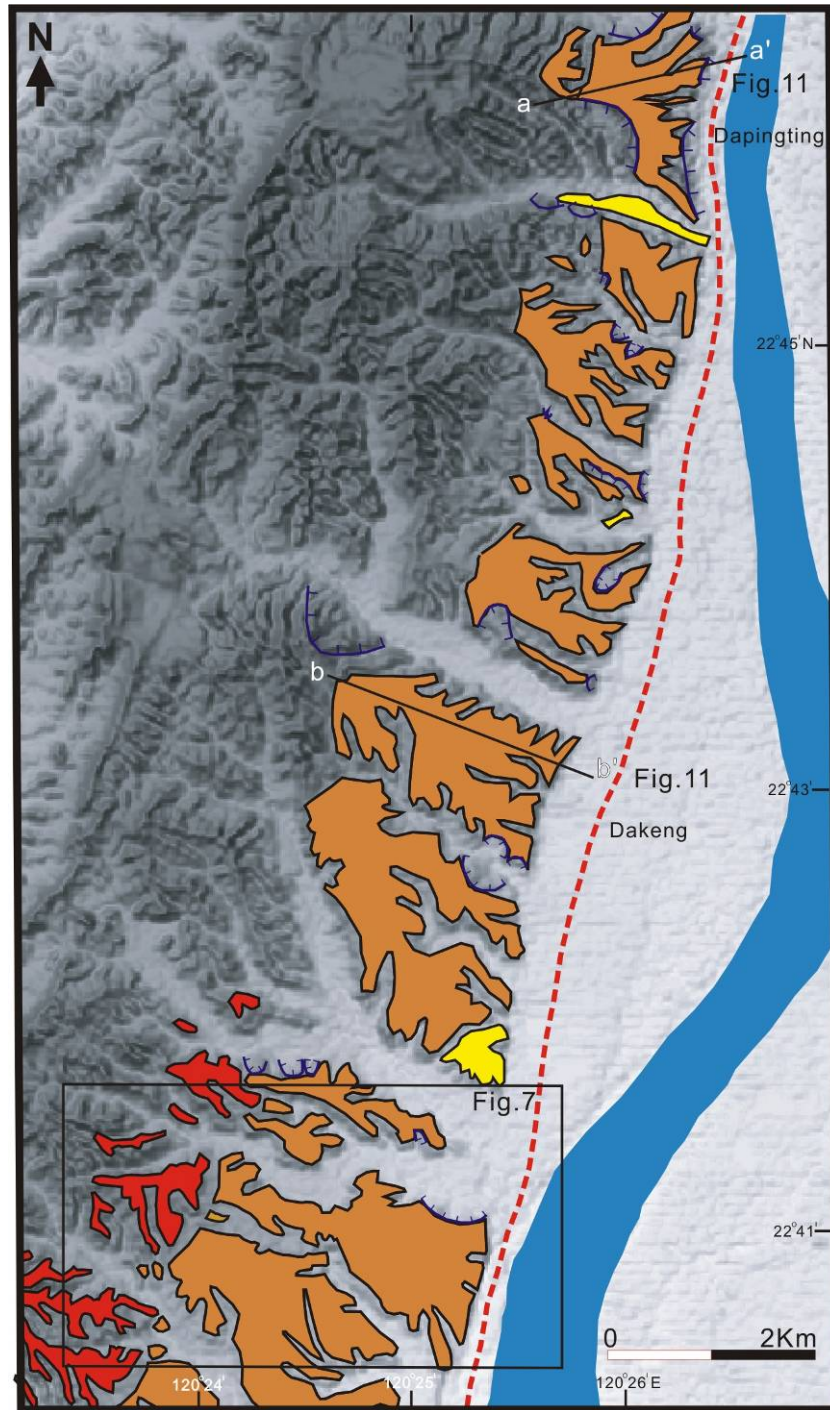


Figure 6. Terrace and fault map on shaded relief map based on DEM in the southern area of west of the Kaoping River. T2 terrace is widely distributed, in addition to the local presence of T1 and T3.

Lineament H1 and H2, east of the sandstone topographic high (A) is ca. 6 km long, and parallel to A. It seems to be also structural relief. Straight lineament I can be divided into three, I1, I2 and I3. They may be also structural origin. But I2 may express tectonic relief because it marks a topographic boundary between mountains to

the east and alluvial lowland to the west. Further detailed fieldworks are required to distinguish tectonic relief and structural one.

III. Terraces and fault on the west bank of the Kaoping River.

Characteristic landforms of the west of the Kaoping River are the presence of three steps of fluvial terraces (T1, T2, and T3 (Figs. 5 and 6), and flexural scarp of the eastern margin of T2 and T3 at northern part (Fig. 5). We describe firstly terrace features and then their deformation.

III-1. Terraces on the west of the Kaoping River

Three steps of fluvial terraces, T1, T2 and T3 in descending order, are present along the west bank of the Kaoping River (Figs 5 and 6). Correlation of these terraces with those on the Yuehkuang Mountains is difficult because of lack of terrace continuity; hence we use different symbols for both areas. N-S trending terrace risers, often parallel to the Kaoping River, suggest that most terraces were formed by the south-flowing Kaoping River. These terraces are not exactly mapped in the previous studies.

T1 is only found at west of Chuliao, southernmost of the study area at about 120 m (inner margin) to 90 m (outer margin) above sea level (Figs. 6 and 7) . Terrace riser, separating from T2, is ca. 20 m high and very clear (profile a-a' in Fig. 7). T1 is underlain by fluvial gravels, composed of subrounded gravels with few matrixes, at least 13 m thick at Loc.5 (Fig. 7). This terrace can be traced northward for 8 km distance, as dissected narrow terrace remnants of 100-120 m above sea level (Figs. 6 and 7).

T2 is the extensive terrace (ca.1 km wide at north and ca. 2.5 km wide at south Figs. 5, 6, and 7) and is developed over 25 km long starting southward from the Chishan Park to the north. Since the inner margin of T2 is N-S trending, parallel to the Kaoping River, terraces, especially T2, could be formed by the Kaoping River. This suggests that there was a relatively stable time to permitting the formation of extensive T2, which is absent in southern part of Fig. 5 due to removal by intensive landslide. Distinction between terrace deposits and underlying Lingkou Conglomerate sometimes is sometimes difficult because of their similarities in facies. Hence the thickness of terrace deposits is often uncertain. One excellent exposure at south of the Chishan Park (Loc. 6 in Fig. 9) reveals that a clear unconformity between the eastward dipping (25°E) **Plistoocene** Lingkou Conglomerate and T2 deposits of ca. 5 m thick (Photo A), mainly composed of subrounded fluvial gravels.

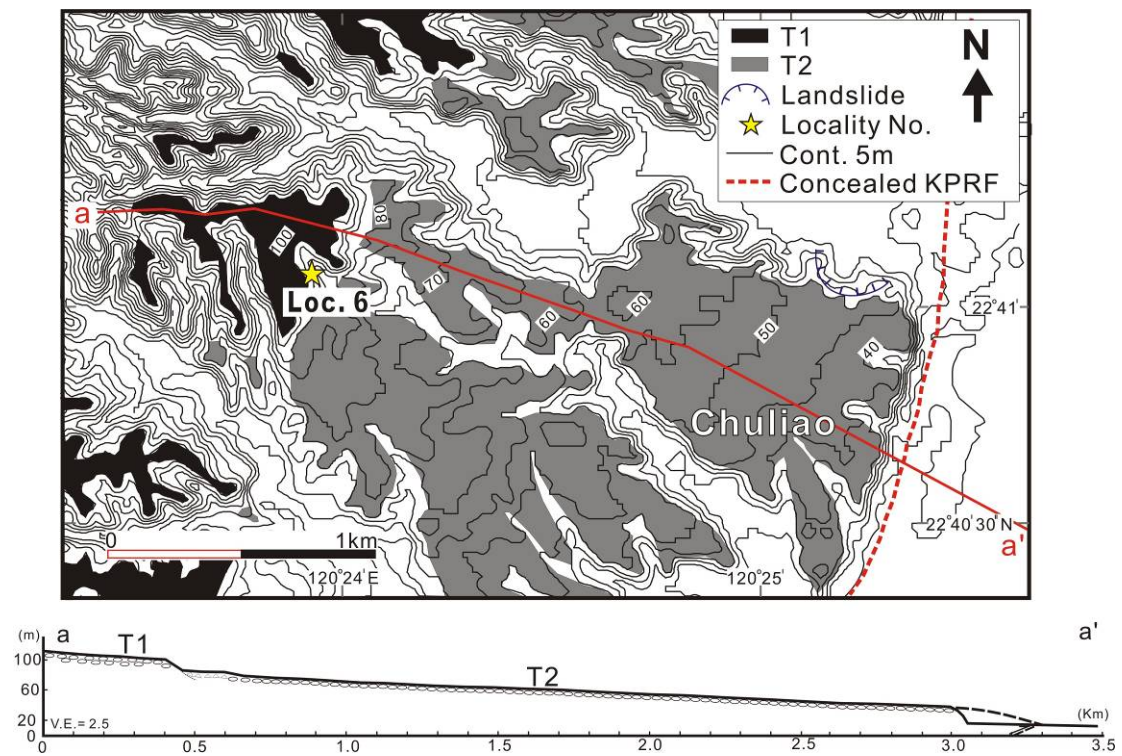


Figure 7. Terrace map of the Chuliao area and profile a-a' across T1 and T2. Eastern margin of T2 is limited by sharply defined erosional cliff, retreated from the original tectonic scarp.

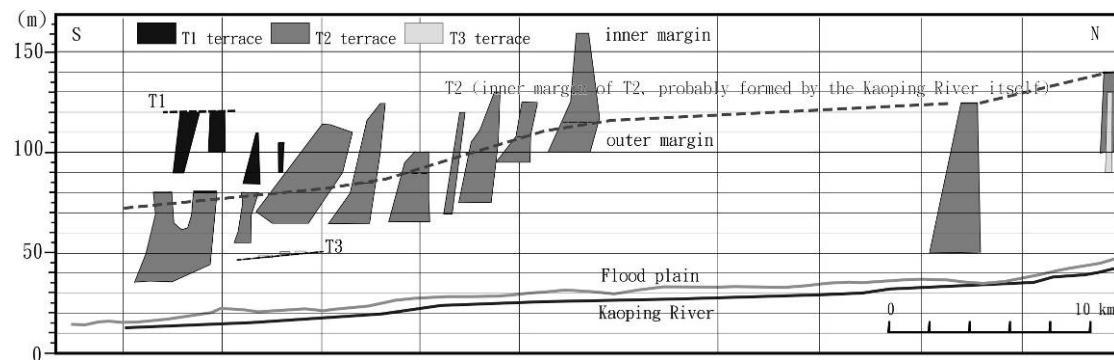


Figure 8. Longitudinal profile of terraces, modern flood plain and the river floor along the Kaoping River, drawn from the photomap of 1:5,000 in scale. Remarkable difference between the inner margin height and outer margin height of T2 is caused by flexural deformation on the north, and by presence of secondary deposits on the south.

The longitudinal height distribution of terraces is shown in Fig. 8. The inner margin of T2 ranges from 140 m at Chishan Park (Fig. 9) and 125 m at Shangcholi (Fig. 10), where the inner margin of T2 is sharply defined. Considerable height difference between the outer and inner margin at these two locations are due to strong eastward deformation of T2, as will be discussed in III-2. In the southern area, the inner margin height is higher than the upper stream, reaching 160 m at maximum, which is significantly higher than the height of Shangcholi, located further upstream. In addition, the inner margin height is rather irregular, and T2 surface dips eastwards considerably, although its outer margin is limited by clear terrace riser from the alluvial lowland. These features suggest that the inner part of original T2 terrace surface, originally created by the Kaoping River, is covered by alluvial fan deposits of various scales, transported by eastward flowing tributaries. A dashed line shown in Fig. 8 is a possible boundary between the original terrace surface and secondary covered fan surface, judging from the different gradient of terrace surfaces and ranges from ca. 115 m to 60 m. The southward gradient of T2, represented by a dashed line, is 40 m/22 km, and larger than 15 m/22 km for the alluvial lowland (Fig. 8).

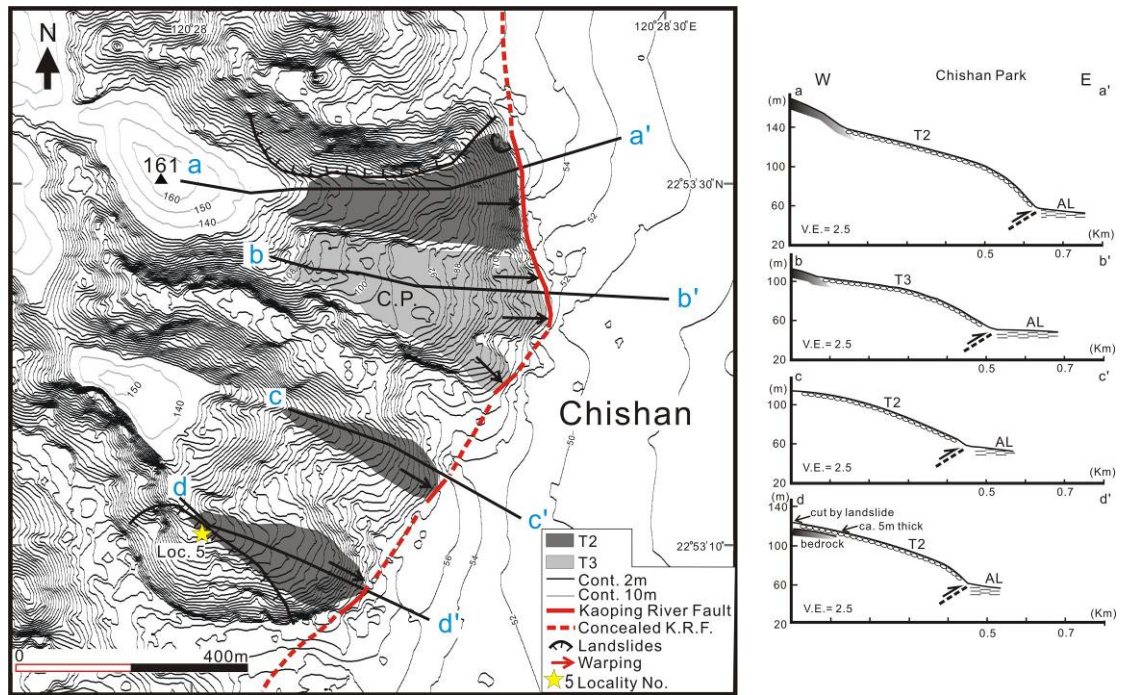


Figure 9. Detailed contour map of fluvial terraces and their deformation in the Chishan Park area (drown by 20 m grid DEM). Contour map and profiles represent the remarkable eastward warping scarp deforming T2 and T3. Smooth and convex profiles on the eastern margin is very distinctive. A buried fault (Kaoping River Fault) is estimated very close to the base of flexural scarp. b-b' profile is for T3, younger terrace than T2. Notice that the apparent amount of vertical offset of T3 is smaller than T2, suggesting progressive deformation.

Terraces lower than T2 are collectively called as T3 (group) and are fragmentary preserved at several sites (Figs. 5 and 6). One is at the Chishan Park, where a small T3 with ca.10 m lower height than T2 (Fig. 9) at its inner margin is present along the small east flowing stream, clearly indicating tributary origin. The other is in the southern part of near Chuliao, where relatively wide T3 is present at ca. 50 m in height, separated by ca. 30 m high terrace riser (Fig. 6). The correlation within T3 group is uncertain.

We have no age control from these terraces, underlain by fluvial gravel without prominent sand or clay lense for dating. It is also difficult to find out a direct relationship between the terrace formation and sea level changes, because the terraces of the study area do not continue to any of marine terraces. However, since this area is not so far from the coast (Fig. 1), it may possible to assume some of terraces correlate with sea level change. We tentatively assume that the most extensive and relatively well preserved T2 terrace as a possible correlative with high sea level of MIS 5e, judging from the following reasons: First, it is unlikely to say that T2 can continue to the lowest sea level of MIS 2, morphology of which should be very much steeper than the alluvial lowland and should be found beneath the Holocene alluvial deposits, although the longitudinal profile of T2 is steeper than the modern flood plain or present river floor. Secondly, the formation of an extensive terrace requires some stable time as mentioned before, Then thirdly, the high sea level of MIS 5e usually leave its morphological trace as a prominent and well preserved marine terraces with presence of younger marine terraces, corresponding to MIS 5c or 5a when the uplift rate is high enough to emerge these terraces on land. Thus, as the first approximation, we assume that T2 possibly represent MIS 5e of ca. 125 ka, although we know that the degree of preservation of the terrace of this stage, is very much changeable depending on the original scale and nature of deposits in addition to the height etc. If the above mentioned correlation is the case, higher T1 can be correlated with MIS 7. In any case, the estimation of formation age of terraces is very tentative, leaving important problems to be solved, supported by dating. Although we are uncertain about the age of terrace, it is quite obvious that T2 is clearly tectonically deformed and provides a positive evidence as the active fault for the Kaoping River Fault.

III-2. Identification of the active Kaoping River Fault

A straight scarp that limits the eastern (outer) margin of T2, and strikes nearly N-S direction, is very distinctive (Figs. 4, 5, and 6). This scarp starts from the Chishan Park at north and continues southward to the west of Pingtung and is ca. 30 km long. Scarp profile is divided into two types.

Flexural scarp: The first type is typically seen at the Chishan Park (Fig. 9) and

Shangchouli (Fig. 10), and is characterized by the smooth and convex profile without any clear knick point between the terrace surface and scarp (profiles in Figs. 9 and 10), photo. 2). Tilted gravel bed parallel to the scarp shows that the scarp is not erosional origin but former terrace surface and represents flexural or warping scarp, created by deformation on the hanging wall of subsurface fault. We consider that this fault is a reverse fault with east facing scarp and with westward dipping fault plane, probably high angle, judging from scarp profile and rather straight trace in the northern part. We use the name of Kaoping River Fault after Shyu et al.(2005) for this fault. We did not find positive evidence to prove the left-lateral offset, proposed by Shyu et al. (2005) from our field observation. Flexural scarp of this pattern is often recognized on the reverse fault in Taiwan (e.g. Chen et al., 2003; Chang et al., 2004; Ota et al., 2004; Lai et al., 2006 for the Chulungpu Fault and Ota et al., 2005 for Tunglo Fault). We assume that the base of the scarp represents the location of the fault, although the base is partly buried by Holocene deposits and no fault exposure was found yet. We examined some lineaments found on the alluvial lowland by the photo interpretation, but no evidence of Holocene activity was found in the field.

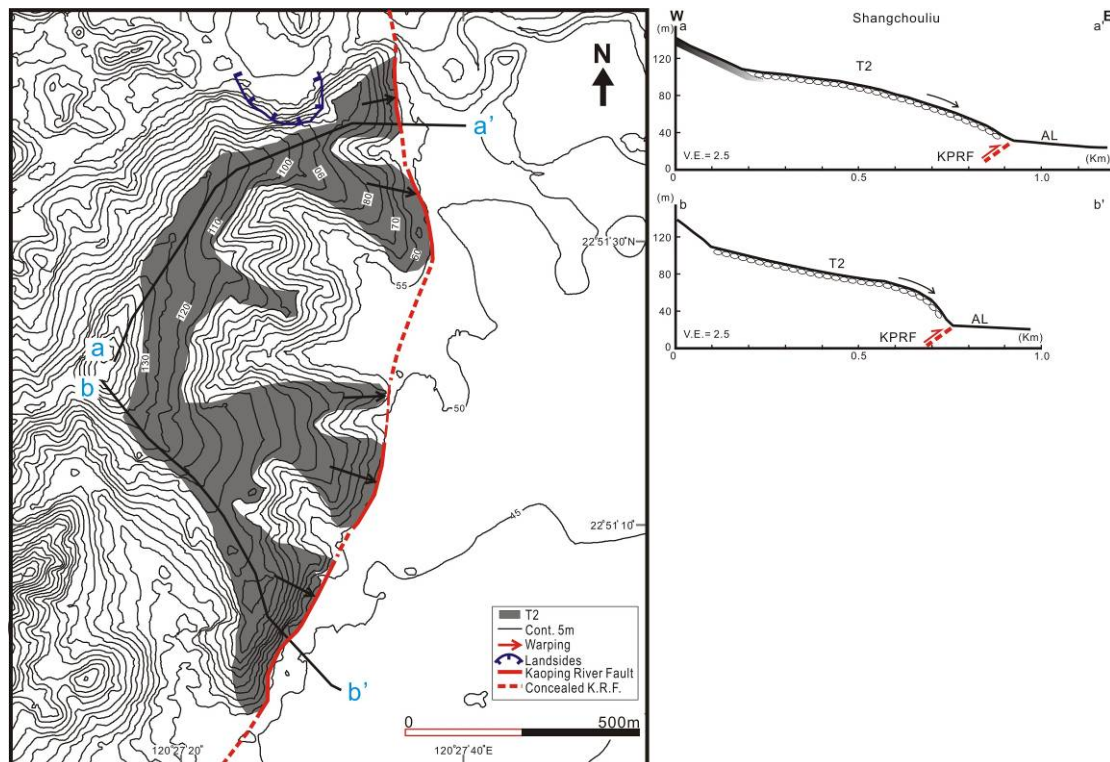


Figure 10. Detailed contour map of fluvial terraces and their deformation in the Shangchouli area (drawn by 20 m grid DEM) and flexural scarp deforming T2. Two profiles across T2 on the Shangchouli area also clearly show the eastward convex scarp by a buried Kaoping River fault.

The amount of vertical displacement is unable to be exactly determined, because of very gradual change from the original slope to deformed flexural scarp. The possible minimum amount of vertical offset of T2 ranges from 50 to 60 m (profiles a-a' to d-d' of Fig. 9, and profile a-a' , b-b' in Fig.10). At the Chishan Park, even a local T3 is also deformed, but the amount of vertical offset is about 30 m (profile b-b' of Fig. 7B), smaller than that of T2, and indicates a progressive deformation since T2 formation.

Erosional scarp modified from flexural scarp: Intensive down cutting and land-sliding in the mudstone area completely removed terrace remnants for 8 km between Shangchouli and Dapingting (Fig. 5), thus here we cannot identify the tectonic scarp. Southward from Dapingting again T2 is extensively preserved, but scarp morphology is different from Chishan Park and Shangchouli area. There is a sharp knick point between terrace surface and terrace riser, as illustrated in the profile shown in Fig. 11. This is the second type of the scarp, and we interpret that this steep scarp was originally formed as a flexural scarp same as those in the northern area, but now is modified by fluvial erosion of the Kaoping River, because this river flows just base of the cliff. Fig. 12A and B illustrates how profiles are different between the northern part (tectonic scarp) and the southern part (erosional scarp, modifying original tectonic scarp) and how they were formed. Such different profiles as a composite result of tectonic and erosional processes are typically preserved in Sado Island, Japan (Ota et al., 1992; Fig. 12C and D). In this study area, the flexural scarp is completely removed, thus we might have difficulty to assume the presence of initial tectonic scarp, unless the preserved flexural scarp at the Chishan Park and Shanchouli. In the case of Sado Island, main flexural scarp with secondary range-facing scarp is well preserved in the Kuninaka plain (Fig. 12 C). In contrast, the major tectonic scarp is eroded out by marine erosion on the open coast, however, still the preserved range-facing scarp indicates that the present sharp cliff is modified from the initial tectonic scarp (Fig.12 D). This gives us a good analogy of the interpretation for two types of scarp along the Kaoping River. Difference between A, B (Kaoping River fault) and C,D (Sado Island) can be explained by the different fault dip. In the case of Sado Island (C, D), range-facing scarplet and associated tectonic bulge on the hanging wall, as well as the flexural scarp by the main thrust, are characteristic, indicating low angle fault dip. In the case of Kaoping River Fault (A, B), the fault dip is rather high angle to create a characteristic range-facing scarp. An information for subsurface structure is necessary for further interpretation. The original position of the fault is uncertain in the case of the erosional scarp, however, but it is not so far from the present scarp, if extending the base of flexural scarp on the northern part southward. Estimated length of the Kaoping River Fault is ca.30 km.

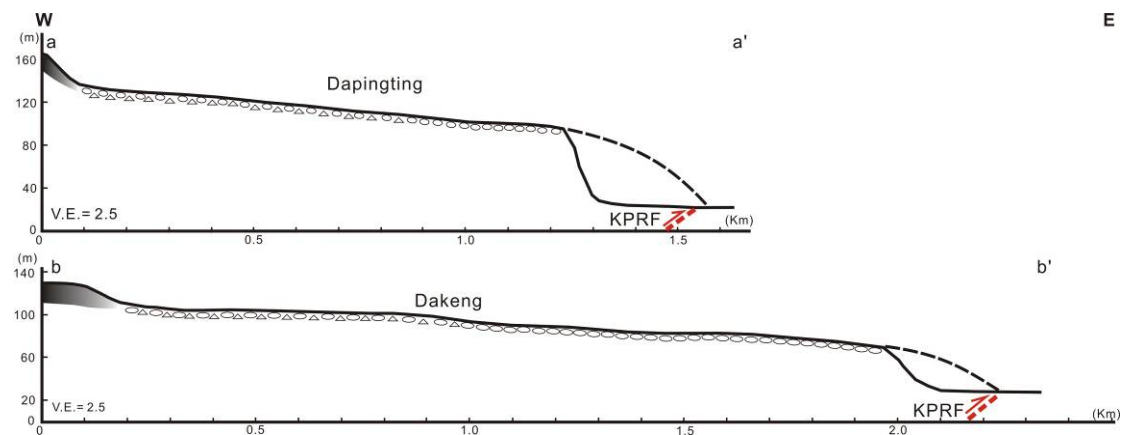


Figure 11. Profiles across T2 show erosional scarp on the eastern margin of T2. a-a' is for Dapingting area and b-b' is for Dakeng area (See Fig. 6 for the location). The outer margin of terrace is sharply limited by steep scarp. The location of supposed buried scarp seems to be apart from the base of the scarp.

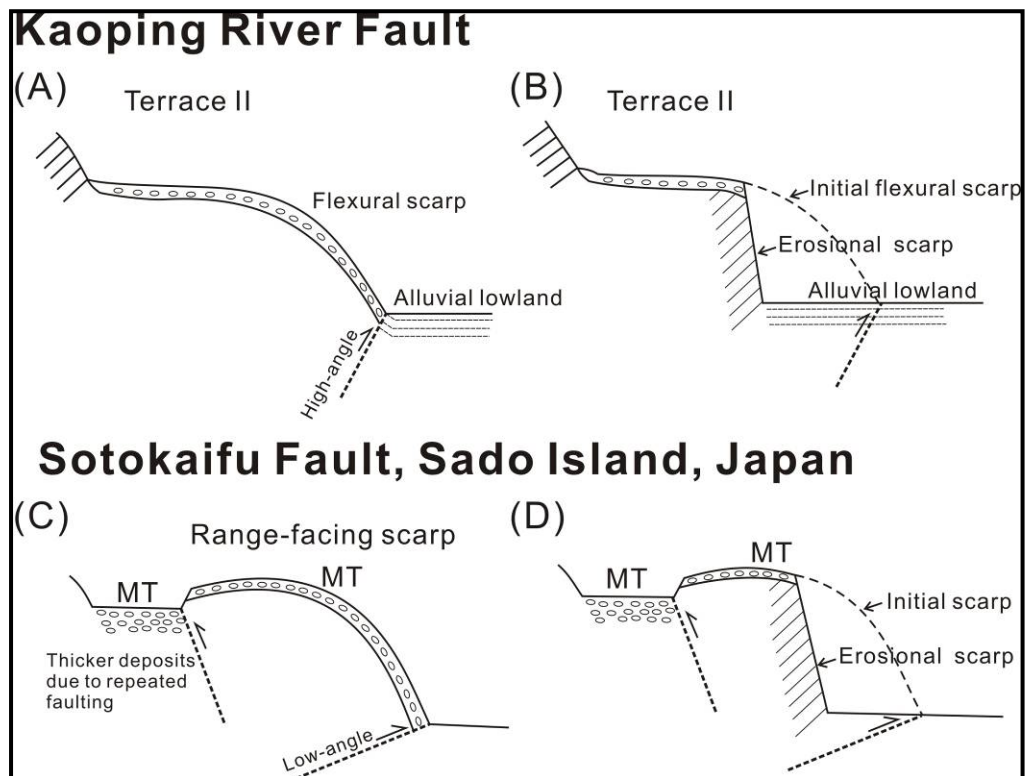


Figure 12. Schematic profiles of warping scarp (A) and erosional scarp (B) modified from initial warping scarp by the Kaoping River Fault. Compare with similar example from Japanese reverse fault shown in C and D (after Ota et al., 1992).

It is difficult to estimate slip rate of Kaoping River Fault, firstly because of uncertainty of terrace age, and secondly due to uncertainty of actual amount of vertical offset. On the hanging wall, the inner edge of T2 may be higher than the original terrace height by covering of alluvial fan deposits, and alluvial deposits bury the initial correlative surface on the foot wall. In addition dip angle of fault plane is unknown. Adopting our tentative correlation of T2 with MIS 5e, and several tens of meter for the vertical separation, the slip rate may be an order of 0.5+- m /ka for Kaoping River Fault, and its activity has been repeated.

IV. Discussions on the nature and significance of the Chishan Fault and Kaoping River Fault

IV-1. Nature of the Chishan Fault and distinction of active trace and structural relief

The strike of the Chungliao Mountains and Yuehkuang Mountains is controlled by the Chishan Fault and related geologic structure mainly through lithological control. Geomorphic evidences as an active fault of the Chishan Fault is newly found from back-tilting of fluvial terrace at western foot of the Yuehkuang Mountains (Fig. 3). Two shattered zones are located on most continuous lineament G1, but fault exposures cutting the young sediments (Chen et al., 2005) are located on short lineaments, G2 and G3. Thus, some portions of the Chishan Fault are certainly active fault. However, we must consider that even in these locations, the fault trace is appeared as simple lineament without positive evidence for morphological deformation.

The fact that the upper part of the Holocene deposits at Loc. 3 is unfaulted may be one reason why we cannot see the morphological expression such as fault scarplet. This also suggests that the recurrence interval is rather long, more than several thousand years. In any case, the preservation of deformed morphology is surprisingly poor in the mudstone areas. Thus we may miss to trace some of active faults in other very erodible mudstone areas. It is difficult to identify tectonic deformation on other lineaments, and probably most of the lineaments, parallel to the main part of the Chishan Fault (G1) can be structural relief reflecting different lithology of bedrock, which is related to geologic structure defined by the Chishan Fault, but lineament I-2 may be active trace, because it makes some morphological boundary. One of unsolved problems is if the above-mentioned fault exposures are located on the single trace G1 with curving, or other short lineament G2 or G3. A trace of G1, except the southern margin and northern margin, is very straight, and suggests the Chishan Fault is a high angle reverse fault.

Shyu et al (2005) mapped an echelon arrangement of several segments of the Chesham Fault, each of which is associated with right-lateral offset. Field evidence was not available to confirm the strike-slip mentioned by Shyu et al (2005) and GPS measurement by Hu et al. (2007) from our observation, however.

In the Lingkou Mountains, lineaments are few except for major lineament I and J group, because most of the mountains is underlain by Lingkou Conglomerate and lacks the distinctive alternation of sandstone and mudstone. Instead, landslides are densely developed especially on the eastern margin of the mountains or terraces.

IV-2. Activity of the Kaoping River Fault

We provided the positive evidence to prove that the north-south striking Kaoping River Fault is an active reverse fault with upthrown side is west and with west-dipping fault plane. Shyu et al. (2005) inferred that the left-lateral component for the Kaoping River Fault, judging from apparent offset of mountains on both sides of the Kaoping River. GPS measurement also supports this deformation (Hu et al., 2007). We agree with this arrangement of the mountains. However, the Chishan Fault does not necessarily continue straightly. Apparent left lateral slip can be created by shortening of the crust due to reverse fault. No morphologic expression showing left-lateral offset is available from our observation so far. We would like to emphasize that the Kaoping River Fault is a reverse fault, which has been activated repeatedly at least during the late Quaternary under E-W compression.

It is difficult to establish the slip rate of the Kaoping River Fault, however, because of several reasons described before. Possible vertical slip rate is an order of several tens cm/ka. The length of the confirmed active trace is only about 5 km, but total length including the southern part, where the original tectonic scarp is removed by erosion, will be more than 30 km. This is long enough to be a seismogenic fault, which is capable to cause large earthquakes of magnitude 7 (Shyu et al., 2005).

IV-3. Relation between the Chishan Fault and the Kaoping River Fault

We have shown that the Chishan Fault and Kaoping River Fault are active faults. Fig. 13 illustrates the three dimensional picture showing both faults. Two confronting major faults striking north-south have contributed to the formation of tectonic basin of the Pingtung Plain. The oldest terrace, deformed by the Kaoping River Fault, is T2, with possible age of ca.125, 000 years old, and this fault truncates the Chishan Fault which has geologically longer history than the Kaoping River Fault. We can assume that the Kaoping River Fault with west-dipping plane can be branched from preexisted Chishan Fault with east-dipping fault plane. When the Chishan Fault has started the activity after Miocene, stress field might be different from the present-day

E-W compressive stress field, in which present activity of both faults accommodated (Hu et al., (2007)). Further work is required to interpret the relation between these two active faults.

Better preservation of tectonic morphology on the Kaoping River Fault is originated from that this fault deforms T2 underlain by sand and gravel beds, in addition to its supposed younger origin. In contrast, most of actual fault trace of the Chishan Fault is expressed as a lineament, connecting depression or streams on the shattered zone of the Chishan Fault, even it dislocates younger deposits. Instead, high standing sandstone ridge on the hanging wall and alternation of sandstone ridge and lineament in between is characteristic morphology of the study area. We consider that structural relief, originally derived from geologic structure and followed by the differential erosion is unique morphology in the Chungliao Mountains area. We must recognize that it is difficult to trace the geomorphic evidence for active fault in the mudstone area where intensive erosion is taken place.

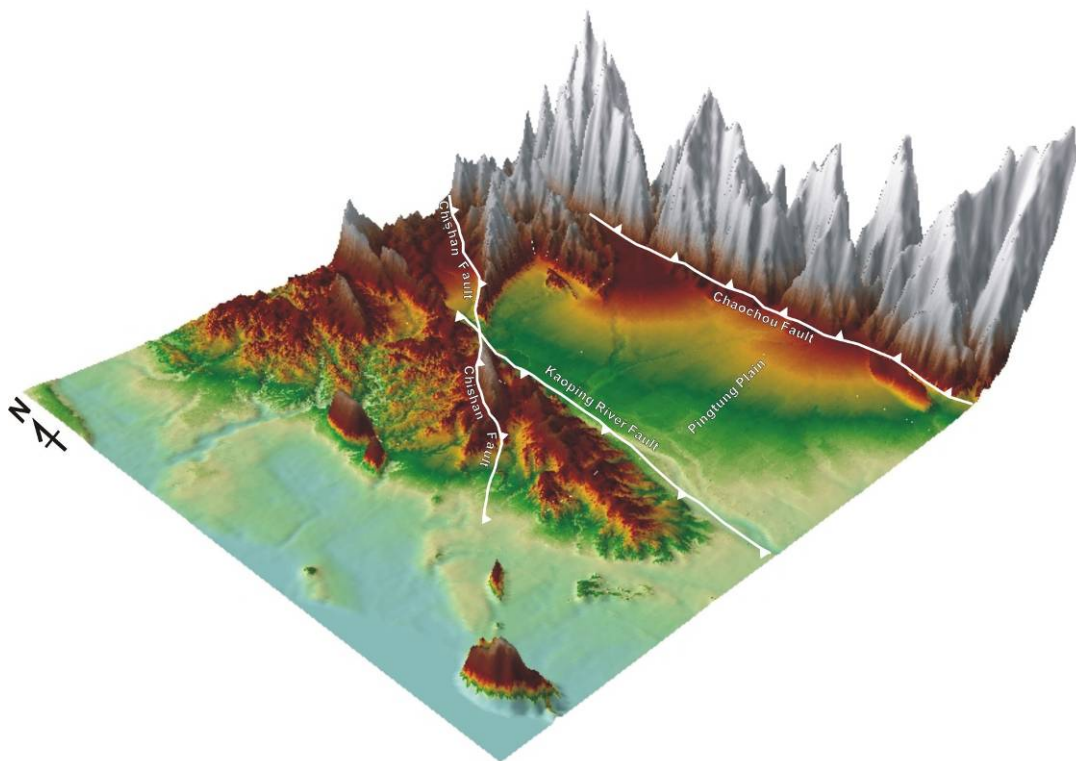


Figure 13. Three dimensional diagrams showing major active faults in the Pingtung Plain and Chungliao Mountains area.

V. Conclusions

1) We have mapped two active faults, the Chishan Fault, striking NNE-SSW and the Kaoping River Fault with N-S trend in the southern Taiwan. Both faults are reverse faults, probably with high angle fault plane. Newly found geomorphic evidence for the identification as an active fault is the back-tilting of the terrace (lineament a-a') for the Chishan Fault and east facing flexural scarps limiting the eastern boundary of T2 and T3 for Kaoping River Fault. No evidence for the strike-slip component for both faults is observed.

2) The Chishan fault, created in Miocene time, has longer history than the Kaoping River Fault. Since the present study area is under the E-W compression, N-S trending Kaoping River Fault, which has activated during the last ca. 100,000 years has a better geomorphic expression as prominent east facing flexural scarp.

3) Both faults are probably seismogenetic faults, but the exact amount of offset and slip rate during the late Quaternary are not determined.

4) The Chishan Fault may have multiple traces. Morphologic expression of the Chishan Fault, oblique to the present shortening direction, is often rather poor, just expressed as lineament following the shattered zone. High-standing sandstone ridge of the Chungliao Mountains and several lineaments along the Chishan Fault are structural relief following the geologic structure related to the Chishan Fault. Understanding structural relief and its distinction from the actual tectonic relief is one of the important problems in the area where presence of soft mudstone or alternation of sandstone and shale is predominated

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國科會補助出席國際會議報告

會議中文名稱：美國地球物理聯合會2007秋季年會

會議英文名稱：American Geophysical Union (AGU) 2007 Fall Meeting

會議舉辦時間：2007/12/10~2007/12/14

會議舉行地點：Moscone Center, San Francisco, California, U. S. A.

一、參加會議經過

本次會議共計發表論文海報共四篇，並於前一晚(12/09)深夜即抵達位於開會地點附近的住宿旅館。

此次 AGU 2007 秋季年會排定五天的議程，包括 24 個領域，每個領域底下再區分不同的主題。除了會議議程五天內上、下午的海報論文發表，由於各個領域的議程再五天的會議中均有，因此主要參與每天 Tectonophysics 與 Seismology 這兩個領域底下的主題，再加上其他領域與本人研究有關的主題。

二、與會心得

每年美國地球物理聯合會的秋季年會(AGU Fall Meeting)是地質學界的一大盛事，主要發表海報論文。與去年相比，此次會議的規模又更形擴大，Moscone Center 的空間已嫌不足，部分議程與相關活動移至鄰近的其他場所舉行。

來到這裡以後，發現地質學界的變化也一日千里，以往模糊的影像與粗略的圖片，現在不僅解析度提高許多，甚至可直接提供 3D 的影像，讓觀眾更能了解作者想表達的內容，而地質學研究的範疇也已從上天下海，進而進入外太空研究其他的行星(ex:火星)。另外，此次由一些觀眾特別踴躍的議程可以了解，現今的地質學已不是解析出某地質事件就足夠，現在的研究必須把地質學中不同領域結合起來做出綜合的結果，甚至做出整個動態改變的過程與模型。所謂坎井之蛙，不知江海之大；參與國際大型會議以及與眾人討論，是了解世界最新發展所必須的，如此才能擠身國際競爭的行列。

本人在此次年會中主要是擔任主持人，從世界各的優秀學者所發表的演說中，更可看出地球科學學門的日新月異，以及各國間的激烈競爭，因此我國乃有必要更進一步加強在地球科學上的研究以及教學，始得跟得上國際腳步。

三、攜回資料名稱及內容

- AGU 2007 Fall Meeting Programs
- AGU 2007 Fall Meeting Abstracts光碟
- 部份與會人士發表之相關資料

四、其他

此次會議時間由於鄰近美國耶誕假期，舊金山至台北直飛班機機票均已售罄，因此取道洛杉磯轉機，增加了不少飛行時間。

附錄：發表論文摘要(共計四篇)

Ground Displacements and Fault-plane Geometry beneath: a case of 1999 Chi-Chi Earthquake (Mw 7.6) at Tsaotun in Central Taiwan

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Abstract

Long-term ground deformation recorded in deformed geomorphic surfaces is supposed to be the cumulative strain produced by associated active structure and certainly related to the subsurface structure geometry. Moreover, by time domain the deformation also can be divided into components: co-, post-, and inter-seismic. A case that may demonstrate the entire process is at Tsaotun in central Taiwan, where widely developed geomorphic surfaces have long been noticed and surface ruptures of 1999 Taiwan Chi-Chi earthquake (Mw 7.6) ran through. Landform investigation, geodetic work, sub-pixel comparison of aerial photos, and D-InSAR analysis are conducted to reconstruct the entire deformation process mentioned above.

In our previous study, we have used sub-pixel correlation on high-resolution aerial photographs to obtain detailed horizontal displacement across the surface ruptures, which has revealed that the fault bends beneath greater and more rapid in the southern segment. Nevertheless, the coseismic ground displacement cannot entirely match the long-term surface deformation recorded in the geomorphic surfaces. However, by the post-seismic ground displacements obtained from InSAR a few other

active structures, such as secondary strike-slip faults, may play a role to accommodate the tentative stress accumulation in a large earthquake.

By available co- and post-seismic ground displacements, we successfully rebuild a fault-plane model at Tsaotun. Using this model we can satisfactorily explain the surface deformation in different time domain. The model also describe the details of when, where, and how much the rate of the ground displacements would occur. Our result is undoubtedly valuable to improve the building code and to assist urbanization plan for the purpose of seismic hazard mitigation.

Give a scientific purpose in the title] Interseismic modeling in the Taiwan region

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The island of Taiwan lies at the junction of the Eurasian and Philippine Sea plates. The convergence between two plates forms the Longitudinal Valley, which has been long regarded as one of the major collisional suture zones, to the east and a fault-and-thrust belt to the west across the island. Based on recent published geological map and relevant studies, several major active faults are currently acting in Taiwan.

In eastern Taiwan, the Longitudinal Valley fault, the most dominant fault within the suture zone, is locked at the northern section and is creeping at shallow depth but locked at deeper part in the southern section. In western Taiwan, active faults imbricate and propagate to the west above a major Taiwan detachment at

depth. Based on ?, most of the active thrust faults and tear faults in western Taiwan are locked. The locking and creeping of the active faults around Taiwan as well as the locking of the subduction zones along the Ryukyu and Manila Trenches constrain the interseismic deformation across the Taiwan region and accumulate strain which may be released during future earthquakes.

In order to characterize interseismic deformation around Taiwan region, we analyze GPS data from 1990-1997 by what?. This time span excludes the effects of large earthquakes in the century, especially the Chi-Chi earthquake. For better understanding interseismic coupling and fault slip, we construct a three-dimensional block model across the Taiwan region to quantify kinematically consistent estimates of block motions and fault slip rates. The model combined elastic half-space and block motions based on the backslip model to describe the GPS velocities and locking faults. The GPS constrained block model provides estimates of present-day fault slip rates and seismic potential within the entire Taiwan region.

Implications of river morphology response to Dien Bien Phu fault in NW Vietnam

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Abstract

In northern Vietnam, most rivers are flowing southeastward sub- or parallel to the valley of Red River and characterized by long but narrow catchments. The Dien Bien Phu fault is associated with the most seismically active zone in Vietnam and situated in the potential eastern boundary of the rotating southeastern Tibetan block. It cuts the Da River, the largest tributary of Red River in northwest Vietnam and has distorted the drainage basin resulting in complex river patterns. To assess the river morphology response to active Dien Bien Phu fault, we use 1/50,000 topographic data and ASTER images to map the precise river courses and digital elevation model data of SRTM to retrieve and analyze the river profiles. From the mapping results, the N-S striking fault results in three conspicuous north-trending river valleys coincided

with the different fault segments to facilitate the measurement and reconstruction of the offsets along the fault. Further combining the longitudinal profile analysis we obtain ca. 10 km offsets by deflected river as the largest left-lateral displacement recorded along the active fault. The restored results show the downstream paleochannel of the Da River had been abandoned and becomes two small tributaries in opposite flow directions at present due to differential crustal uplift. Also the present crisscross valley at the junction of the Da River and the fault is resulted from the capture by another river which has been also deflected by the neotectonics. Based on our observations on river response, the Dien Bien Phu fault is a sinistral dominant fault with an uplift occurring in its eastern block. Furthermore the active Dien Bien Phu fault does not cut through the Red River northward indicating the western block of the fault can not be regarded as a single rigid block. There should be possible to find NW-SE trending faults paralleling to Red River to accommodate the deformation of the western block of the fault.

The implication of elevated lacustrine sediments in the middle reach of the Yarlung-Tsangpo and Nyang River, Tibet

Shao-Yi Huang¹, Yu-Nung Lin¹, Jingwei Liu², Yue-Gau Chen¹, Ling-Ho Chung¹, Kuang-Yin Lai¹, Ray Y. Chuang¹, Shujun Zhao², Gongming Yin² and Zhongquan Cao³

1. Department of Geosciences, National Taiwan University
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3. Seismological Bureau of Tibet Autonomous Region

The interaction mechanisms among climate, crustal uplift and related erosion processes in the orogenic belt became one of the popular topics in the past decade, especially in the collisional margin of Eurasian Plate and Indian Plate where stands the most spectacular plateau in the world in terms of elevation and geomorphology. We investigated the outcrops of lacustrine deposits in the lower terraces of the Nyang River and established the stratigraphic column for entire depositional sequence. Woods and charcoals were collected for radiocarbon dating and sands for optical stimulated luminescence (OSL). Based on our observation, the alluvial and lacustrine environments occurred alternatively. Among them two well developed varve layers were identified in the sequence.

The occurrence of varve strata and moraine-related delta facies have raised subsequent questions such as did the breakout of the dammed lake strike this drainage repeatedly? What is the mechanism of the dammed lakes, were the paleolakes dammed by monsoon driven valley glacier or tectonic structures? And, the timing of the paleolakes will be crucial as well.

Based on the preliminary radiocarbon and OSL dates from the bottom and the top of the depositional succession, the paleolakes took place no younger than 20ka. The interbedded sand and silt recorded abundant ripple cross beds, parallel lamination, and syndepositional deformation, representing the transition of environments from delta front to beach ridges of the frontal floodplain. Two sections of varve layers indicate two gradational stages of the delta. This coarsening-upwards sequence recorded details of episodic changes of depositional environment from delta front to floodplain and the evolution of this moraine-related delta.

國科會補助出席國際會議報告

會議中文名稱：美國地球物理聯合會2007秋季年會

會議英文名稱：American Geophysical Union (AGU) 2007 Fall Meeting

會議舉辦時間：2007/12/10~2007/12/14

會議舉行地點：Moscone Center, San Francisco, California, U. S. A.

一、參加會議經過

本次會議共計發表論文海報共四篇，並於前一晚(12/09)深夜即抵達位於開會地點附近的住宿旅館。

此次 AGU 2007 秋季年會排定五天的議程，包括 24 個領域，每個領域底下再區分不同的主題。除了會議議程五天內上、下午的海報論文發表，由於各個領域的議程再五天的會議中均有，因此主要參與每天 Tectonophysics 與 Seismology 這兩個領域底下的主題，再加上其他領域與本人研究有關的主題。

二、與會心得

每年美國地球物理聯合會的秋季年會(AGU Fall Meeting)是地質學界的一大盛事，主要發表海報論文。與去年相比，此次會議的規模又更形擴大，Moscone Center 的空間已嫌不足，部分議程與相關活動移至鄰近的其他場所舉行。

來到這裡以後，發現地質學界的變化也一日千里，以往模糊的影像與粗略的圖片，現在不僅解析度提高許多，甚至可直接提供 3D 的影像，讓觀眾更能了解作者想表達的內容，而地質學研究的範疇也已從上天下海，進而進入外太空研究其他的行星(ex:火星)。另外，此次由一些觀眾特別踴躍的議程可以了解，現今的地質學已不是解析出某地質事件就足夠，現在的研究必須把地質學中不同領域結合起來做出綜合的結果，甚至做出整個動態改變的過程與模型。所謂坎井之蛙，不知江海之大；參與國際大型會議以及與眾人討論，是了解世界最新發展所必須的，如此才能擠身國際競爭的行列。

本人在此次年會中主要是擔任主持人，從世界各的優秀學者所發表的演說中，更可看出地球科學學門的日新月異，以及各國間的激烈競爭，因此我國乃有必要更進一步加強在地球科學上的研究以及教學，始得跟得上國際腳步。

三、攜回資料名稱及內容

- AGU 2007 Fall Meeting Programs
- AGU 2007 Fall Meeting Abstracts光碟
- 部份與會人士發表之相關資料

四、其他

此次會議時間由於鄰近美國耶誕假期，舊金山至台北直飛班機機票均已售罄，因此取道洛杉磯轉機，增加了不少飛行時間。

附錄：發表論文摘要(共計四篇)

Ground Displacements and Fault-plane Geometry beneath: a case of 1999 Chi-Chi Earthquake (Mw 7.6) at Tsaotun in Central Taiwan

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² Division of Geological and Planetary Sciences, Caltech, California, U.S.A.

Abstract

Long-term ground deformation recorded in deformed geomorphic surfaces is supposed to be the cumulative strain produced by associated active structure and certainly related to the subsurface structure geometry. Moreover, by time domain the deformation also can be divided into components: co-, post-, and inter-seismic. A case that may demonstrate the entire process is at Tsaotun in central Taiwan, where widely developed geomorphic surfaces have long been noticed and surface ruptures of 1999 Taiwan Chi-Chi earthquake (Mw 7.6) ran through. Landform investigation, geodetic work, sub-pixel comparison of aerial photos, and D-InSAR analysis are conducted to reconstruct the entire deformation process mentioned above.

In our previous study, we have used sub-pixel correlation on high-resolution aerial photographs to obtain detailed horizontal displacement across the surface ruptures, which has revealed that the fault bends beneath greater and more rapid in the southern segment. Nevertheless, the coseismic ground displacement cannot entirely match the long-term surface deformation recorded in the geomorphic surfaces. However, by the post-seismic ground displacements obtained from InSAR a few other active structures, such as secondary strike-slip faults, may play a role to accommodate

the tentative stress accumulation in a large earthquake.

By available co- and post-seismic ground displacements, we successfully rebuild a fault-plane model at Tsaotun. Using this model we can satisfactorily explain the surface deformation in different time domain. The model also describe the details of when, where, and how much the rate of the ground displacements would occur. Our result is undoubtedly valuable to improve the building code and to assist urbanization plan for the purpose of seismic hazard mitigation.

Give a scientific purpose in the title] Interseismic modeling in the Taiwan region

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The island of Taiwan lies at the junction of the Eurasian and Philippine Sea plates. The convergence between two plates forms the Longitudinal Valley, which has been long regarded as one of the major collisional suture zones, to the east and a fault-and-thrust belt to the west across the island. Based on recent published geological map and relevant studies, several major active faults are currently acting in Taiwan.

In eastern Taiwan, the Longitudinal Valley fault, the most dominant fault within the suture zone, is locked at the northern section and is creeping at shallow depth but locked at deeper part in the southern section. In western Taiwan, active faults imbricate and propagate to the west above a major Taiwan detachment at depth. Based on ?, most of the active thrust faults and tear faults in western Taiwan are locked. The locking and creeping of the active faults around Taiwan as well as the

locking of the subduction zones along the Ryukyu and Manila Trenches constrain the interseismic deformation across the Taiwan region and accumulate strain which may be released during future earthquakes.

In order to characterize interseismic deformation around Taiwan region, we analyze GPS data from 1990-1997 by what?. This time span excludes the effects of large earthquakes in the century, especially the Chi-Chi earthquake. For better understanding interseismic coupling and fault slip, we construct a three-dimensional block model across the Taiwan region to quantify kinematically consistent estimates of block motions and fault slip rates. The model combined elastic half-space and block motions based on the backslip model to describe the GPS velocities and locking faults. The GPS constrained block model provides estimates of present-day fault slip rates and seismic potential within the entire Taiwan region.

Implications of river morphology response to Dien Bien Phu fault in NW Vietnam

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