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Paleoseismic Study of the Chelungpu Fault in the Mingjian Area

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ABSTRACT

Our profile observation at a trench near the Chelungpu fault rupture in the Mingjian area, central Taiwan, confirms the existence of at least one buried old fault trace that was probably due to a previous coseismic displacement. The paleoseismic analysis reveals clear evidence of recurrence timing of the Chelungpu fault occurring younger than 200 yr BP by ^{14}C dating. Based on the historical earthquake record, AD 1792 and AD 1848 earthquakes were the two markedly damaging earthquakes striking central Taiwan. We suggest that one of the strong earthquakes may have caused the above-mentioned paleoseismic rupture.

Key words: Chelungpu fault, paleoseismic study, central Taiwan

INTRODUCTION

Repeated coseismic displacements along a fault commonly display clear morphological expressions. Particularly, thrust faults make apparently vertical offsets at both sides of the fault zone, such as the Chi-Chi earthquake ruptures (Chen *et al.*, 2000a). In central Taiwan, the Chelungpu fault was documented to be an active mountain-front thrust fault bounding the Western Foothills and Taichung piggyback basin (Chen *et al.*, 2000b). Several terraces were conspicuously preserved on the hanging wall of the Chelungpu fault. Here, stream terraces on the frontal foothills are also well exposed adjacent to the recent fault rupture. West of the foothills on the footwall of the Chelungpu fault, however, terraces are not found in the subsided Taichung basin (Chen *et al.*, 2000a). Based on the field investigation and ^{14}C dating for terraces, the Chi-Chi earthquake ruptures frequently followed the preexisting Holocene terrace scarps that have already been recognized as a Holocene fault scarp by ^{14}C dating (Chen *et al.*, 2001a). Uplifted Holocene terraces are important indicators of active tectonics, and its presence can be interpreted as a geomorphic expression of active faulting (Pantosti *et al.*, 1996). Therefore, the Quaternary fold-and-thrust belts along the Chelungpu fault in central Taiwan is one of the best areas for neotectonic studies. In this study, we are to discuss paleoseismicity of the Chelungpu fault with the help of careful observation along a trenched profile. Paleoseismic information combining with the trench and geomorphic observations suggest the paleoseismic occurrence of the Chelungpu fault.

These displacements have soon been leveled or modified by reconstruction engineering and severe surface erosion and deposition especially by heavy rain. In one of the engineering projects, we, fortunately, found a trench nearly perpendicular to the rupture, where another rupture trace is hidden parallel with the present rupture. This profile is therefore deemed important for the assessment of the paleoseismity of the Chelungpu fault.

STRATIGRAPHY

This section is located near Mingjian town on the north riverbank of the Choshui River (Fig. 1). A north-trending trace of the earthquake rupture cuts across the Mingjian and the Choshui River. The Chi-Chi earthquake caused vertical displacement ranging from 0.6 m to 3 m adjacent to Mingjian (CGS, 1999; Chen *et al.*, 2000a; Chiang *et al.*, 2000). The rupture across the Chi-Chi railroad and river embankment adjacent to this section shows particularly obvious surface deformation. At the railroad, field measurement shows a vertical displacement about 3 m and horizontal shortening about 5.5 m, and slip direction was oriented N80°W showing pure thrusting related with the rupture (Fig. 2), while at the north Choshui River embankment, we obtained the oriented slip direction of N90°W, 1.5 m vertical and 1.9 m horizontal displacements (Fig. 3; Chen *et al.*, 2000a).

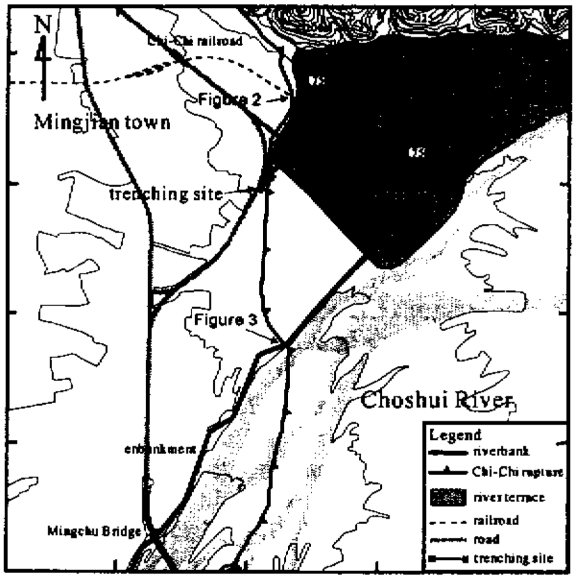

Figure 1

Figure 1. Geomorphic and earthquake rupture map of the Mingjian region. Locations of other figures are also shown.

Figure 2. The earthquake rupture across the Chi-Chi railroad in the Mingjian , the eastern side shows a ground uplift of about 3 m.

Figure 3. At this location on the north embankment along the Choshui River, the road obviously shows a horizontal offset of 1.9 m caused by left-lateral thrust faulting.

This section was excavated across the fault scarp for a distance of 80 m in the northeast trend. Here, the fault cuts through a succession of Holocene fluvial deposits that can be divided into four units: coarse gravels, sand, brown fine sandy clay, and backfill sediments in the ascending order (Fig. 4). The stratigraphically lowest deposits exposed in this profile consist of unconsolidated coarse-gravel and boulder beds of at least 3-5 m thickness, which represent major channel deposits of the Choshui River. Clasts range from 5-20 cm in diameter and are well-rounded, well-sorted and clast-supported, and are composed of quartzite obviously derived from the Central Range. Preserved thickness of the overlying sand horizon is about 1.5 m and well sorted. This horizon is interpreted as fluvial deposits in a flood plain as commonly seen in the current Choshui River. ^{14}C dating of charcoal obtained from the sand horizon has yielded an age of < 200 yr BP (sample MJ200704-4), thus confirming its Holocene age. The third unit, brown silt clay horizon exhibits mottled feature, high organic contents and prismatic soil structure, suggesting a soil layer developed on the uppermost overbank deposits, where a pottery bowl and porcelain flakes are discovered. The depositional age of the clay horizon should not be too far from that of the sand horizon, because the earliest immigrants reportedly came to live in Mingjian about AD 1860 (Lee, 1832).

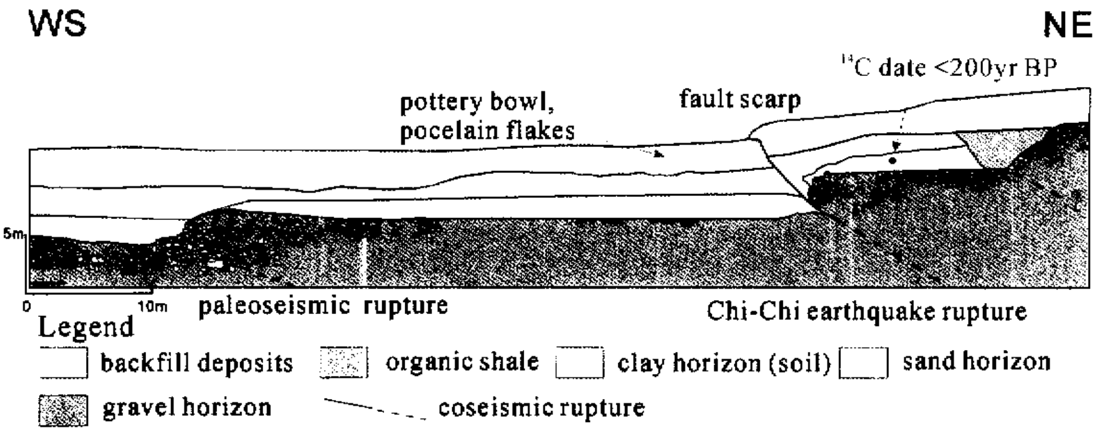

Figure 4. The sedimentary sequence is divided into gravel, sand, clay and backfill horizons in the ascending order. The Chi-Chi earthquake rupture and a buried paleoseismic rupture are identified from this profile according to the relationship between fault and strata. ^{14}C age obtained from the sand horizon is younger than 200 yr BP.

CHI-CHI EARTHQUAKE RUPTURE

Based on the surface measurements, the Chi-Chi earthquake rupture produced a broad warping on the upthrown block of a frontal fault scarp with 1-3 m vertical displacement adjacent to this profile. The excavation shows that the gravel deposits have an about 2.5 m vertical displacement by an east-dipping reverse fault. The fault plane near the surface strikes approximately north-south and dips 40° to the east (Fig. 5). The reverse fault exhibits development of a fault-bend fold in the hanging wall near the top of the fault. The rupture cuts through fluvial and backfill deposits and reaches the surface. The displacement, however, during the Chi-Chi earthquake is inconsistent in the clay and backfill horizons where only 1 m displacement in terms of bedding-plane offset is commonly observed. Much of the near-surface deformation becomes ductile deformation as the rupture propagated through unconsolidated deposits. Commonly, the displacement in clay and backfill horizons with reference to bedding may not represent complete offset during the rupturing. Actually, the two horizons are obviously thickening and tilting on the hanging wall by folding and faulting deformations.

Figure 5. The gravel horizon thrust onto the sand and clay horizons, and the gravel bed dragged by the Chi-Chi earthquake rupture forming an anticline in the hanging wall.

PALEOSEISMIC FAULT

Fluvial deposits at the site are affected by a paleoseismic fault with a vertical offset of 1 m referring to the sand horizon. The stratigraphically lowest gravel horizon is also dislocated about 1 m height and forms a west-facing scarp on top of the sand horizon (Figs. 4 and 6). The sand horizon near the rupture was eroded, and the clay horizon covers the sand and gravel horizons. The clay horizon is not ruptured nor displaced. Therefore, a paleoseismic fault must have occurred before deposition of the younger clayey overbank deposits, and we suggest the top of the sand horizon formed a free surface representing an obvious fault scarp of about 1 m height during the paleoseismic event. Thickness of the clay horizon on the downthrown side of the fault is about 1.9 m while that of the upthrown side about 0.8 m. Attitude of the paleoseismic rupture is unclear, because the rupture cutting through a gravel bed is very difficult to identify. In addition, based on our trenching studies, thick-bedded sediments frequently control the near surface deformation, so that the true fault plane may not be still observable along a preexisting fault zone (Chen *et al.*, 2001b). The Chi-Chi rupture formed on the hanging wall of the paleoseismic rupture about 45 m apart from it. A fault commonly bifurcates upward if it cuts through thick-bedded sediments. Therefore the bifurcated faulting often formed an unobvious gentle fault scarp.

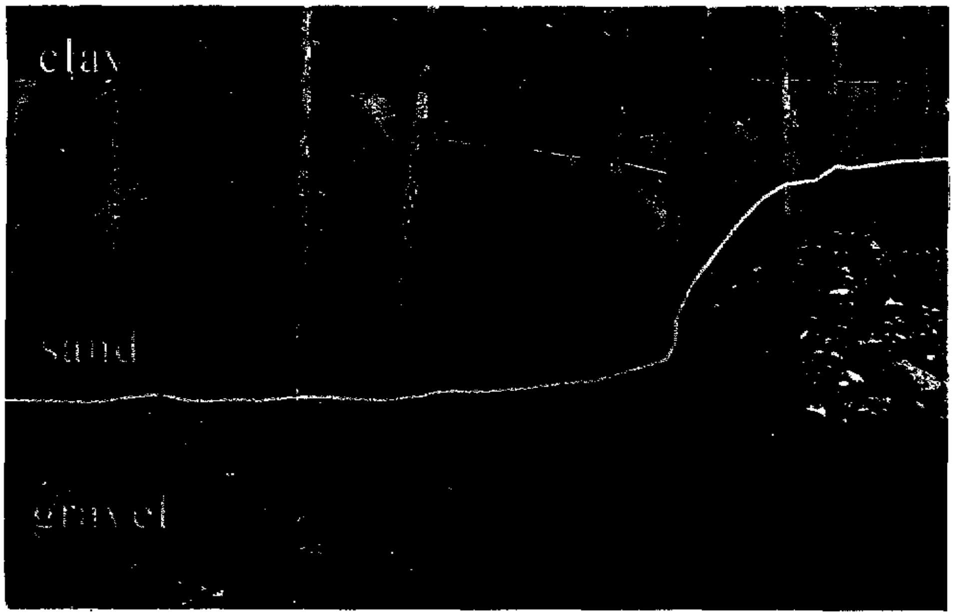

Figure 6. A paleoseismic rupture forming a fault scarp displaces the gravel and sand horizons overlain by the clay horizon.

In the east part of the profile, on top of the gravel horizon a scarp morphology was noted in the upthrown block of the Chi-Chi rupture, which shows a vertical separation of 2.5 m. An organic shale lens including lot of driftwoods was deposited at the foot of a scarp of eroded sand and clay horizons, which creates a depression retaining water under the scarp. Although it is possible that a fault has ruptured these sedimentary horizons, but there is no evidence by observation of their structural and stratigraphic relations. Hence, we cannot ascertain whether or not the scarp is a fault-generated.

DISCUSSIONS AND CONCLUSIONS

Based on geologic characteristics, we divided the Chi-Chi earthquake master rupture into three segments, the Shihkang, Tsaotun and Chushan segments along the Shihkang, Chelungpu and Tajianshan faults, respectively (Chen *et al.*, 2000a). The excavated section is across the southernmost Chelungpu fault. Therefore, the conclusion of this research is in connection with occurrence of the Chelungpu fault.

Presently, we are still unable to strictly constrain recurrence of the paleoseismic event by using ^{14}C dating. Certainly, we need much more detailed trenching and dating studies to achieve the aim. However, the historical seismic record may be helpful in suggesting a probable age corresponding to the paleoseismic rupture in the excavated section. The historical data of seismic events in Taiwan only cover the past four hundred years. Based on the historical earthquake record, it was documented that AD 1792 and AD 1848 powerful earthquakes struck the Taichung, Changhua, Nantou and parts of Chaiyi counties (Hsieh and Tsai, 1985), and their radius of felt area was greater than 300 km. A seismic modeling of the two earthquakes estimated their magnitude to be about 7.1 (Tsai, 1986). In addition, the paleoseismic rupture in the excavated section has a vertical displacement of more than 1 m which is compatible in magnitude (about *M7*) with the Chi-Chi earthquake rupture in the adjacent area. Therefore, we suggest that one of the above earthquakes produced the paleoseismic rupture observed in the excavated section, because we are not able to find any other larger earthquakes occurring within the central Taiwan since 200 years.

Studies of the fold-and-thrust belts in central Taiwan have shown that the Chelungpu fault was formed at the beginning of middle Pleistocene, about 0.7-0.5 Ma (Chen *et al.*, 2000b, 2001c). Seismic reflection profile indicates that the late Pliocene Chinshui Shale is overthrust onto the recent fluvial deposits along the Chelungpu fault with the vertical displacement of about 5000 m (Chang, 1971; Chiu, 1971, Suppe, 1981). Then, we can roughly estimate the long-term vertical offset of each larger earthquake based on the above data assuming the recurrence timing is approximately 200 years. The vertical offset produced by each surface-faulting earthquake is obtained to be about 1.5-2 m since middle Pleistocene. The evaluation is approximately the same order with the observation on the paleoseismic and the Chi-Chi earthquake ruptures. Therefore, the recurrence timing of about 200 years by ^{14}C dating seems to be reasonable.

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WESTERN PACIFIC EARTH SCIENCES
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PALEOSEISMIC STUDY OF THE CHELUNGPU FAULT IN THE WANFUNG AREA

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ABSTRACT

The excavation in the Wanfung area has provided evidence for at least three earthquake ruptures, including the 1999 Chi-Chi one. The Chi-Chi earthquake formed an obviously major reverse fault, backthrust, and several minor normal faults, accompanied by a teardrop-shape anticline in the fault tip. Paleoseismic ruptures I and II show the vertical displacement of 0.4 m and 1.2 m, respectively, which is similar in magnitude to the offset by the Chi-Chi earthquake in this area. Based on the stratigraphical and structural relations, and ^{14}C dating, rupture II may not have occurred before 300 yr B.P. From the historical record, it may be suggested that the paleoseismic rupture II may have been caused by either the 1792 A.D. or 1848 A.D. strong earthquake in central Taiwan.

Key words: Chelungpu fault, paleoseismic study, central Taiwan

INTRODUCTION

This is a followup study of the Mingjian trenching site after the Chi-Chi earthquake. The Wanfung site, to the south of Wufung, was excavated during reconstruction of rice field across the Chi-Chi earthquake rupture, exhibiting some noteworthy paleoseismic subsurface features (Fig. 1). We divided the Chi-Chi earthquake major rupture into the Shihkang, Tsaotun and Chushan segments (Chen *et al.*, 2000), and the Wangfung trenching site is across the Tsaotun segments. The major rupture has a sinuous trace along the frontal foothills that follows the boundary between the Western Foothills and Taichung piggyback basin (Chen *et al.*, 2000; Chen *et al.*, 2001b). However, the rupture in this site is some 200-300 m apart from the foothills, cutting through the Wushi-River alluvial fan. The fluvial boulder deposits here exceed 15 m in thickness in a hole by the site. We would take advantage of the engineering excavation and try to report about the Holocene rate of slip along the Chelungpu fault and some evidence for the recurrence interval of large earthquakes in this particular area.

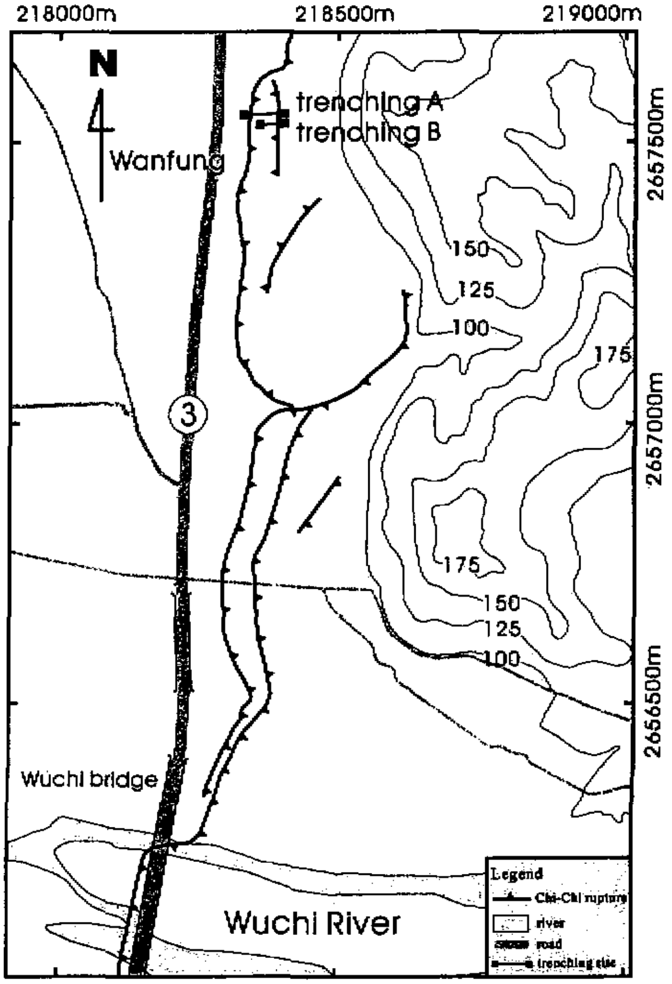

Figure 1. Geomorphic and earthquake rupture map of the Wanfung region.

STRATIGRAPHICAL RELATIONS

The Wushi River flows in a 20-50-m-wide braided channel that lies on an alluvial plain. The excavated profile is at this alluvial plain, exposing near-surface deposits of about 3.5 m thick, which can be divided into boulder, alternating sand/paleosoil, and backfill deposits in the ascending order. The lower horizon, boulder deposits in the excavated profile consists of well-rounded and -sorted cobble, boulder and lenticular coarse sands which represent a high-energy braided channel. Clasts range from 10-100 cm in diameter and are well-rounded, which are composed mainly of quartzite derived from the Hsuehshan Range. Two charcoal samples (WF000327Ds, WF000327D) from the boulder bed yield age estimates of 42,850±1,080 yr B. P. and 32,520 ± 290 yr B.P. (Fig. 2). Top surface of the boulder bed shows a step shape, reflecting scarp topography, which is buried by several sand and paleosoil layers. Furthermore, a gravel wedge was deposited at the foot of the scarp which can be interpreted as a scarp-derived colluvial deposits (Fig. 3).

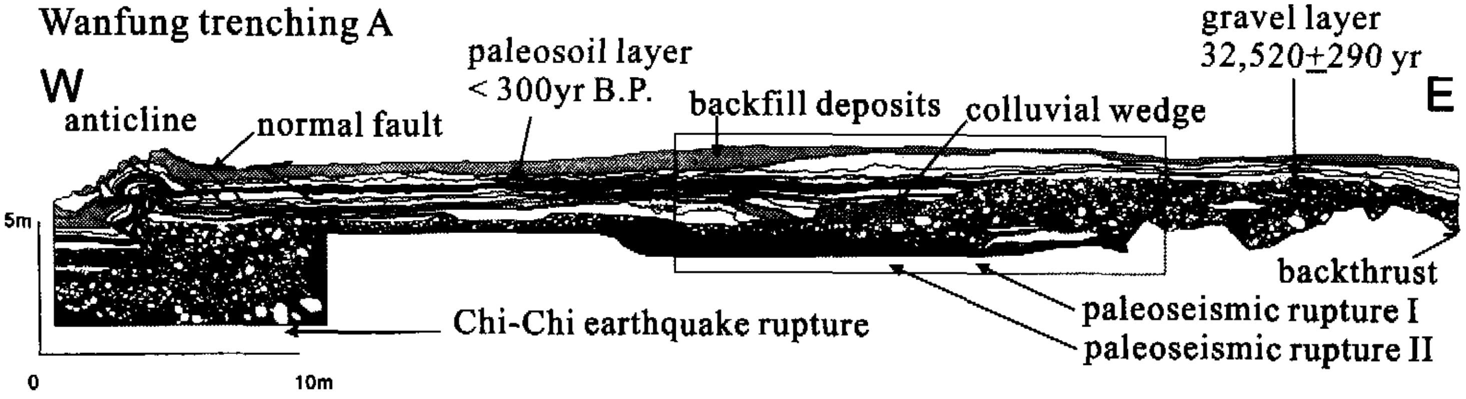

Figure 2. Trenching A can be divided into three units: coarse gravels, alternating sand and paleosoil, and backfill sediments in the ascending order. In this profile, we can find the Chi-Chi earthquake rupture and two paleoseismic ruptures.

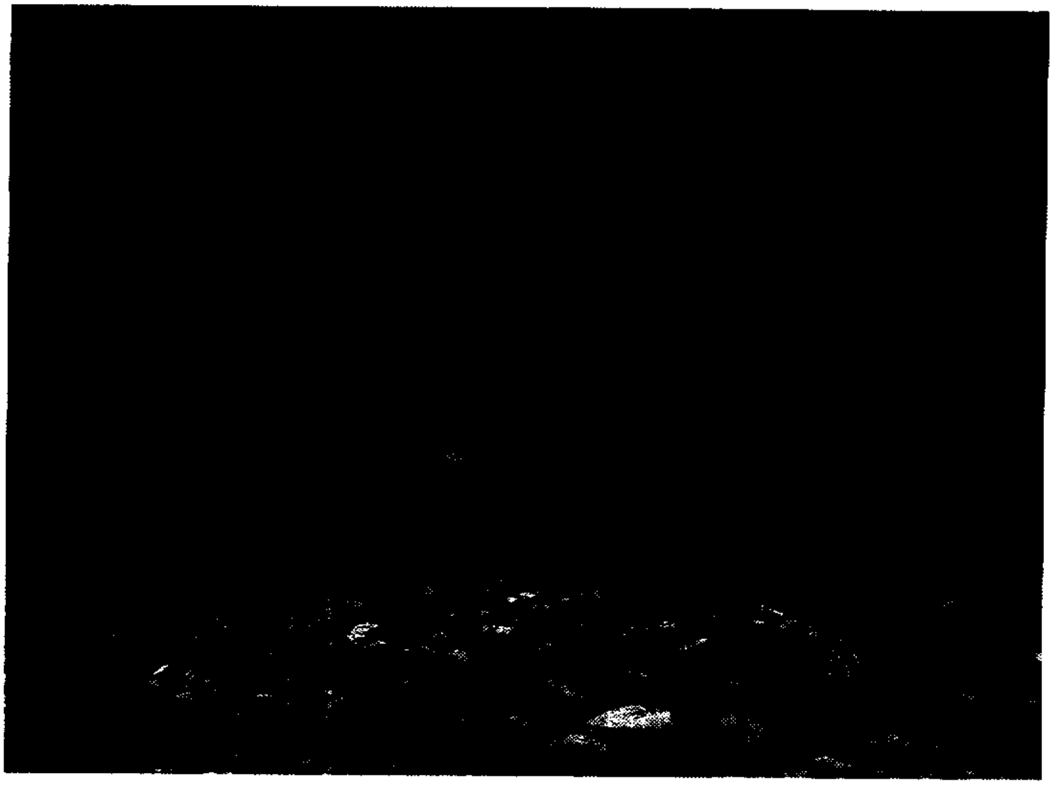

Figure 3. Top of the gravel layer formed a free surface representing an obvious fault scarp of about 1.2 m height during the paleoseismic I event. On the downthrown side of the rupture I is deposited wedge-shaped colluvial deposits. In addition, several sand and paleosoil layers unconformably cover the scarp.

Throughout the profile, the boulder bed is overlain by several layers of alternating sand and paleosoil layers, which represent overbank deposits of the Wushi River. The overbank deposits exhibit slight soil development, containing abundant organic material and mottled features, forming dark brown clays. A charcoal sample (WF000327A) from one of the paleosoil deposits yields an estimated ^{14}C date of younger than 300 yr B.P. (Fig. 2). The stratigraphically upper deposits on the surface consist of backfilled gray clay of about 0.5 m thick. The upper part of the sand and paleosoil layers underlying the backfill deposits is highly modified by human activity.

SEISMIC RUPTURES

This profile crosses the 1999 Chi-Chi earthquake rupture and shows in addition two paleoseismic ones. They were all brought up by thrusts showing an average strike of N-S trending, displacing Holocene and modern alluvial fans. Apparent lack of obvious scarps along the paleoseismic sites suggests that erosion and sedimentation of the Wuchi River has obscured all topographic evidence of fault activity. However, the rupture features are well preserved underground. Thanks to deformation and displacement, the paleoseismic ruptures I and II can be still identified along the trenching profile (Fig. 2). Both ruptures are now covered by the sand and paleosoil layers which represent older events.

Rupture I in the trenching A represents the oldest event, which deformed the lowest unit of boulder bed forming a west-facing scarp about 1.2 m high (Fig. 2). A colluvial wedge has developed under the scarp on the footwall, which is composed of gravel and coarse sand without stratification. Here it is difficult to identify a fault zone within the boulder bed proper (Chen *et al.*, 2001a), but two lenticular sandy beds within the boulder bed near the scarp have developed bending displaying deformation of the rupture I. Therefore, we infer that this deformation and the scarp were produced by an old coseismic event that occurred before the deposition of the colluvial wedge.

Rupture II is clearly shown in the trenching B profile adjacent to the main section (Fig. 4). The rupture cut through the lowest sand and paleosoil bed and the colluvial wedge forming a dragged antiform on the hanging wall. It is an east-dipping thrust fault at an angle of 24°, with a vertical displacement of about 0.4 m (Fig. 4a). Gravels within the rupture zone are imbricated along the fault plane. Rupture II is overlain by a thick-bedded brown paleosoil which is dated by ^{14}C to be a modern age (< 300 yr B.P.). The event, therefore, may be very young occurring after deposition of the colluvial wedge.

The Chi-Chi earthquake brought up complex structural features in this site, an obviously major reverse fault, backthrust, several minor normal faults and anticline (Fig. 5). The amount of the vertical displacement, as referring to dislocated fences, roads and scarps along the fault trace, was commonly from 0.5 to 1.8 m (CGS, 1999; Chen *et al.*, 2001b). By measurement along a dislocated fence in this site, we got vertical displacement of about 1.3 m, horizontal shortening about 1.8 m, and slip direction N90oW, showing pure thrusting related with the rupture. By calculation from the displacements, we obtained a dip angle of 36° near the surface. The surface ruptures are also accompanied by a backthrust on the hanging wall 50 m apart from the major thrust fault.

The surface folding in the fault tips takes a form of a teardrop fold (mushroom shape) associated with tensile cracks, thrusts and normal faults, and both limbs of the fold are overturned (Fig. 5). The tensile cracks are well developed near the roof of the mushroom fold showing surface stretching of backfilled clayey deposits during the folding. In addition, the soft-sediment layers in the hinge zone further exhibit bending and flexing that display a flexural-flow fold in the fault tips.

DISCUSSIONS AND CONCLUSIONS

Colluvial wedges have been a useful criterion in identifying paleoseismic events, which are usually deposited near the fault scarp (Swan *et al.*, 1980; Schwartz and Coppersmith, 1984). Based on the trenching observation, the coseismic ruptures in the Wangfung site occurred farther away from the foothill toes, and cut through the Wushi alluvial fan. Furthermore, we have difficulties in finding colluvial deposits along the rupture within alluvial fans due to post-seismic modification by the Wushi River. At this site, fortunately, we were able to find a colluvial wedge at the foot of a fault-generated river-terrace scarp, which is buried along with the simultaneous deformation of rupture I. Originally, alluvial terraces should have occurred on the hanging wall during successive thrusting events, but we did not find any more terrace deposits along the frontal foothills in this region (Chen *et al.*, 2000; Chen *et al.*, 2001b). The gravel, boulder and cobble deposits in the Wushi alluvial plain are evidently transported by debris-flow process of flash floods during the storm season. They are stratigraphically beneath the sand and paleosoil deposits dated to be younger than 300 yr B.P. The two charcoal samples collected from the boulder bed yielded date that is unreasonably old and probably not representative of the deposition of the boulder bed, because the surface of the boulder has been kept so fresh without slight laterization, that we hardly believe that the boulder bed is older than Holocene in age (Liu, 1990; Chen and Liu, 1991). Therefore, we interpret that these charcoal samples may be a piece of reworked detritus derived from older terraces or colluvial deposits.

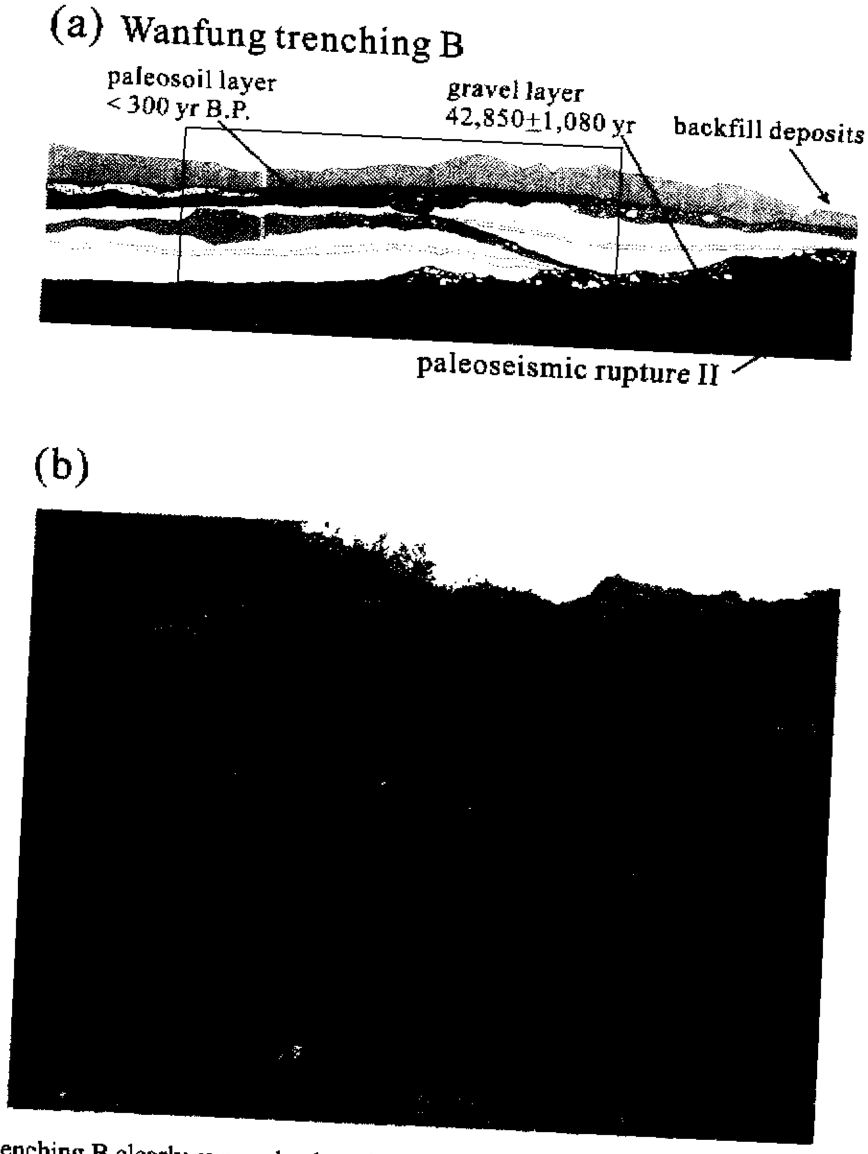

Figure 4. Trenching B clearly exposed paleoseismic rupture II with a 24°-east-dipping fault plane and about 40 cm vertical displacement.

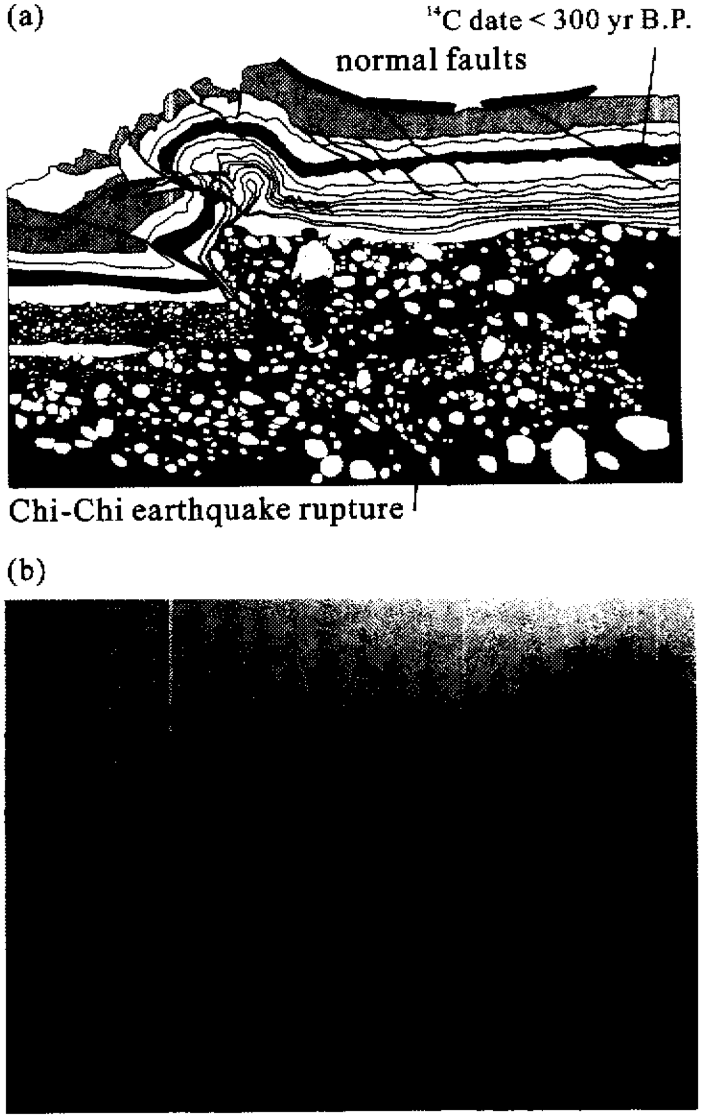

Figure 5. The Chi-Chi earthquake rupture formed a mushroom-shaped, overturned fold at the fault tip, which is associated with several minor thrusts.

We interpret the presence of the above stratigraphic and structural relations in this profile as evidence for the two paleoseismic ruptures. Rupture I cuts through the boulder bed and is overlain by the sand and paleosoil deposits preserving a 1.2-m-high fault scarp. Apparently, there is possibility to infer that rupture I occurred before the deposition of the lower sand deposits. Actually, we have no constraint on the time gap between the depositions of the boulder and the sand deposits. However, close observation of rupture II reveal that sandy seams of the sand and paleosoil deposits above the boulder bed and the colluvial deposits were evidently penetrated by the rupture, and, all the more, between the former deposits and the latter, there seems no sedimentational break represented, for example, by unconformities. Therefore, we believe that the timing of rupture II event is not very far from that of the sand and paleosoil deposits.

Paleoseismic ruptures I and II have the vertical displacement of about 0.4 and 1.2m which is similar to that of the Chi-Chi earthquake ruptures in the adjacent area ranging from 0.3m to 1.8 m (CGS, 1999; Chen *et al.*, 2000). We infer that the magnitude of these paleoseismic events resemble that of the Chi-Chi earthquake. Based on the historical earthquake record since 400 yr B.P., it was documented that in 1792 A.D. and 1848 A.D. two strong earthquakes struck central Taiwan (Hsieh and Tsai, 1985). We suggest that one of the above earthquakes may have caused the paleoseismic rupture II, which may be correlated with the paleoseismic rupture at the Mingjian site (Chen *et al.*, 2001a).

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