Re-evaluating an active fault in a major computer-manufacturing area in northern Taiwan using '1 sec' shallow reflection seismics

Chien-Ying Wang, Yi-Hen Lee, and Yu-Yen Hu

Institute of Geophysics, National Central University, Chung-Li, Taiwan

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[1] Recently abundant evidence from surface geologic investigation has been cited to identify an active fault which happens to pass through a major computer-manufacturing area in northern Taiwan. Great public concern has arisen as a consequence. In this paper, we use '1 sec' high-resolution shallow seismic reflection sections to examine the near-surface structure of this fault. The results, however, do not support the geologic observations. A folding above a shallow decollement was found in the fault's northern portion, which may include shallow minor faulting. In the remaining portion, the structural layers were found to lie flat without offsets, except for slight buckling. The fault could have displacements at deeper places ('blind thrust'?), but the shallow parts do not seem much affected. These results indicate that the threat of active faulting in the area is actually less than previously feared. **Citation:** Wang, C.-Y., Y.-H. Lee, and Y.-Y. Hu (2005), Re-evaluating an active fault in a major computer-manufacturing area in northern Taiwan using '1 sec' shallow reflection seismics, *Geophys. Res. Lett.*, *32*, L08313, doi:10.1029/2005GL022344.

1. Introduction

[2] Since the foundation of shallow reflection seismics in the nineties [*Steeples and Miller*, 1990; *Pullan and Hunter*, 1990], fault detection has been one of its most important applications. In comparison with oil-exploration reflection seismics (deep seismics), shallow seismics is characterized by higher resolution and lower cost. However, due to the use of small aperture arrays and of reduced sources, the shallow seismic method is not adequate to explore large structures (e.g., thousands of meters). On the other hand, seismic imaging of near-surface structures (e.g., tens of meters) is often hampered by the difficulty in collecting good-quality data, which can be instead affected by ground-roll noises, scattering phenomena and strong static problems. Thus the detectable depth of the method may be restricted between 50 m to 1500 m, which roughly corresponds to seismic stack sections with the length of '1 sec'. This '1 sec' time range is not commonly cared during the oil exploration, also not so perceived for the engineering application. However, in the investigation of active faults, this range is crucial to link deep faulted structures imaged by commercial profiles to surface observation, as part of an integrated interpretation of the fault activity [*Dolan and Pratt*, 1997]. This paper attempts to examine the effectiveness of the '1 sec' seismic method for detecting the fault, compared with the '5 sec' deep seismic method. The Shincheng fault, a 'well recognized' active fault, will be used as an example for illustration.

[3] Recently a lot of evidence from geomorphologic and geologic studies has been found that verifies the Shincheng fault [*Chen et al.*, 2003]. This fault passes through a computer-manufacturing area, the Shinchu Science Park (SSP), in northern Taiwan (Figure 1). This area is the acknowledged 'Silicon Valley' of Taiwan, which explains great disturbances caused by introducing such an active fault. The first substantive proof of the Shincheng fault was provided by the Chinese Petroleum Corporation (CPC) in the 1970's, based on seismic reflection profiles and borehole data [*Namson*, 1984]. The fault was postulated to be a low-angle thrust which had lifted an older formation (CL) to the surface. Recently in response to the threat of earthquake faulting during the 1999 Chi-Chi earthquake (Mw = 7.6) [*Wang et al.*, 2004], a re-examination of all active faults on the Taiwan island has been encouraged by the Taiwan Central Geologic Survey (CGS). Several outcrops of the Shincheng fault have been traced, which not only confirm the fault, but re-classify it to be a 'hazardous' active one. Nevertheless, the background seismicity of the area is much less than other places in Taiwan [*Wang and Shin*, 1998]. In this paper, we use '1 sec' shallow seismic lines, some co-siting with the CPC's deep seismic lines, to examine the near-surface structure of the expected fault. This re-evaluation will be of help in settling the 'active fault' issue and in assessing the seismic hazard of the area.

2. Regional Geology and Deep Reflection Seismic Profiles

[4] Figure 1 shows the geologic structure of the study area. Two faults and two anticlines (the Shinchu-Chingtsaohu and the Shincheng-Paoshan systems) are the main features. It is noticed that these structural systems merge to a point at their NE ends (the A1 position on Figure 1a). The three major stratigraphic units are: the Pleistocene Yangmei Formation (Yc; mudstone and gravel), the late Pliocene Cholan Formation (CL; sandstone and shale) and the early Pliocene Chinshui Formation (Cs; shale and mudstone). The older Cholan Formation has thrust over top of the younger Yangmei Formation at some parts of the fault (between A3 and A6). However, on the Bouguer gravity anomaly map (Figure 1b), this part is found to have the slowest gravity variations. There are some conflictions. Figure 1c shows a CPC's description of the fault. It could be a low-angle thrust fitting either the 'fault-bend-fold' [*Suppe and Namson*, 1979] or the 'fault-propagation-fold' [*Yang et al.*, 1996] models. *Yang et al.* [1996] explained that the two structural systems may represent 'broad folds accompanied by low-

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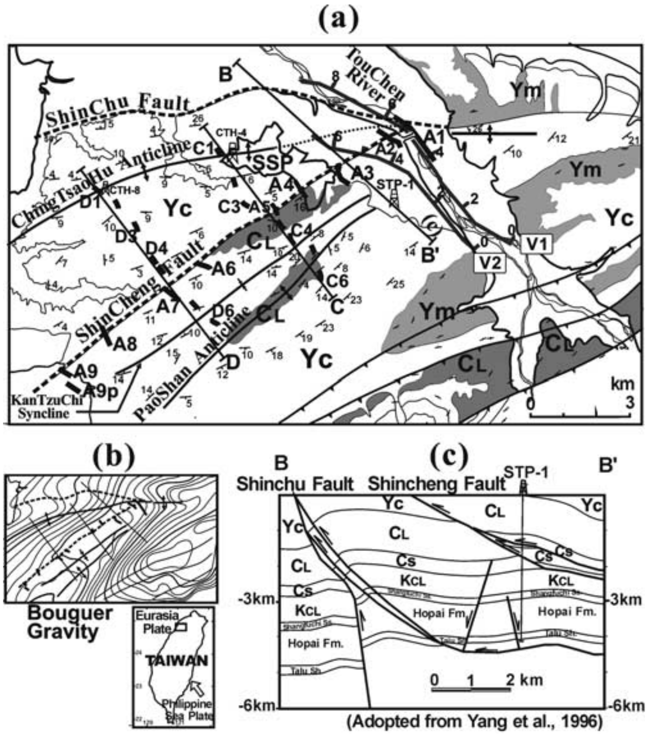

Figure 1. (a) Geologic map of the study area; (b) Bouguer gravity anomalies; and (c) a representative profile BB′ [*Yang et al.*, 1996]. Two thrust-and-fold systems (the Shinchu and the Shincheng faults) are the main features. The older Cholan formation (CL) even thrusts over the top of the younger Yangmei formation (Yc) along some parts of the Shincheng fault.

angle thrusts' that developed along the deformation front of Taiwan's western foothills. The Shinchu fault could be a reactivated reverse fault of an ancient normal fault, which later acted as a 'lateral ramp' terminating the Shincheng fault at its NE end.

[5] Two SE-NW deep reflection seismic profiles from the CPC are shown in Figure 2. Profile V1 follows the northern bank of the Touchen river, and V2 the southern bank (Figure 1a). Most of the fault's outcrops have been found here by the CGS. The Shincheng fault, denoted by the black lines, can be interpreted as a thin-skinned thrust, which slips along the Chinshui Formation (Cs). The layer bending forms are quite obvious, constituting a flat-and-ramp geometry characteristic of the thin-skinned thrust model. The ramp may have pushed the layers above it to form a flexure structure. On V2, the rising of the layers in its NW portion is expected as it is closer to the Chingtsaohu anticline. Due to blurred images, it is difficult to ascertain whether the fault trace (dashed black lines) may have reached the surface or not.

3. Methods: '1 sec' Shallow Reflection Seismics

[6] Based on the terminology of 'high-resolution' shallow reflection seismics [*Steeples and Miller*, 1990], we may designate '1 sec' shallow reflection seismics as follows: 'high resolution' must be maintained while expanding the survey range to cover 'more depth'. '1 sec' seismics needs to be coupled with three factors: 1) small intervals; 2) large channel numbers; and 3) a high-energy source. Small intervals, including the receiver and the time intervals, are required to maintain the high space-time resolution, which is essential to the elimination of groundroll noises by using '2D filters' in the laboratory, rather than using a 'geophone array' in the field [*Dolan and Pratt*, 1997]. Large channel numbers are used to expand the receiver spread distance, and consequently to increase the detectable depth. Furthermore, a powerful source is involved to provide signals with high frequencies as well as high depth penetration. When these factors are satisfied, the 'high-resolution' details of the shallow seismics can be maintained, and, at the same time, greater depth for mapping larger structures is possible.

[7] The equipments used in the '1 sec' seismic survey in this study were: 1) source, an EWG-III weight drop impact pulse generator (stack more than 10 times); 2) receiver, OYO 40 Hz geophone; 3) recorder, GEODE 144 channel seismograph (24 bits). The acquisition geometry followed end-on shooting with the following survey parameters: 1) 2 m receiver interval; 2) 6 m source interval; 3) 0.25 ms sampling rate; 4) fold of 24; 5) 72 m near-offset; 6) 40 Hz low-cut setting. The end-on shooting and the large channel number make the spread range longer to expand the depth coverage. A high stack number of source pulses and a high CDP fold (at least 24) help in the extraction of the available signals from the background noises. The data processing follows standard procedures for CDP data, as described by

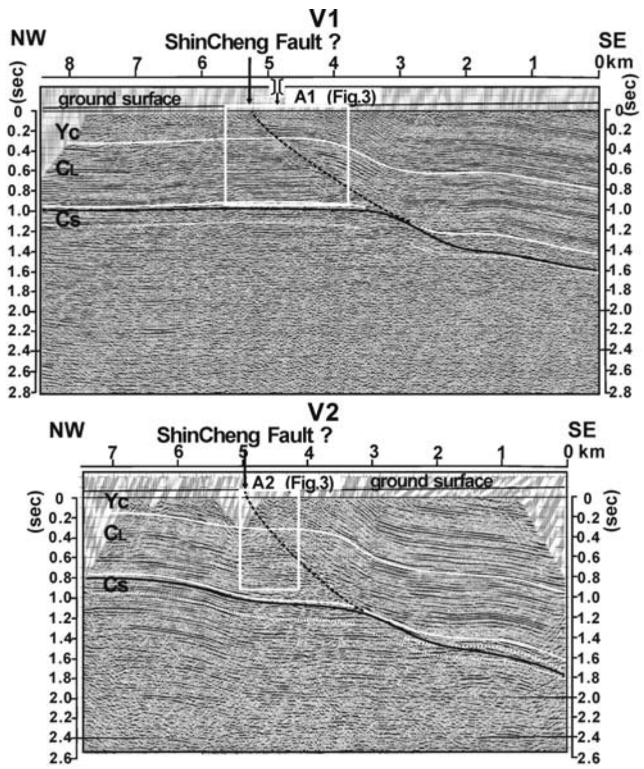

Figure 2. Two deep reflection seismic profiles collected by the CPC along two banks of the Touchen river. The Shincheng fault, denoted by thick lines, can be interpreted as a thin-skinned thrust that slips along the Chinshui Formation (Cs). The squares indicate the areas to be studied by the shallow seismics.

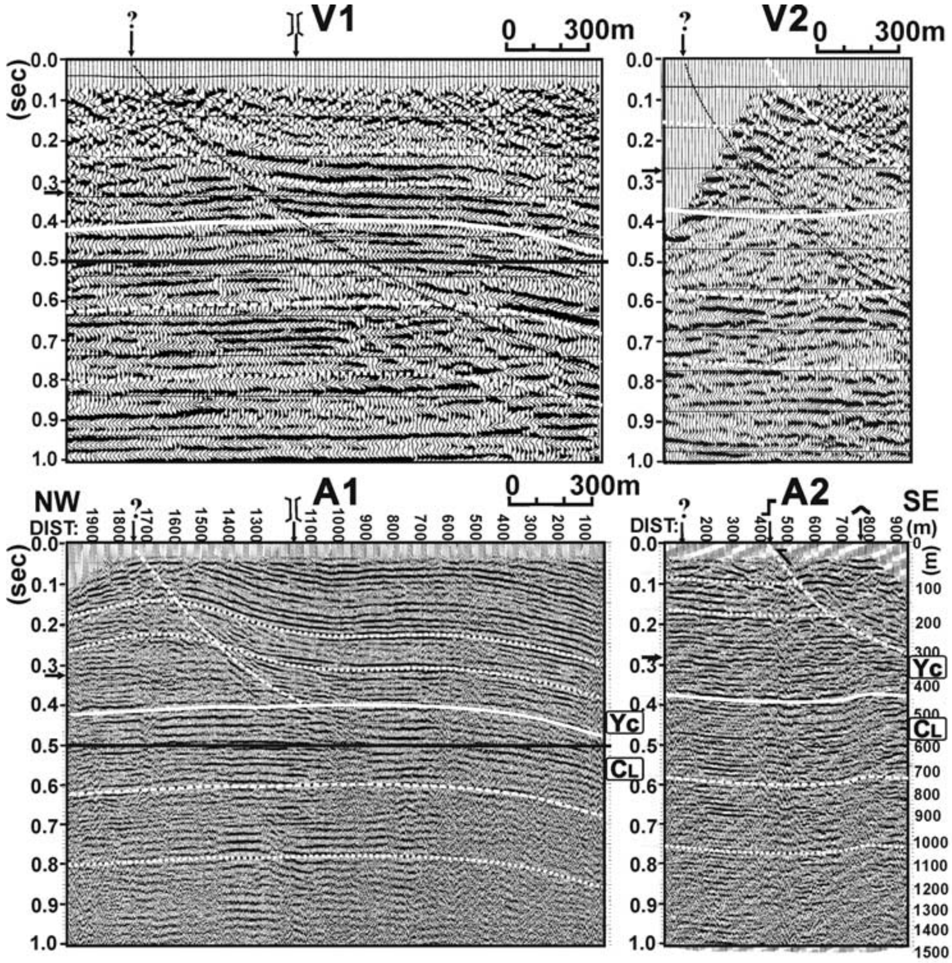

Figure 3. Shallow seismic sections A1 and A2 follow the same positions as deep seismic profiles V1 and V2, respectively. They are used to examine details of the structural variation of the fault as it approaches the surface. A quite interesting 'detachment fold' gracefully appears in the upper 450 m of A1, and a small shallow fracture appears in A2.

Wang et al. [2004]. Due to relatively short ranges and shallow depths, all sections are not migrated.

4. Seismic Survey Results

[8] Twenty-four seismic sections (each about 300 m to 600 m long) are collected as shown in Figures 3 to 6. A referred depth scale is plotted on the right-hand vertical axis, and an approximate 1:1 horizontal to vertical scale is kept for all sections. Figure 3 shows the shallow reflection seismic sections, A1 and A2, collected along the two banks of the Touchen river. These two sections have been designed to co-site with the deep seismic profiles, V1 and V2, respectively, shown in Figure 2 and magnified in Figure 3 (upper panel). Shallow seismic sections were used to examine details of the structural variation of the Shincheng fault as it approaches the surface ('?' symbols in the figure). A very interesting and striking 'detachment fold' (folding above a shallow detachment) appears on the upper 450 m of the A1 section. Below this, the bent layers, caused by the ramp along the main 'fault-bending fold' system, are detached from the above 'detachment fold'. A minor faulting happens inside the fold, which may propagate to the surface, but not penetrate down into deeper layers. On section A2, a small slip can be seen in the shallow part, a similar minor faulting pattern as in A1. These minor faults represent shallow phenomena, which may not have deep 'roots'.

[9] Figure 4 collects 7 sections which cross the Shincheng fault sequentially from NE to SW. Sections A3, A4 and A5 are in the vicinity of the SSP (Figure 1a). In A3 and A4, it is apparent that the layers dip uniformly to the SE, which represents a part of the Chingtsaohu anticline, which is located to the NW. Some minor faults can be identified, and these agree with surface outcrop observations. However, the breakage scale is small and near the surface. The layers in section A5 become surprisingly flat but with slight buckling in the middle. In fact, this kind of 'buckling' persists in all sections (indicated by the 'buckle' symbols) of Figure 4.

[10] Sections A6 and A7 are located near the middle of the Shincheng fault. The structures of both sections show broader folds. The amplitude of the fold is greatest in A7, which is at the town of Shincheng. This suggests that the Shincheng fault may be centered at Shincheng, with less layer bending toward either side. Sections A8 and A9 are located on the southwestern side of the fault. We can see flat homogeneous layers with little buckling at certain places.

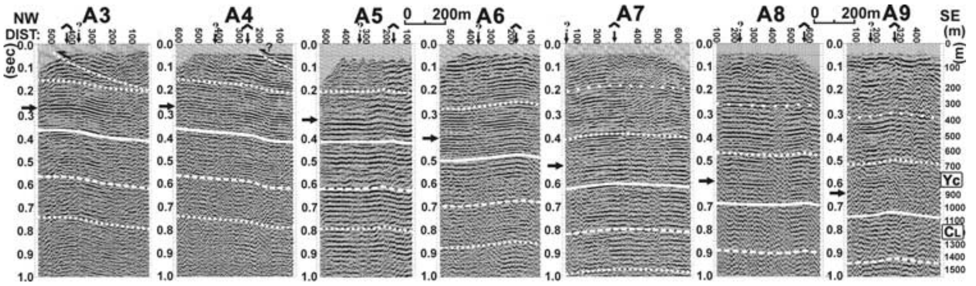

Figure 4. Sections A3 to A9, that cross the Shincheng fault, are distributed along the fault trace from NE to SW. It is apparent that the layers are uniformly laid without noticeable offsets. However, a slight buckling or flexural warping exist on all sections.

None of the sections in Figure 4 show any significant fault propagating from the deep structure up to the surface. No large scale thrusts appear. The layers are bent by slight buckling, but not by slipping. This is more or less opposite the surface geologic observations.

[11] Two profiles (C and D) vertically transecting the fault were further collected to investigate larger structural variations as shown in Figures 5 and 6 (see auxiliary material[1]). Each profile is about 7 km long and consists of several 400 m-long '1 sec' seismic sections. The structural strata in these profiles are found to vary smoothly without noticeable thrust offset. We may not exclude that some minor faults could occur, however, there should not be such a large thrust event as predicted by the geologic map.

5. Conclusions

[12] The '1 sec' shallow seismic method is an appropriate tool to extend surface geologic observations to the deep underground. It is nimble enough to be moved at any road, and more important, is cheap enough to be widely used. Fault detection and local geology mapping should be benefited by the application of the shallow seismic method discussed in this paper.

[13] The Shincheng fault is probably a 'blind thrust' buried more than 2 km deep as revealed by the CPC's deep seismic sections (Figure 2). However, the layers above it do not seem much affected by this buried thrust fault. At the northern portion of the fault, where several structural systems merge, a 'detachment fold', with internal minor faulting occurs at shallow depths, which may have induced some surface fault outcrops. However, in the other portions, the structural layers are laid flat without significant offsets except for slight buckling that occurs in all sections. Pushing induced by the detachment movement of the buried thrust could be the possible cause of this buckling. Based on these high-quality seismic images and moderate seismicity activities of the area, we suggest to lessen the Shincheng fault as a 'hazardous' active fault. The fault may suffer displacements at deeper places, but the shallow structures are only limitedly influenced.

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[1]Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2005GL022344.

Y.-Y. Hu, Y.-H. Lee, and C.-Y. Wang, Institute of Geophysics, National Central Univ., Chung-Li 32054, Taiwan. (wangcy@cc.ncu.edu.tw)