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Characteristics of Submarine Topography off Northern Taiwan

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ABSTRACT

Based on bathymetric data collected in recent years, the topographic features and their structural implications on the northern offshore area of Taiwan are described. The Chilung Shelf is representative of the submarine physiographic units in this region. It occupies the shallow water area eastward to the City of Chilung between the Chilung Valley and the Mien-Hua Canyon. To its north and west, the East China Sea Shelf reveals a gentle ocean bottom such that water depths on its edge (the shelf break) are found to be at least 150 meters shallower than those on the Chilung Shelf. Taiwan is a product of orogeny which resulted in compressive imprints throughout the island. On the Chilung Shelf, a series of topographical lineaments extending from onland Taiwan and oriented in the SW-NE direction are present; however, seismic profiles indicate that these lineaments are a factor of normal faulting mechanics. It is suggested that the offshore area of northern Taiwan has been under a different tectonic stress from that represented on the island.

(Key words: Bathymetry, Tectonics, Chilung Shelf)

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1. INTRODUCTION

The sea floor off the northern coast of the Island of Taiwan mainly consists of three major submarine physiographic units: the East China Sea continental shelf (the Tunghai Shelf, hereafter), the East China Sea continental slope (the Tunghai Slope), and the southern Okinawa Trough. Physiographically, the Tunghai Slope acts as a northern flank of the Okinawa Trough. Bathymetrically, it is a transit zone separating the shallow shelfal area to the northwest from the deep ocean to the southeast.

In general, the Tunghai Shelf is seen as a broad, smooth, flat featureless sea floor. Although such low relief bottom features have been observed, marine geologists have suggested these features resulted from subaerial processes during the glacially lowered sea level period of the late Pleistocene (Emery *et al.*, 1969; Boggs *et al.*, 1979).

In the 1990s, thousands of sets of digital bathymetric data positioning from the Differential Global Positioning System (the DGPS) method were systematically collected in the area off northern Taiwan (Song & Chang, 1993). The survey tracks are shown in Figure 1. Based on the distances of the ship's track intervals, they present a view of the sea floor with a resolution of less than 1 mile.

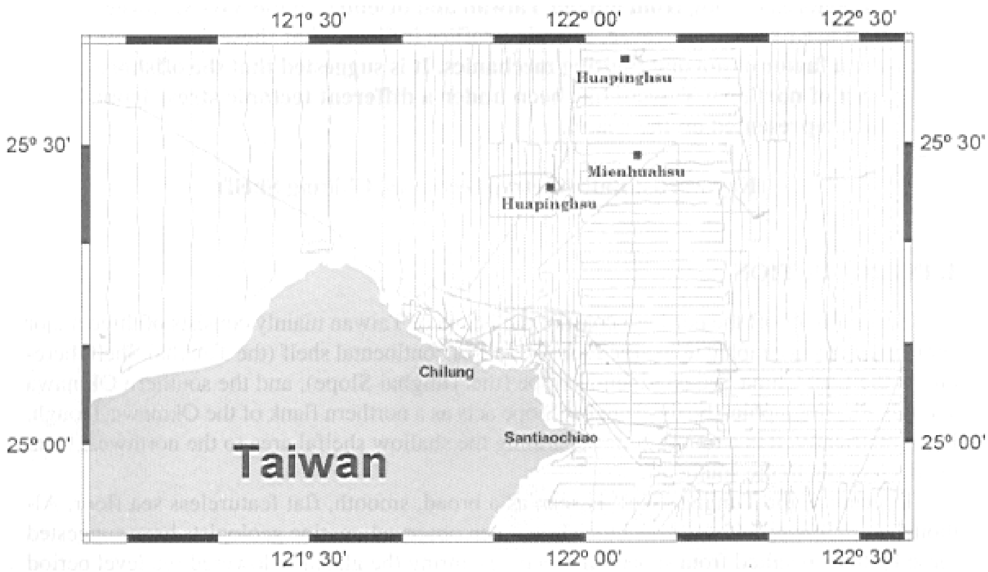

Fig.1. Survey lines collecting the sounding data employed in this paper. Along the tracks, sampling density averages one depth data per 100-meter distance.

Besides this, some secondary submarine physiographic units have been recognized in this area (Yu. 1992; Song & Chang, 1993. and Song, 1994) as shown in Figure 2. These include (i) the Mien-Hua Canyon, a well developed canyon indenting into the shelfal region around the islets of Mienhuahsu and of Huapinghsu, (ii) the Chilung Valley, a submarine valley with its structural genesis lying north parallel to the coast of northern Taiwan (Song *et al.*, 1997); (iii) the North Mien-Hua Canyon, a submarine canyon located at about 30 km north of the Mien-Hua Canyon which diminishes immediately on the shelf; and (iv) the Chilung Shelf, a shelf with a rugged surface, located immediately north of the Chilung Valley.

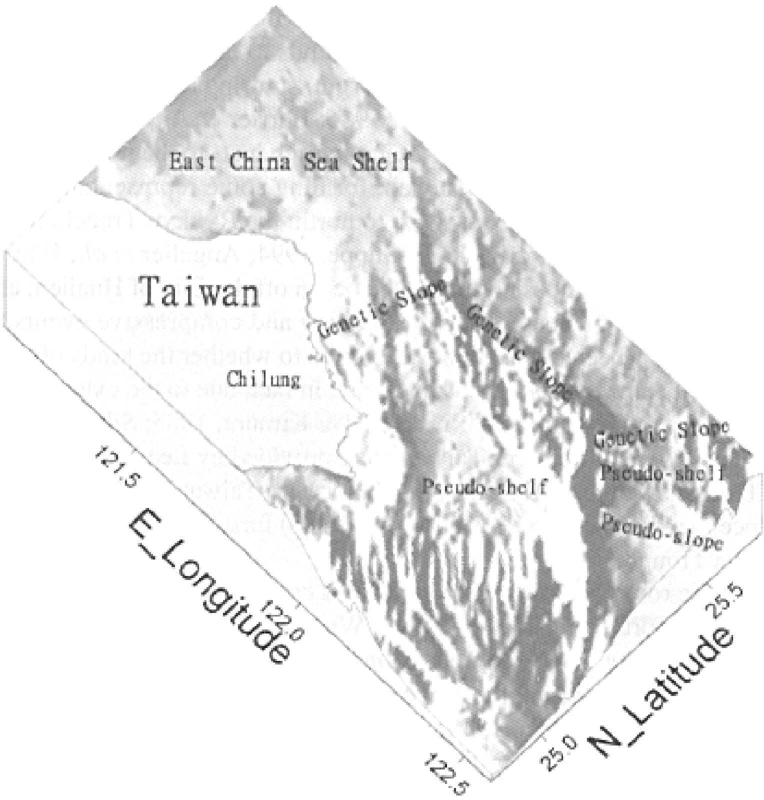

Fig. 2. 3-D plot of the researched area of northern Taiwan, viewed from the southeast and illuminated from the northeast. Each province on the plot is defined in the text.

The Chilung Shelf was originally defined on the basis of its unique bottom features relative to the surrounding Tunghai Shelf (Song & Chang, 1993; Song, 1994) As for the Chilung Shelf, Song and Chang (1993) stated that, first, it is bounded between the Mien-Hua Canyon and the Chilung Valley. Secondly, they reported that, to the east, the Chilung Shelf crosses a deeper shelf break at the 220-meter isobath, and reaches the tail portion of the southern Okinawa Trough. Finally, on the surface, it is characterized by a rugged floor of tens of meters of relief giving it a different appearance from the adjacent Tunghai Shelf.

However, in terms of naming the submarine physiographic units off northeastern Taiwan, Song and Chang (1993)' s discussion focuses only on the bottom view. The characteristics of the bottom features off northern Taiwan have never been discussed systematically. The bottom topographic features that have always been categorized are the products of relicts resulting from subaerial erosion (Emery el al., 1969; Boggs et al., 1979). In this paper, bathymetric data with a fine resolution are used. Together with the seismic profiles obtained in the area, it is pointed out that the Chilung Shelf is basically tectonically dominant.

2. TECTONIC SETTING

Taiwan is situated within the western Pacific Rim on the boundary between the Eurasian plate and the Philippine Sea plate. The Philippine Sea plate is moving relative to the Eurasian plate at a rate of about 70mm/year in a northwest direction (Seno, 1977). Consequently, it first carries the northern tail of the Luzon volcanic islands to the northwest, and it obliquely collides with the eastern Eurasian continental margin, suturing along the Taitung Longitudinal Valley/Fault (Bowin *et al.*, 1978; Ho, 1982, 1986; Barrier & Angelier, 1986; Huang & Yin, 1990; Teng *et al.*, 1992; Huang *et al.*, 1992). It then subducts to the north beneath the Eurasian continental margin off northeastern Taiwan, forming some representative submarine topographic features in the sequence from south to north: the Ryukyn Trench, the Ryukyu island arc and the Okinawa Trough (Karig, 1973; Suppe, 1994; Angelier *et al.*, 1986).

The Longitudinal Fault goes north into the ocean off the City of Hualien; as a result, it can be said that Taiwan has been a product of orogeny and compressive events throughout the island. However, it has been a question of debate as to whether the kinds of which stress have been dominant in the area of northern Taiwan are, in fact, due to the existence of the Okinawa Trough in the vicinity (Kimura, 1985; Letouzey & Kimura, 1985; Sibuet *et al.*, 1987).

The stress analyses of northern Taiwan were provided by Lee & Wang (1988) and Yeh *et al.* (1991). They showed that the stress field in northern Taiwan has been under an extensional condition since the Pleistocene. Lee and Wang (1988) further related it to the opening process of the Okinawa Trough.

Many basaltic rocks and ultrabasic inclusions can be found in the Tatun and the Chilung volcanic groups in northern Taiwan (Chen & Wu, 1971; Chen, 1978; Yen *et al.*, 1979; Yen, 1980). On the Chilung Shelf, andesites have been found in the Chilungtao and in the Pengchiahsu. They reveal similar the rare earth elements (REE) patterns to those shown in the Tatun andesites (Huang & Chen, 1988). In addition, the Tatun volcanic group seems to be a better candidate for a shallow-extruded volcanism in that it has lower crustal contamination than does arc volcanism (Chen, *et al.*, 1993). This means that volcanic products in northern Taiwan might be more basaltic than those of a typical volcanic arc. This implies that at some time shallow extensional dynamics must have been dominant in the surrounding region, including the area of the Chilung Shelf.

It has been suggested that the Chilung Valley lying parallel to the coast off northern Taiwan is a regime dominated by right-lateral shearing (Huang *et al.*, 1992; Song *et al.*, 1997). This shearing fault moving in a strike-slip behavior may have been a barrier separating the straining outcome on the Chilung Shelf due to the compressive thrust mechanics occurring mainly onland Taiwan under the environment of orogeny.

3. DESCENDING BEHAVIOUR OF THE CHILUNG SHELF

The boundary between the continental shelf and the continental slope is known as the shelf break or the shelf edge. It has an average depth of 130m which may be representative of the regression of sea level during the Pleistocene glacial period worldwide (Kennett, 1982). In addition, continental shelves are seen as mostly flat and smooth with a gradient of less than l/1000 (Kennett, 1982). Conversely, the Chilung Shelf has a clearly descending rugged surface to the southeast with a deeper shelf edge (Figure 2). In addition, its bottom shape varies greatly from that found off the Tunghai Shelf (Figure 3).

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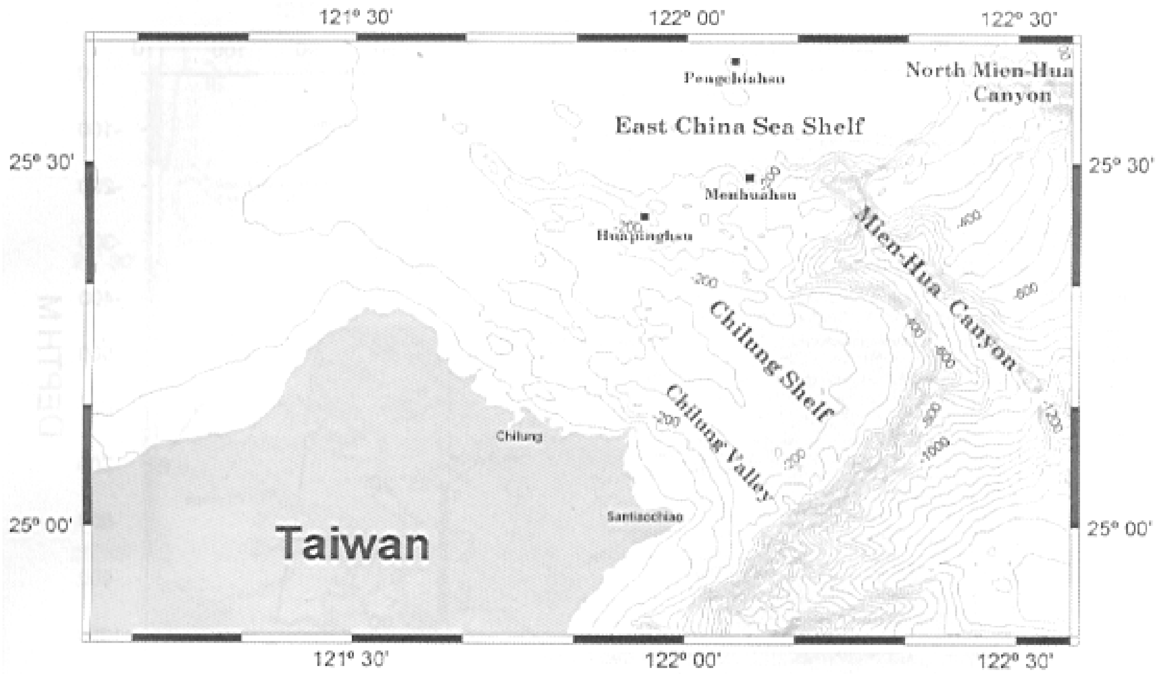

Fig. 3. Contour map of the researched area; contour interval is 50 meters.

Two interpolated profiles across the continental terrace off northern Taiwan are shown in Figure 4. The line a-e represents the bathymetric profile beginning at the Tunghai Shelf and crossing over both the Chilung Shelf and the Chilling Slope. The line A-E represents the protile crossing the Tunghai Shelf and the Tunghai Slope. Comparing those profiles to those of the world average, the Tunghai Shelf carries the shape of a typical continental shelf but with a more gradual continental slope; in contrast, the Chilung Shelf has a rugged profile representing a steeper and unusual surface.

The surface of the Tunghai Shelf that is situated west of the Chilung Shelf is demonstrated by the a-b section. In this region, the sea floor shows a flat surface with water depths around 110-120 meters, which is similar to those shown in the A-B profile. The points B and b in Figure 4 at the same depth level of 120-meters represent the minimum depth of the shelf edge of the Tunghai Shelf (called the inner shelf break, hereafter).

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In general, the trace of the shelf break indicates the paleo-coastline of the last Pleistocene glacial period. Boggs *et al.* (1979) demonstrated that the sea level was about 140 meters lower off northern Taiwan in that period. Two isobaths of 120-meter and 140-meter, as depicted in Figure 5, define the presumed paleo-coastal zone that occupies the region in-between these depths. The 140-meter isobath follows the northern edge of the Mein-Hua Canyon and connects with the southern edge of the Chilung Valley. The shallow water (or the landward) area is in the territories of the Tunghai Shelf and the coastal zone off northeastern Taiwan.

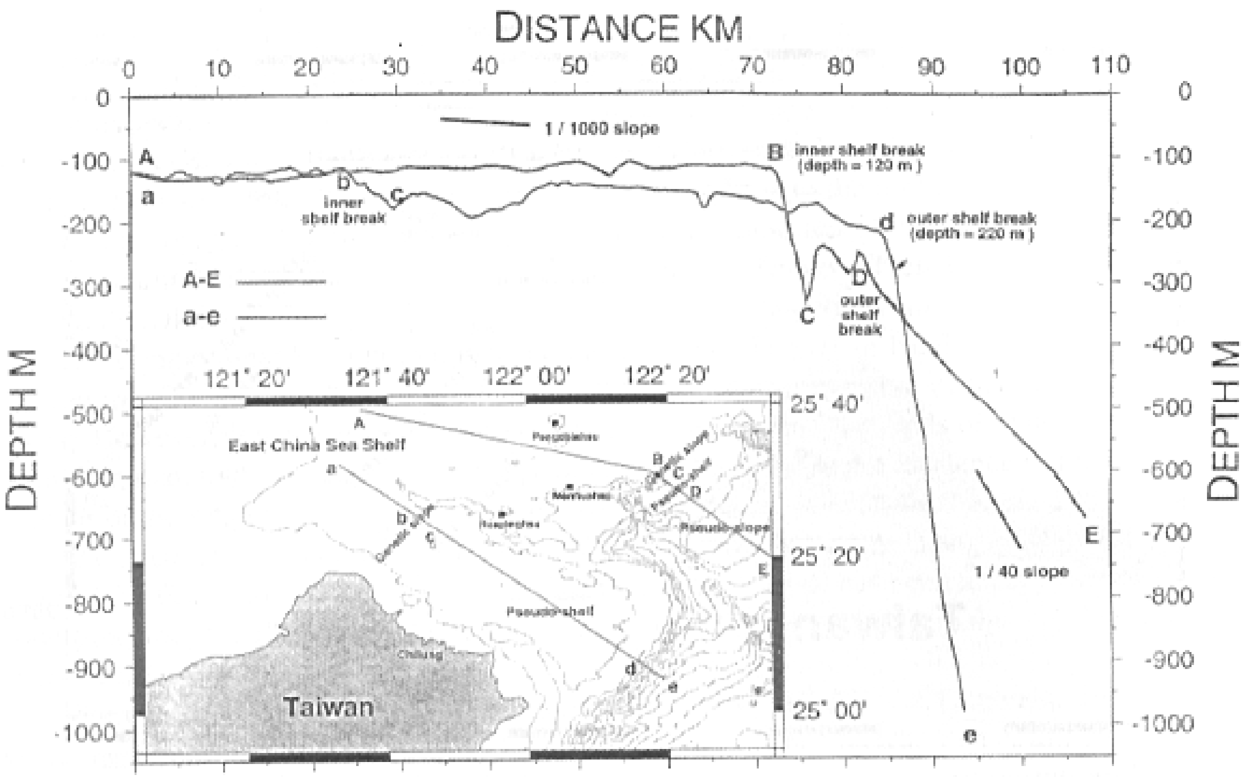

Fig. 4. Two typical profiles on the continental terraces off northern Taiwan. Categorized features, such as the inner and outer shelf-break, are shown along the profiles. In addition, two short lines with gradients of 1/1000 next to the shelf and 1/40 next to the slope are indicated for reference. The profiles and the provinces defined in the text are shown on the map in the lower-left hand corner.

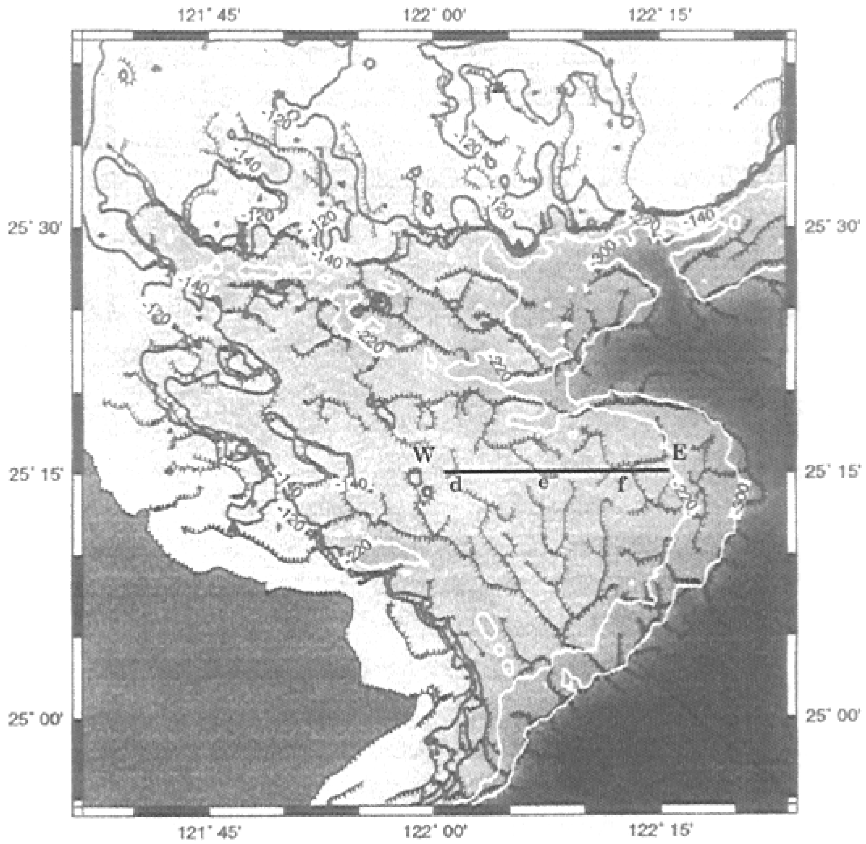

Fig. 5. Map showing 120, 140, 220 and 300m isobaths indicating the traces of the inner and the outer shelf breaks. The E-W straight line is the location trace of the seismic profile shown in Figure 9. d, e and f mark the targets found along the profile intersecting with the "break" lines. The "break" lines are done by the self-developed automatic line extraction computer program (Chang, 1997). These "break" lines indicate the edge traces of the break topography as discussed in the text.

If the 140-meter isobath represents the coastline of the last glacial period, it follows that the Chilung Shelf has been submerged for 15,000 years. However, the Chilung Shelf was exposed and under the subaerial process during the last glacial period. Because of that, its surface covers with the relicts without the deposit of terrigeous sediments on the bottom off northern Taiwan (Niino and Emery, 1961; Boggs *et al.*, 1979). The sediments of the relicts consist of poor sorted gravel mixed with plenty of shelly fragments (Boggs, *et al.*, 1974). Figure 6 shows the distribution of shells in the shelfal region, including the area of the Chilung Shelf, and implies that the paleo-coastline might not follow the 140m isobath in the region of the Chilung Shelf.

This being the case, it might be asked what happened to the Chilung Shelf. There is a difference in elevation of more than 150 meters between the shelf breaks of the Chilung and Tunghai Shelves. From the b-d profile in Figure 4, the sea floor of the Chilung Shelf descends at a gradient of 1/600 to the southeast which is about two times greater than that of the world average as well as that of the Taitung Shelf. Although profile b-d shows that the edge of the Chilung Shelf is at the water depth of 220 meters, the shelf break following the 300m isobath in the Chilung Shelf is determined in Figure 5.

Tectonic subsiding behavior might have been acting in the Chilung Shelf area since the last Pleistocene glacial period. First, the stress analyses indicate that northern Taiwan has been under an extensional condition since the Pleistocene (Lee & Wang, 1988; and Yeh *et al.*, 1991). Secondly, volcanism implies that extensional dynamics have been dominant in the region surrounding the Chilung Shelf (Chen, *et al.*, 1993). Finally, several tectonic models suggest that the extensional processes might have been taking place in the Chilung Shelf as a result of the occurrence of a series of strike-slip faults in/off northern Taiwan in the orogenic environment (Huang *et al.*, 1992; Lu and Malavieille, 1994; and Song *et al.*, 1997).

Off northern Taiwan, topographic lineaments that extend from the fault zones onland seem to be aligned northeastwardly (Figure 7). These lineaments are closely correlated with the topographic imprints in terms of the compressive thrust mechanics under the orogeny (Song *et al.*, 1997). In the 3-D view, Figure 8 shows a typical step-like bathymetric feature outlining the western boundary of the Chilung Shelf. The offshore trace of the Chinshen Fault; however, can barely be identified in the drawing, but this is on account of its trace being severely truncated by the Chilung Valley (Song *et al.*, 1997)

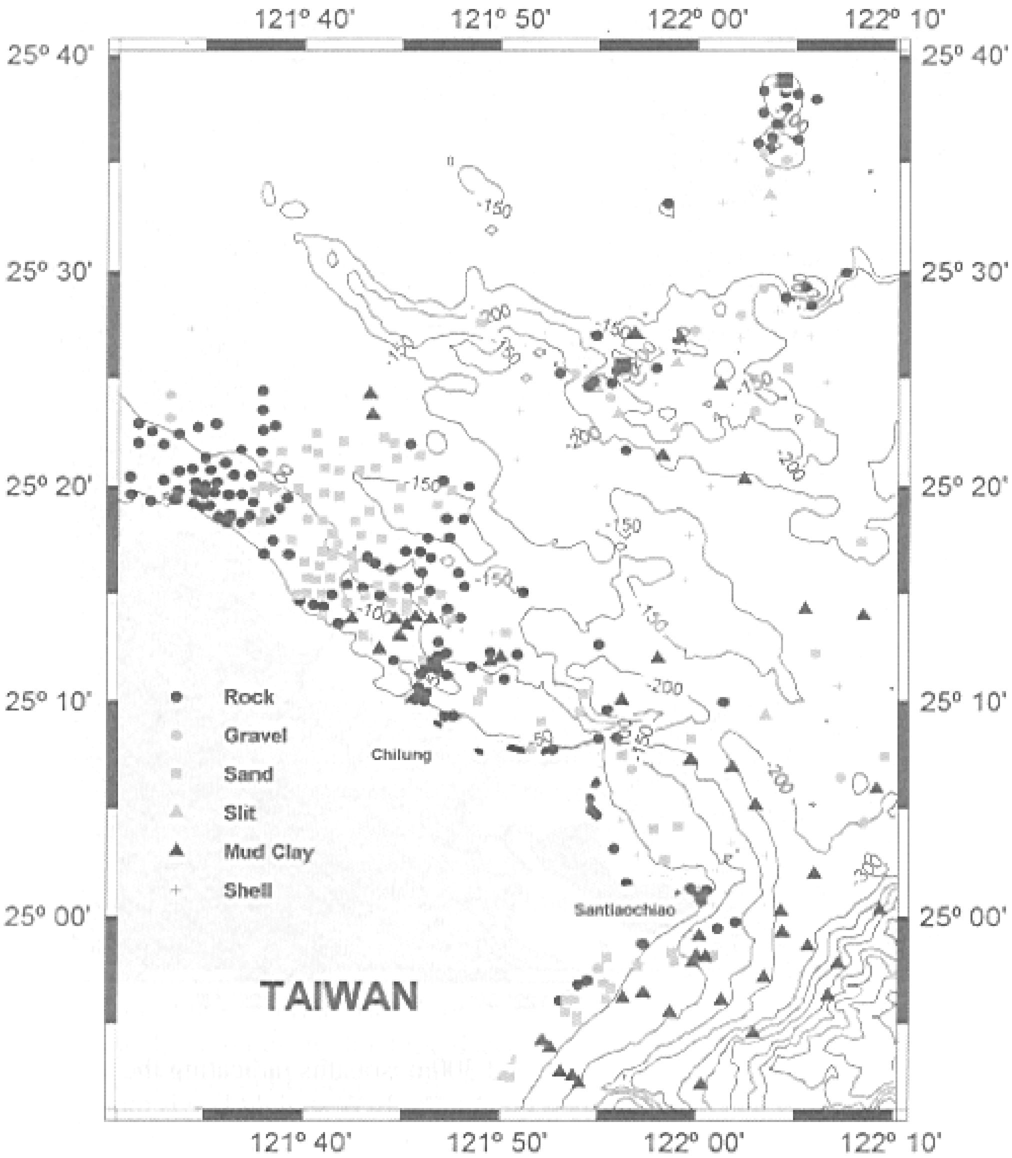

Fig. 6. Surface sediment distribution map. Types of sediments are based on the Chinese Navy Chart, No.0352, 3rd. ed., 1975.

In the Chilung Shelf, a number of semi-parallel lineaments are aligned in the NE-SW direction (Figure 7). Although the occurrence of thrust mechanics is suggested (Song *et al.*, 1997), the normal mechanics exerted along the trace of the lineaments are found. The seismic profile in Figure 9 indicates the motions of normal faulting behaviour occurring in the three locations, d, e and f which can be identified with the respective traces of the lineaments (Figure 7).

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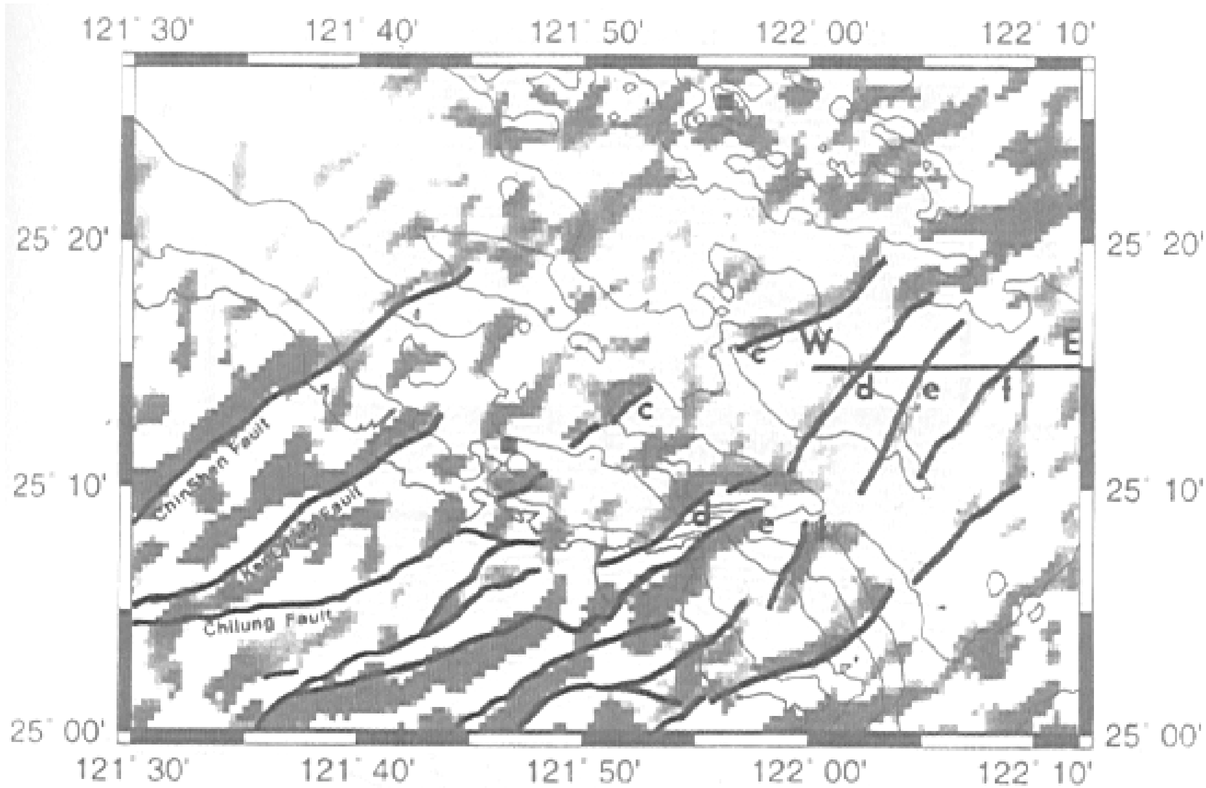

Fig. 7. Topographic traces denoting the fault lineaments which show the structural relationship between the Chilung Shelf and northern Taiwan. The shadings shown on the plot are the illuminated shadow from the northwest, representing the blocked sides of topographic highs. The plotting of the traces of the faults is described in Song *et al.* (1997).

The location of the seismic profile of Figure 9 is again shown in Figure 5. Nevertheless, three faulting features of d, e and f intersect with the "break" lines that characterize a cliff-like or a "break" topography. In Figures 5 and 10, the pins of the comb-shaped "break" lines stand at the downslope sides crossing the "break". According to their geometries, the edges of the banks fencing the territories of the Chilung Valley and the Mein-Hua Canyon are determined (Figure 10).

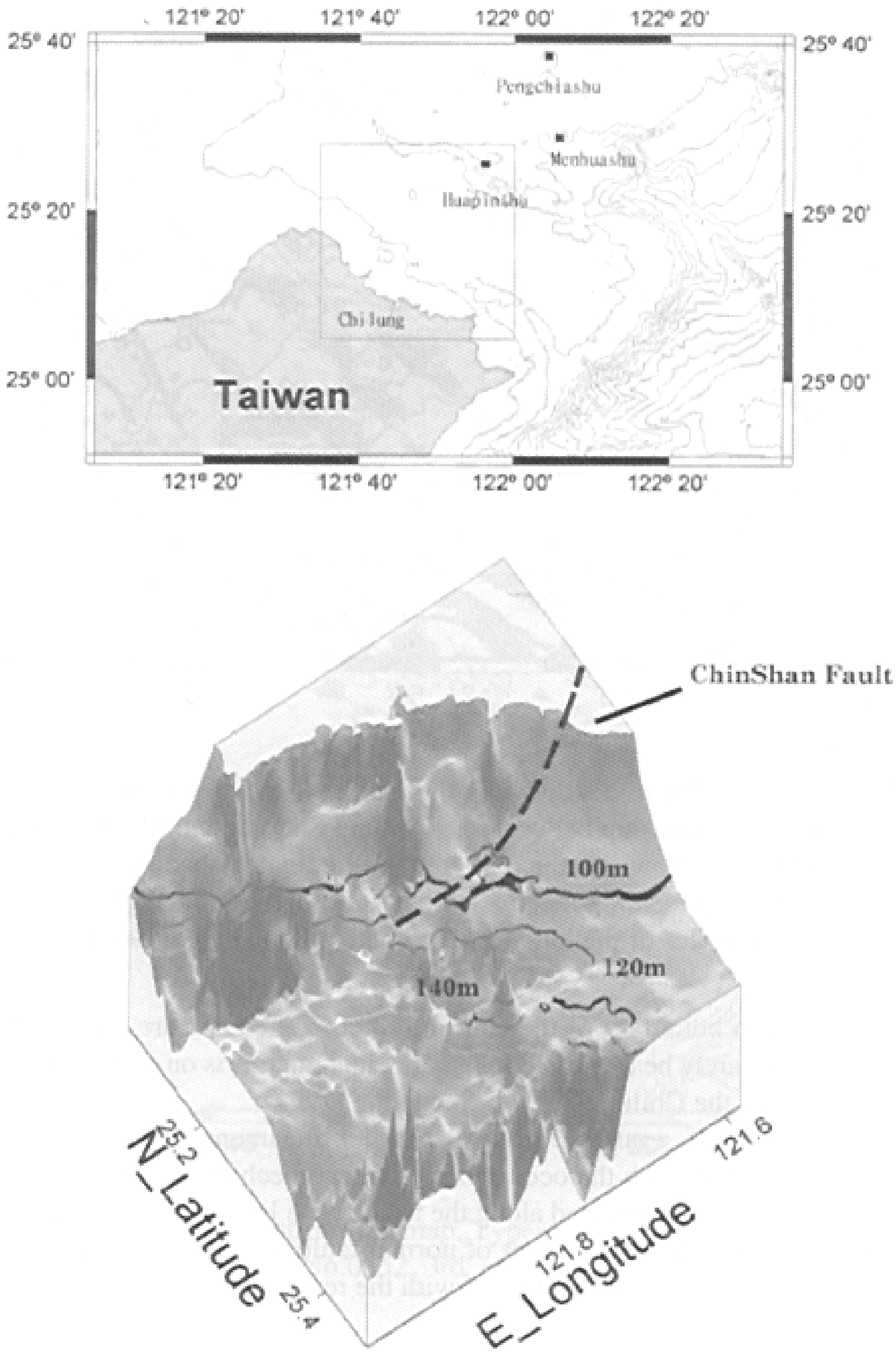

Fig.8. 3-D plot around the west end of the Chilung Shelf. The 100m and 120m isobaths are shown by solid black lines, while the 140m isobath is shown by the white line. The dash line represents the possible path of the Chinshen Fault under the ocean.

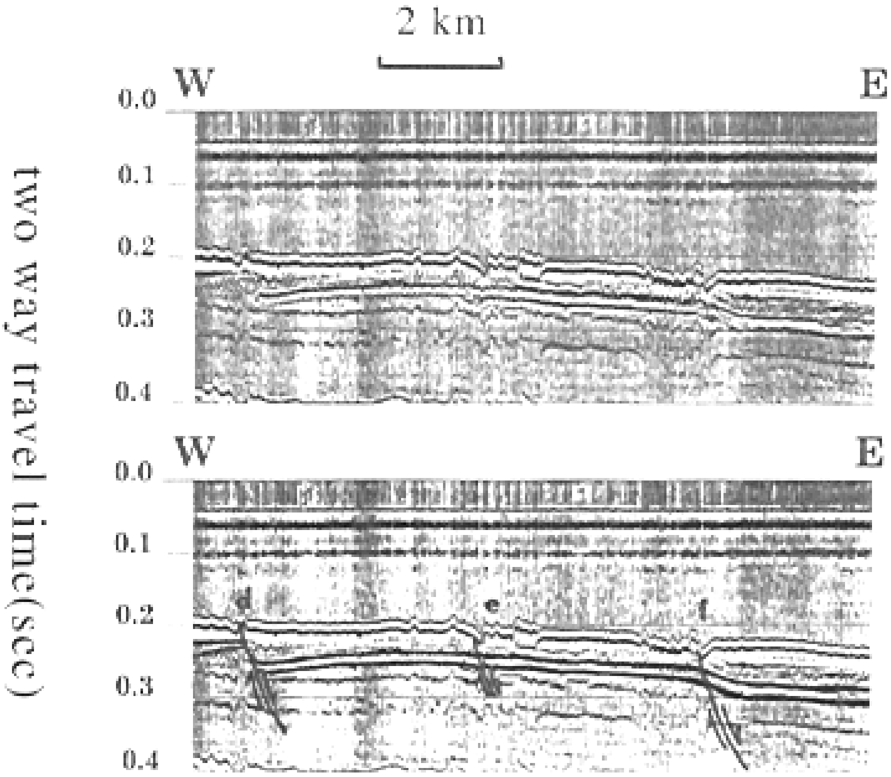

Fig. 9. Seismic profile across the THPS area. A single-fold seismic reflection data set using the 120 cubic inch, 2 air-gun array was obtained on the 355 cruise of reasearch vessel of the Ocean Reasearch I (the R/V OR-1). The Locations of the profile (denoted by E-W) are shown on Figures 5 and 14.

The "break" topography transgressing to the east is dominant in the Chilung Shelf. This implies that the Chilung Shelf descends in terms of the normal motions sliding on the paleothrust planes which originally extented from onland Taiwan. To the east, it descends even more. Figure 11 shows four bathymetric profiles across the outer region of the Chilung Shelf. The steepness of declining gradients average six times greater (at 1/100) in the deep shelfal region between the 220m isobath and the shelf break (Figures 10 and 11). These profiles show the shelf breaks at varying depth levels from 264m to 331m.

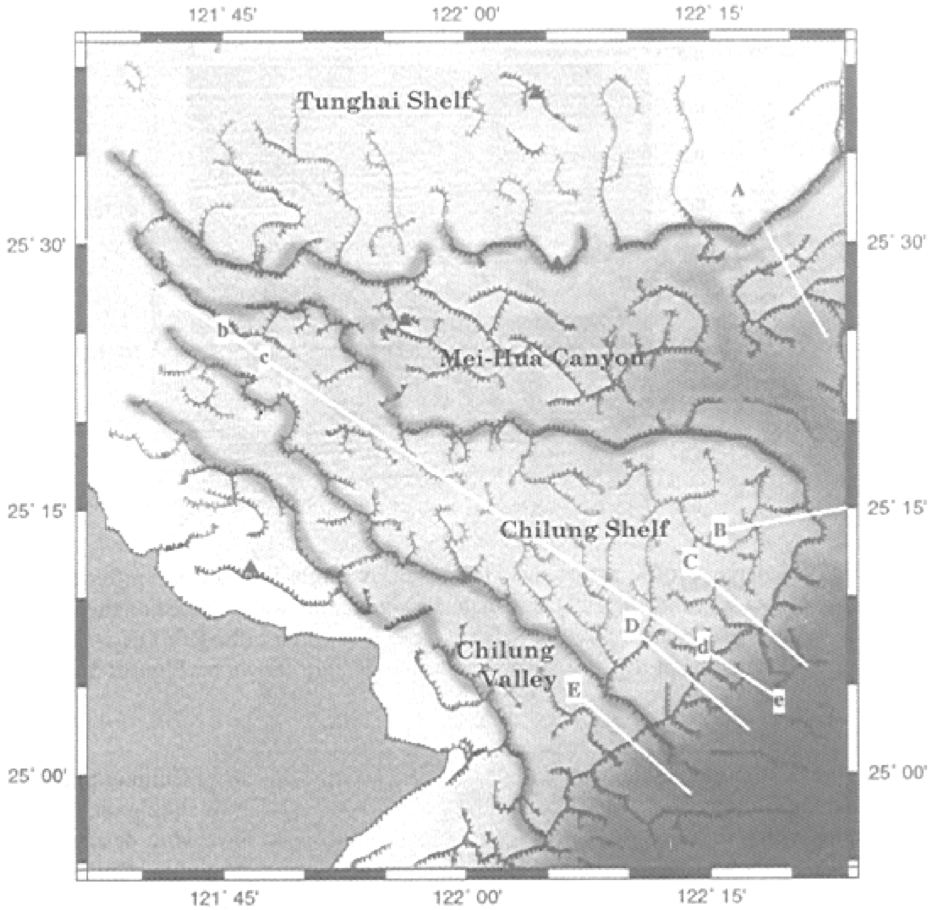

Fig. 10. Topographic map illustrating the regions of the physiographical units Each unit is defined by the solid lines on the basis of the distribution of the "break" lines. The white lines across the outer region of the shelves denote the locations of the A, B, C, D and F profiles shown in Figure 11. The profile across the Chilung Shelf shown in Figure 4 is also indicated for reference.

4. DISCUSSION

The Greater Okinawa Trough was called by Kimura (1985), to define the area which has been affected by back-arc extension. This area has a width about twice as large as that in the region occupied by the Okinawa Trough (Figure 12). The north boundary of this zone is defined by the Tunghai Shelf Fault. In Figures 2 and 13, this fault is located along the edge of the Tunghai Shelf to the north of the Mein-Hua Canyon, but it loses its trace going into the Chilung Shelf. Thus, the tensile rifted phenomenon that results in the opening of the Okinawa Trough prevails in the Tunghai Shelf/Slope but diminishes once it has crossed the Mein-Hua Canyon or is in the Chilung Shelf.

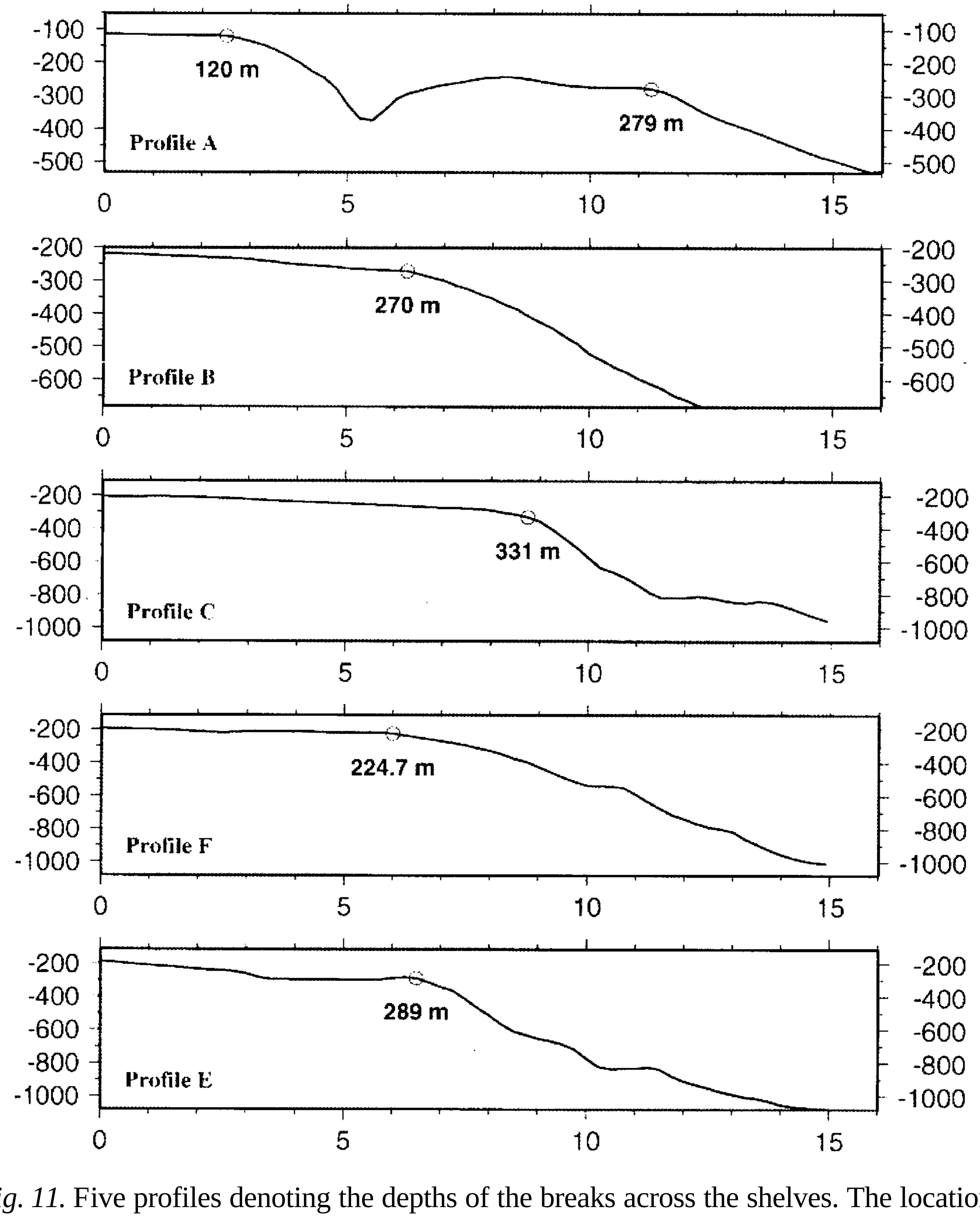

Fig. 11. Five profiles denoting the depths of the breaks across the shelves. The locations of the profiles are shown in Figure 10. The X axes represent the horizontal distances in kilometers, while the Y axes are the water depths in meters. The locations of the shelf break determined numerically (Chang, 1997) are marked by open circles.

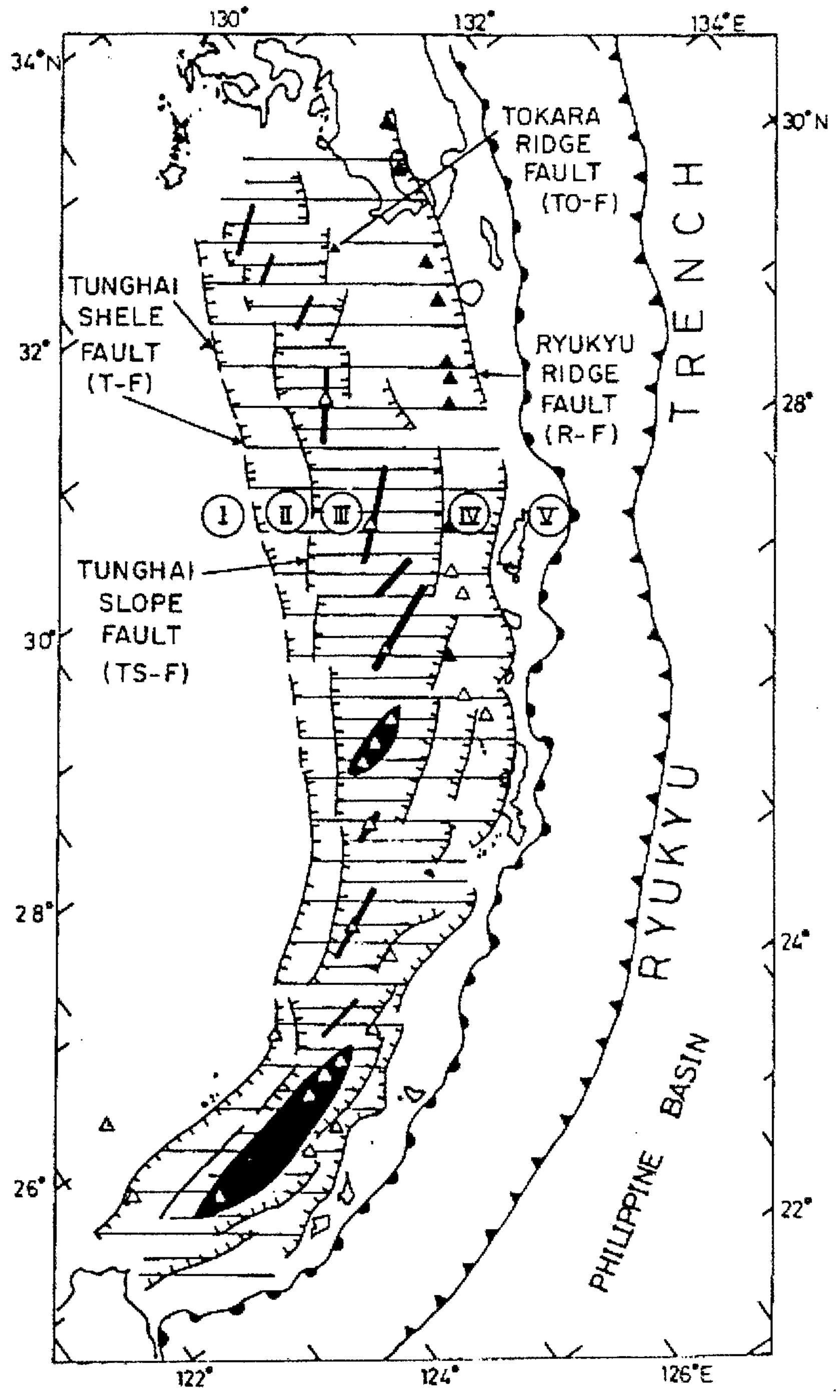

Fig. 12. Great Okinawa Trough and its structural units, as defined by Kirnura (1985). In this plot, the Tunghai Shelf Fault marks the trace of the northern boundary of the Great Okinawa Trough.

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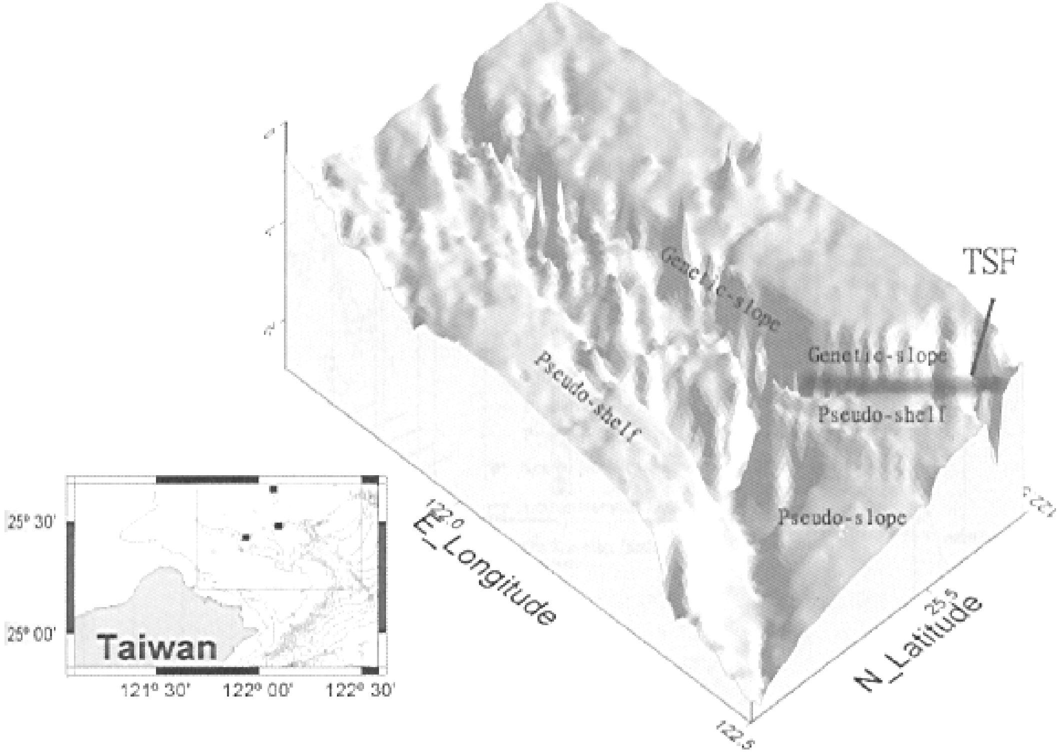

Fig. 13. Simulated 3-D plot. The values along the Z axis stand for D where D = -ln((d+100)/100), and d is the measurement of water depth and denotes the categorized units around the region of the Mien-Hua Canyon, as viewed from the southeast and illuminated from the northeast. The extent of this area is shown by the location map in lower-left hand corner.

A genetic slope is circled by the trace of the inner shelf break off northern Taiwan. This suggests that this slope was formed by a certain extentional mechanism. Consequently, the genetic slope defines the boundary between the Tunghai Shelf and the Chilung Shelf (Figure 2). The inner shelf break is at a water depth of about 120 meters, and it separates the region from the processes of subsidence.

Surrounded by the genetic slope, a pseudo-shelf is named for those subsiding continental shelves which stand at retreating portions of the Tunghai Shelf. Therefore, it has a deeper depth and a steeper surface than the ones of typical shelves or of the Tunghai Shelf. Its seaward boundary is at the outer shelf break around the water depth of 300 meters (Figures 4 and 5) representing the paleo-shelf break under considerable subsiding motions.

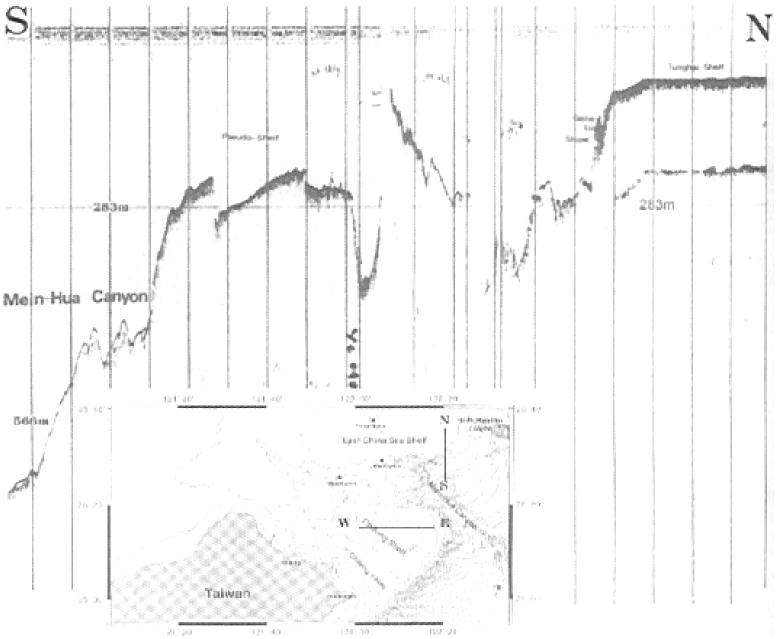

Fig. 14. 3.5kHz profile across the CLPS area. This subbottom profiler data set was obtained on the 348 cruise of the R/V OR-1. The profile shows normal faulted behavior with subsided blocks on/toward the flank of the pseudo-slope (Song et al., 1997). Location map of the profile (denoted by S-N) is in the lower-left hand comer.

In the area off northern Taiwan, two pseudo-shelves are identified (Figure 5). South of the Mein-Hua Canyon, the ChiLung Pseudo-Shelf (CLPS) includes the regions of the Chilung Shelf, the Chilung Valley and a portion of the southern flank of the Mei-Hua Canyon. North of the Mien-Hua Canyon, the TungHai Pseudo-Shelf (THPS) designates the region that slides downward upon the Tunghai Shelf Fault plane (Figure 13).

The THPS area is about 10 kilometers wide and is situated between the Mein-Hua and the North Mein-Hua Canyons. Its surface is truncated by several high angle normal faults (Figure 14), indicating that it has been under a concentf ated rifting process exerted by the opening of southern Okinawa Trough. These faults extending deep to the base of the trough result in the continental slope being too gentle compared with a more typical slope (the pseudo-slope is called in Figure 2 and 13). The average gradient of this slope is at 1/77, which is about seven times less steep than that of the Chilung Slope (Figure 4).

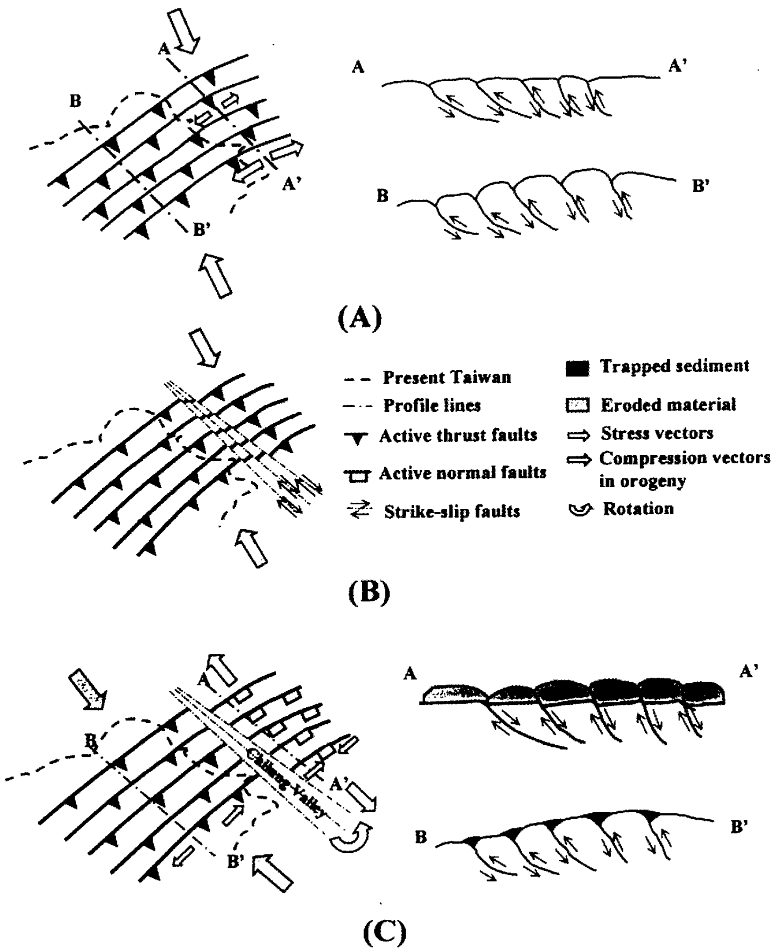

Fig. 15. Model demonstrating the straining processes in/off northern Taiwan.

The CLPS area may lie northward off the southern bank of the Chilung Valley where the inner shelf break (at the water depth of 120 meters) follows the trace of the "break" lines in Figure 5. The area includes the Chilung Valley because the descending gradient down the axis of the valley is almost identical to that shown on the Chilung Shelf (Song et al., 1997). Song et al. (1997) show the Chilung Valley is molded by a series of right-lateral strike-slip faults that were created under an orogenic environment. However, in the beginning of orogeny, the compression resulting in a series of faults in terms of the thrust mechanism aligned in the NE-SW direction must extend under the ocean off northern Taiwan (Figure 15A) (Lu and Malavieille, 1994; Song et al., 1997). As soon as the fractures appeared and the strike-slipping occured, the coastal zone was formed and uplifted (Figure 15B) Subsequently, the CLPS was rebound from compression, and the NE-SW oriented thrust planes turned into sliding surfaces contributing to the subsidence of the CLPS (Figure 15C).

5. CONCLUSIONS

Off northern Taiwan, the pseudo-shelf has a subsided morphology whose boundary is governed by structural traces with normal-faulted mechanics. North of the Mein-Hua Canyon, the region called the THPS mainly suffers from back-arc rifting exerted by the opening of the southern Okinawa Trough. South of the Mein-Hua Canyon, the region called the CLPS has tectonic imprints suffering and recovering from the processes of orogeny.

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