

Morphological and Seismic Characteristics of the North Mien-Hua Submarine Canyon off Northeastern Taiwan

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ABSTRACT

The North Mien-Hua Canyon on the East China Sea Slope off northeastern Taiwan is a multi-headed canyon. Four distinct heads immediately below the shelf edge coalesce to form a single canyon near the 900 m isobath in the lower slope region. Morphologically, the North Mien-Hua Canyon can be divided into two distinct units: the upcanyon segment which is the fan-shaped sloping region extensively cut by these four tributary canyons, and the downcanyon section which is short and straight with no tributaries.

These four tributary canyons are characterized by steep-sided V-shaped troughs with high reliefs in excess of 500 m, suggesting intense down-cutting of the canyon. The single canyon course on the lower slope still maintains a V-shape in cross-section but with a curved and irregular canyon bottom, implying partial sediment infilling. The seismic profiles show termination of parallel reflectors of slope sediments against the canyon walls and slumping features, providing evidence of downslope submarine excavation along the canyon course. Cut-and-fill features are only recognized in the downcanyon section. Morphological and seismic characteristics indicate that the upcanyon segment is dominated by erosion and the downcanyon section is represented by multiple episodes of canyon erosion and deposition.

The North Mien-Hua Canyon began as submarine incisions or gullies on the upper part of the East China Sea Slope. Downslope excavation deepened and widened the gullies into tributary canyons which in turn flowed downslope and joined together to form a single canyon. The seismic data provide no evidence of faults along or across the canyon course, suggesting the origin of the canyon might not be fault-related.

(Key words: Canyon, Morphology, Seismics, Taiwan)

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1. INTRODUCTION

The sea floor off northeastern Taiwan consists of three major physiographic provinces: the East China Sea Shelf, the East China Sea Slope and the Okinawa Trough. Near Taiwan, the East China Sea Slope is a gentle slope with an average angle of 1.3 degrees. The upper boundary of the slope is placed at the shelfbreak, which is about 120 m deep, and the base of the slope is at a depth which ranges from 1700 to 2000 m near the bottom of the Okinawa Trough (Yu *et al.*, 1997). Near Taiwan the East China Sea Slope is extensively cut by two major submarine canyons and many gullies which incise intercanyon slopes producing irregular topographic features (Figure 1).

Submarine canyons on the East China Sea Slope off northeastern Taiwan have been discovered but not fully investigated. Boggs *et al.* (1979) suggested that these unnamed submarine canyons were initiated by subaerial erosion during the low stand of sea level in the Late Pleistocene and were later submerged, due to Quaternary transgression which preserved them. The naming of sea valleys and submarine canyons off northeastern Taiwan was discussed by Yu (1992, 1993) and Song and Chang (1993). Yu and Hong (1993) described the morphology of the Mien-Hua Canyon which is characterized by a channel/canyon system. The North Mien-Hua Canyon is located northeast of the Mien-Hua Canyon on the East China Sea Slope (Figure

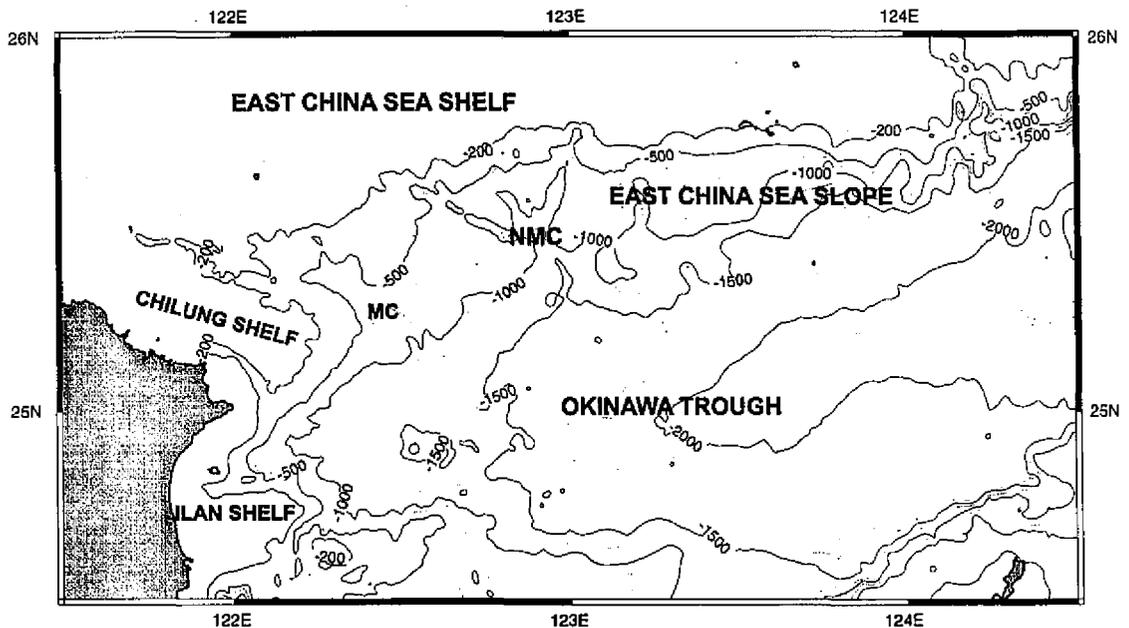


Fig. 1. Map showing that East China Sea Shelf, East China Sea Slope and southern Okinawa Trough make up the continental margin off northeastern Taiwan. Two major submarine canyons appear on the East China Sea Slope: Mien-Hua Canyon (MC) and North Mien-Hua Canyon (NMC). Contour intervals in meters.

1). Until now, there is no single published paper specifically dealing with the North Mien-Hua Canyon.

The purpose of this paper is to describe the morphology of the North Mien-Hua Canyon in detail and the relationship between the morphology and canyon-forming processes. It also discusses a possible origin of the canyon using bathymetric data and multi-channel seismic reflection profiles.

2. DATA

Bathymetric data and multi-channel seismic reflection profiles in the areas covering the North Mien-Hua Canyon were acquired on board R/V Ocean Researcher I. Bathymetric data (about 450 km tracklines) were recorded by a Simrad EK 500 Sonar. Newly collected bathymetric data were integrated into the bathymetric data bank compiled by the Institute of Oceanography, National Taiwan University (Figure 2). The bathymetric chart showing the North Mien-Hua Canyon is then generated from the bathymetric data bank using the GMT system (Wessel and Smith, 1991). An air-gun array is the seismic source. The DFS-V floating gain digital system on board R/V Ocean Researcher I is the recording device. Field seismic data are processed using the SIOSEIS system at the Institute of Oceanography, National Taiwan University. The tracklines are about 450 km of which six transects across the North Mien-Hua Canyon are used in this study (Figure 2).

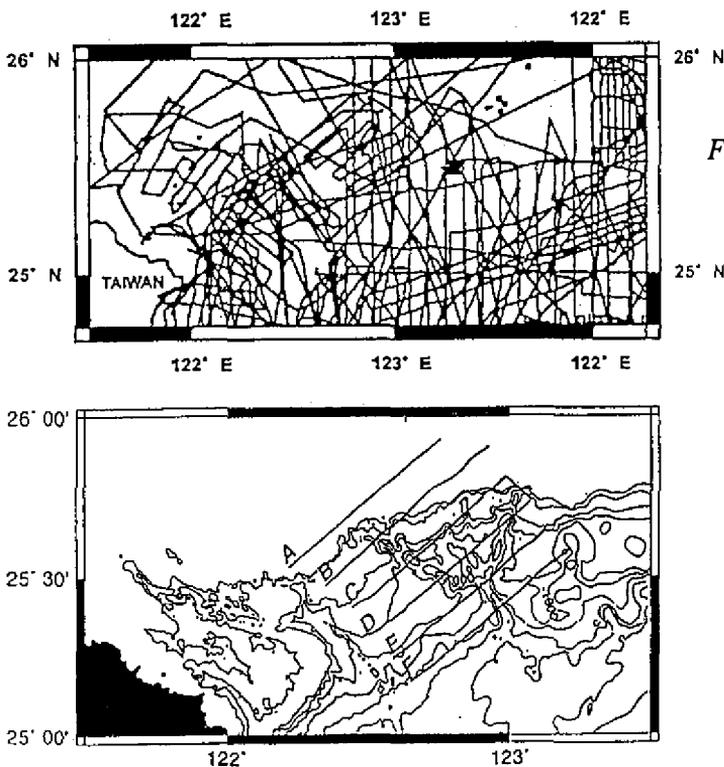


Fig. 2. Map showing tracklines derived from bathymetric data bank compiled by Institute of Oceanography, National Taiwan University. These tracklines cover parts of the continental margin off northeastern Taiwan, including North Mien-Hua Canyon (top of this figure). Locations of six bathymetric and seismic profiles across North Mien-Hua Canyon collected by this study are shown at the bottom of this figure.

3. MORPHOLOGY

3.1 Shape

The North Mien-Hua Canyon consists of four discrete tributary canyons on the upper slope of the East China Sea Slope and a single straight canyon on the lower slope (Figure 3). These four tributaries in the headward region are tentatively named from west to east as canyons W, X, Y and Z, respectively. In plan view, the North Mien-Hua Canyon displays a fan-shaped or triangular erosional feature. The apex of this triangle is located at approximately 122° 50' E and 25° 30' N where the water depth of the canyon floor is about 1400 m (Figure 3). Clearly, the areal extent of the East China Sea Slope affected by canyon erosion decreases from the heads to the canyon mouth. The area occupied by the four tributary canyons at the upper slope is about 1,200 square km. In contrast, the single straight main canyon at the lower slope occupies about 120 square km. Note that the cross-sectional span opened up the four tributary canyons is about 60 km and that this narrows to a 7 km-wide cut for the single canyon.

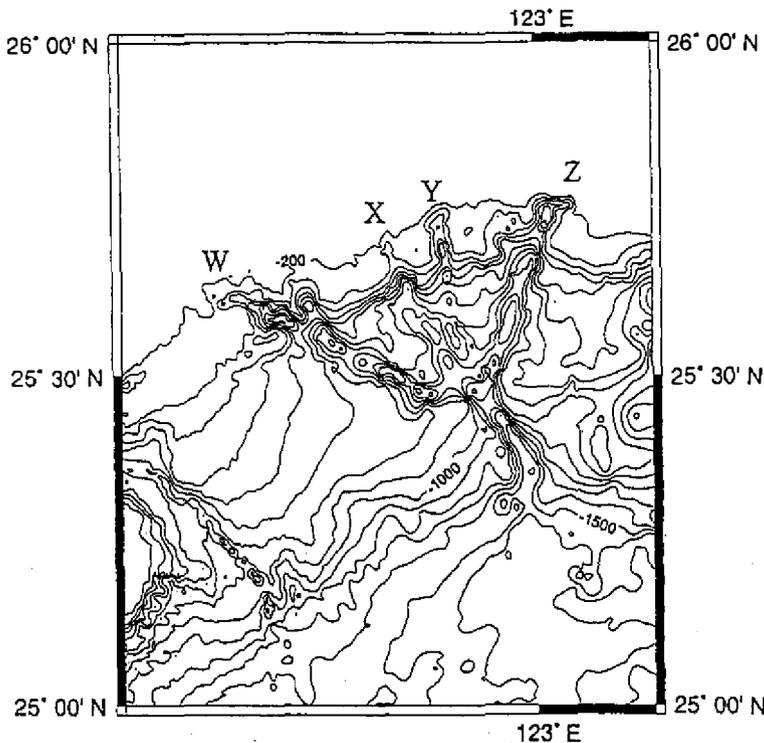


Fig. 3. North Mien-Hua Canyon displays a fan-shaped erosional feature and consists of four discrete tributary canyons in the headward region and a single straight canyon in the downcanyon segment. These four tributary canyons are tentatively named from west to east as canyon W, X, Y, and Z, respectively.

Morphologically, the North Mien-Hua Canyon can be divided into two distinct units: an upcanyon section, a fan-shaped sloping region extensively cut by four tributary canyons, and a downcanyon section, a straight and deeply-cut V-shaped trough with steep walls in the lower slope, which merges on the upper slope with four discrete tributary canyons.

3.2 Cross-sectional Forms

As shown in Figure 4, six bathymetric profiles across the North Mien-Hua Canyon reveal steep-sided V-shaped troughs with varying incision depth which are a typical cross-sectional morphology for submarine canyons (Shepard and Dill, 1966; Shepard, 1973; Bouma, 1990).

Profile A near the shelf edge shows that the sea floor is a smooth and flat surface, suggesting no down-cutting features. Profile B, which cuts across canyon W, shows that the head of canyon W is a shallow V-shaped notch. Profile C, located further downslope, transverses the upper slope and shows three distinct narrow V-shaped troughs with steep sides. These three troughs are designated as canyons W, X and Y, respectively. Canyons X and Y have widths ranging from 4 to 5 km and reliefs from about 360 to 420 m, reflecting relatively intense erosion. Profile G is a short section trending NW-SE across the head of tributary canyon Z which is characterized by a steep-sided trough with relief in excess of 400 meters. Further downslope, Profile D shows four discrete tributary canyons within a distance of about 35 km. Note that these four tributary canyons are characteristic V-shaped cross-sections with steep walls.

Tributary canyons W, X, Y and Z merge together to form a single steep-sided canyon at a water depth of about 800 m at the canyon edge (Profile E). This canyon segment is about 7 km wide with a bottom depth of about 1400 m and a relief in excess of 600 m. Note that the bottom of this canyon segment is relatively irregular, implying erosional/depositional features. In contrast, Profile F shows a single U-shaped trough near the 1000 m isobath. It is noted that the canyon floor is relatively flat, probably resulting from sediments filling up the deepest part of the canyon axis. The main course of the North Mien-Hua Canyon continues to extend south-eastward to the deep basin of the Okinawa Trough.

3.3 Dimensions

Depth, width and relief measurements for the North Mien-Hua Canyon are described here. The width of the head of Canyon W is about 2.7 km and the depth of the canyon floor is around 616 m. As shown on profiles B, C and D, in a downcanyon direction, Canyon W increases its depth from 616 to 1310 m and its width from 2.7 to 4.2 km. The reliefs of Canyon W along its course range from 337 to 518 m. The slope angles of both walls of Canyon W range from about 5.5 to 20.1 degrees, showing typical steep canyon walls.

Further downcanyon (profiles C and D), the width of Canyon X is about 5.1 km with depth ranging from 953 to 1241 m. Both walls are steep with slope angles in excess of 16 degrees. Similar to Canyon X, the width about 4 km, depth range and canyon wall slope angles of Canyon Y are 674 to 1111 m and greater than 15 degrees, respectively. The width and axial gradient of Canyon Z were not measured from bathymetric profiles because of the obliqueness

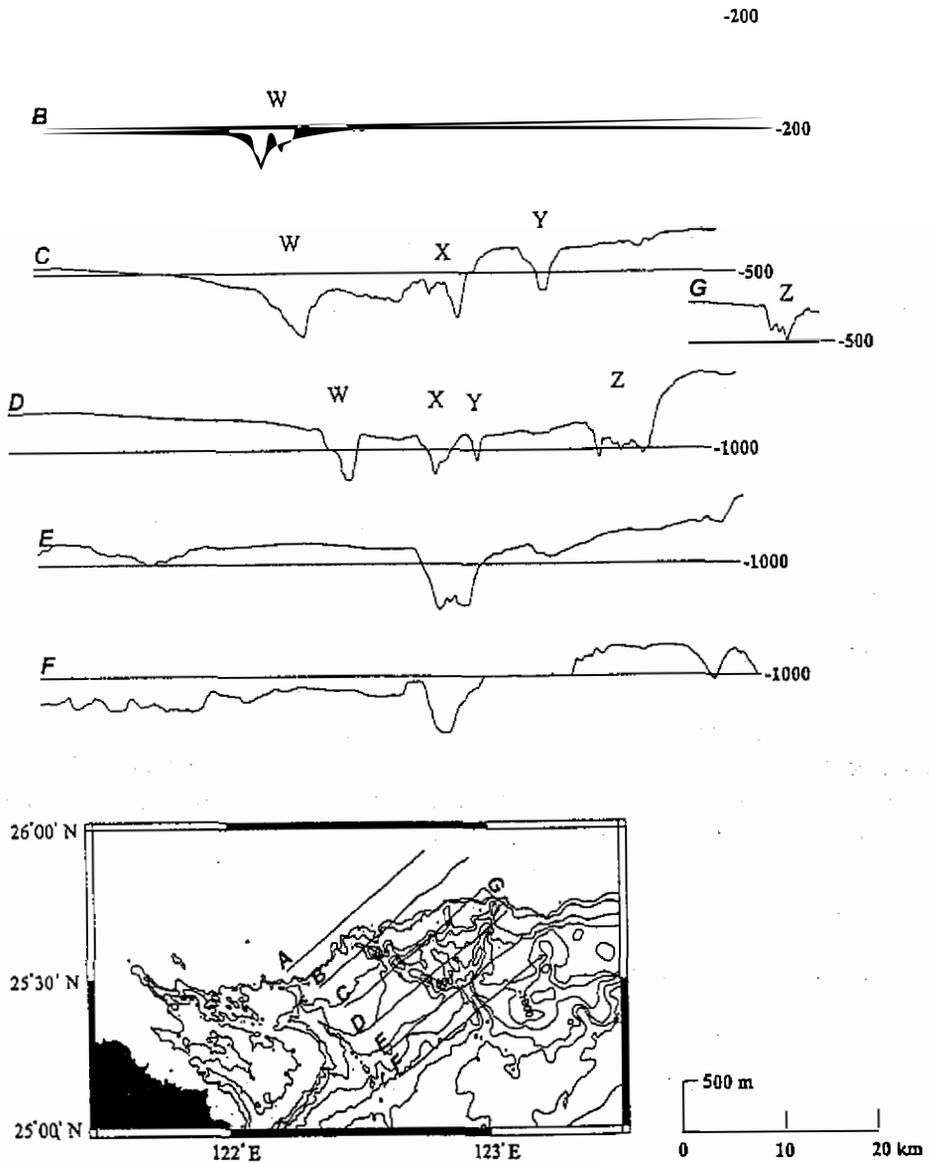


Fig. 4. Cross-sectional morphology of North Mien-Hua Canyon. Locations of six bathymetric profiles are shown at the bottom of this figure.

of the crossing of the canyon course.

Tributary canyons W, X, Y and Z join together to form the single main course of the North Mien-Hua Canyon at a water depth of about 900 m at the canyon edges as shown on profile E. The width of the North Mien-Hua Canyon in profile E is about 6.9 km and the canyon floor is at a depth of about 1463 m. Both canyon walls display steep slope angles in

excess of 17 degrees. Further downcanyon, the canyon morphology revealed in profile F is similar to that in profile E.

In general, these four tributary canyons W, X, Y and Z increase their width and deepen their canyon floor in a downcanyon direction and the steep canyon walls maintain slope angles of between 10 and 15 degrees. The straight main canyon course is about 6.5 km wide and 17 km long and has steep walls angled at around 10 degrees.

3.4 Longitudinal Profile and Relief

As shown in Figure 5, the thalweg of tributary canyon W, with an average gradient of 1.25 degrees, extends southeast for about 58 km to the canyon junction C where the main course of the North Mien-Hua Canyon begins. The canyon axis of tributary X, with an average slope angle of 2.15 degrees, follows a southeast direction for about 34 km, then joins the main course of the North Mien-Hua Canyon. Tributary canyon Y, which has an average gradient of 2.1 degrees, has its head in 200 m of water and extends south across the slope for about 37 km where it joins the main course of the canyon. Tributary canyon Z has an average gradient of 1.93 degrees and trends southwest for about 41 km to the canyon junction C.

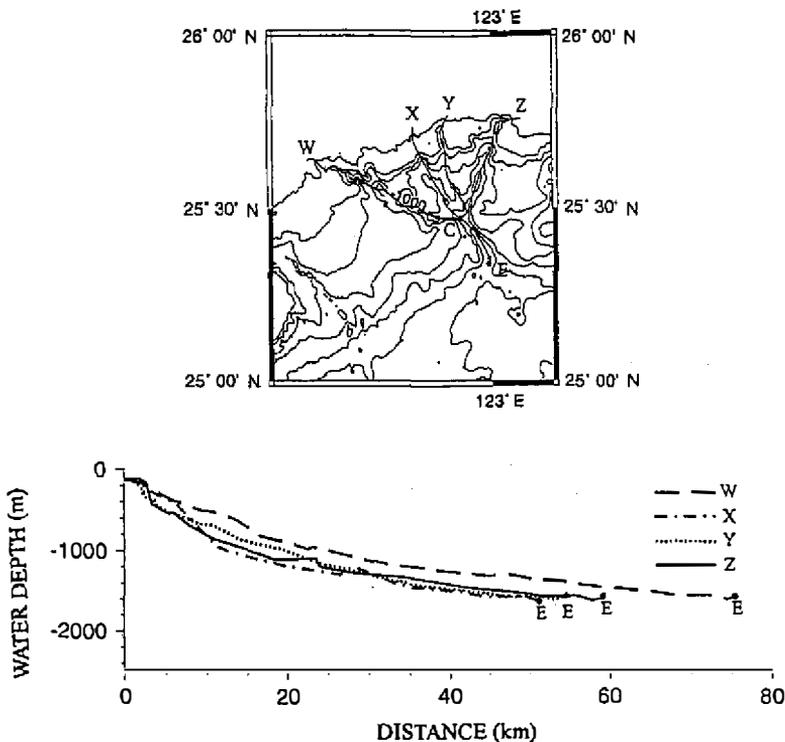


Fig. 5. Axial profiles of tributaries and main course of North Mien-Hua Canyon showing seaward gentle slopes. Note that the gradients of upcanyon segment are greater than that of the downcanyon course.

The main course of the North Mien-Hua Canyon, with an average slope angle of 0.12 degrees, begins at a water depth of about 1463 m and extends southeast for about 17 km where the canyon discharges on the basin floor of the southern Okinawa Trough. In general, the floors of the North Mien-Hua Canyon, including the four tributaries, show gentle continuous slopes which are typical of continental slope canyons (Bouma, 1990).

Reliefs of the North Mien-Hua Canyon increase along its courses, from the heads of its tributaries to the mouth where it ends. For instance, the relief of tributary canyon W increases from 337 m in the head portion to 580 m at the canyon mouth. The increasing incision depth along the canyon course suggests that down-cutting into slope sediments predominated in the downcanyon section, although the gradients (about 1.8 degrees) of canyon thalwegs in the upcanyon region are an order greater than that (0.12 degrees) in the downcanyon segment. It seems that the gradient of the canyon axis is not directly related to canyon erosion of the main canyon course. Alternatively, the energy level of downslope-eroding sediment flows is probably an important factor in the deepening and widening of the North Mien-Hua Canyon.

Morphological measurements suggest that the North Mien-Hua Canyon is a relatively small canyon in terms of width (2 to 7 km) and length (about 80 km). Bering Sea canyons (100 km wide, 800 km long) are the world's largest canyons (Carlson and Karl, 1984, 1988). Morphological comparison of canyons of the North Mien-Hua Canyon and the Bering Sea indicates that the North Mien-Hua Canyon is indeed a very small canyon. The V-shaped troughs, steep canyon walls with slope angles of between 10 and 15 degrees and great reliefs ranging from about 300 to 600 m together indicate intense incision of slope sediments. Therefore, erosion of down-cutting predominated on the East China Sea Slope near northeastern Taiwan, resulting in the formation of the North Mien-Hua Canyon.

4. SEISMIC CHARACTERISTICS AND SEDIMENTARY PROCESSES

Six seismic reflection profiles trending NE-SW across the course of the North Mien-Hua Canyon are shown to display seismic characteristics and to infer sedimentary processes forming the canyon (Figures 6-13). The locations of these seismic sections are in Figure 2.

Profile A, located immediately north of the canyon heads, shows that the sea floor is represented by a strong and relatively flat reflector, suggesting no down-cutting features (Figure 6). However, some slightly inclined reflectors are truncated against the reflector of the sea floor to form stratigraphic pinchouts, suggesting a denudation effect in the Late Pleistocene period of glacially lowered sea level (Boggs *et al.*, 1979). The southwest part of Profile B below the 200 m isobath (Figure 4) shows a small shallow trough characterized by a V-shaped cross-section and terminated parallel reflectors at the walls of the trough (Figure 7). This trough is considered to be the head of tributary canyon W. The northeast portion of Profile B on the shelf shows truncation of inclined reflectors without down-cutting troughs.

The upper slope immediately below a shelf edge is the place where slope failure commonly initiating canyon erosion and development (Twichell and Roberts, 1982; Farre *et al.*, 1983). Therefore, it is reasonable to expect the head of tributary canyon W to begin at such a place just below shelfbreak. Profile C, farther downslope, shows three distinct V-shaped troughs which are designated as tributary canyons W, X and Y, respectively (Figure 8). Thicker se-

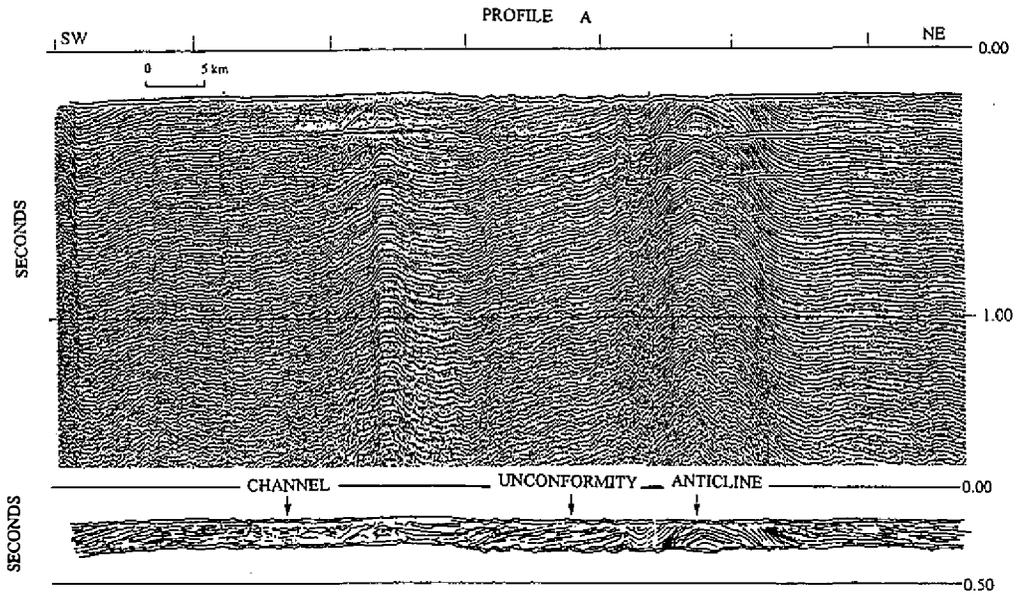


Fig. 6. Seismic section and line drawing interpretation of Profile A showing inclined reflectors are truncated by sea floor due to erosional effect of denudation. Canyon heads are not present on the outer shelf.

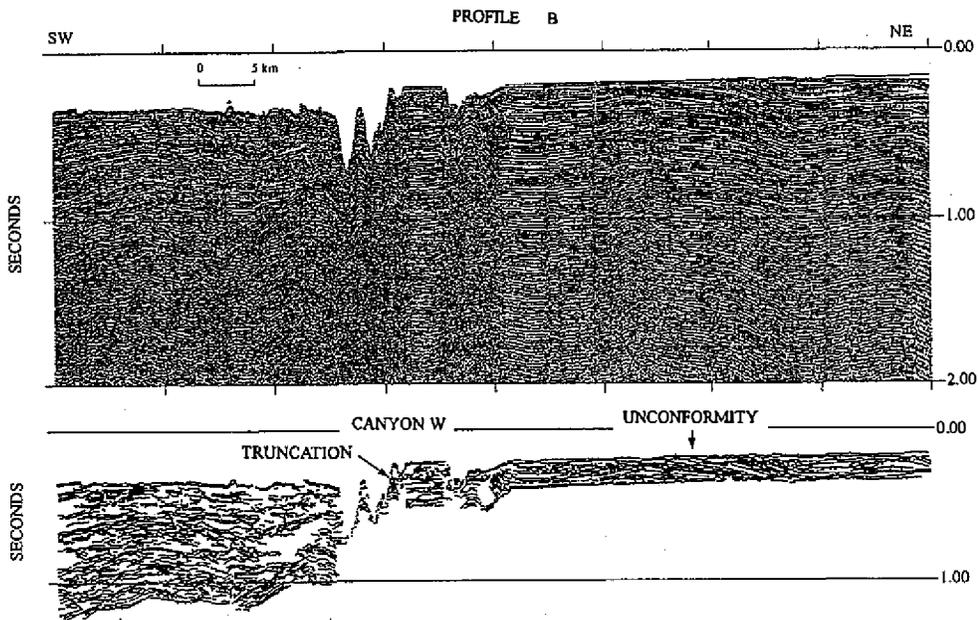


Fig. 7. Seismic section and line drawing interpretation of Profile B showing the down-cutting of the sea floor on upper slope initiating the canyon heads.

quences of slope sediments are eroded away, suggesting that canyon erosion of down-cutting continued at a greater intensity. Farther downcanyon, four tributary canyons appear on profile D (Figure 9). Tributary canyon W is characterized by a V-shaped trough with a nearly-vertical east wall. This very steep canyon wall is clearly formed by down-cutting as suggested by truncation of subparallel reflectors of slope sediments. The west wall of tributary canyon W displays a stepped and curved surface which may result from slumping or sliding (Figure 10). A slumping block may be discernible at the lower part of the west wall.

Tributary X also shows a V-shaped trough. Both sides of the canyon wall are formed by down-cutting of slope sediments, as implied by truncation of flat-lying reflectors on the canyon walls. Similar to tributary canyon W, the west wall of canyon X displays slumping features. Tributary canyon Y becomes a very small V-shaped trough, probably because of decreasing erosional intensity. Tributary canyon Z shows a wide open trough with an irregular canyon floor. The canyon walls show erosional truncation of the sediment layers and widening of the canyon. It is suggested that the irregular floor is an erosional/depositional feature. Sediments from upcanyon and both walls could accumulate temporarily on the canyon floor.

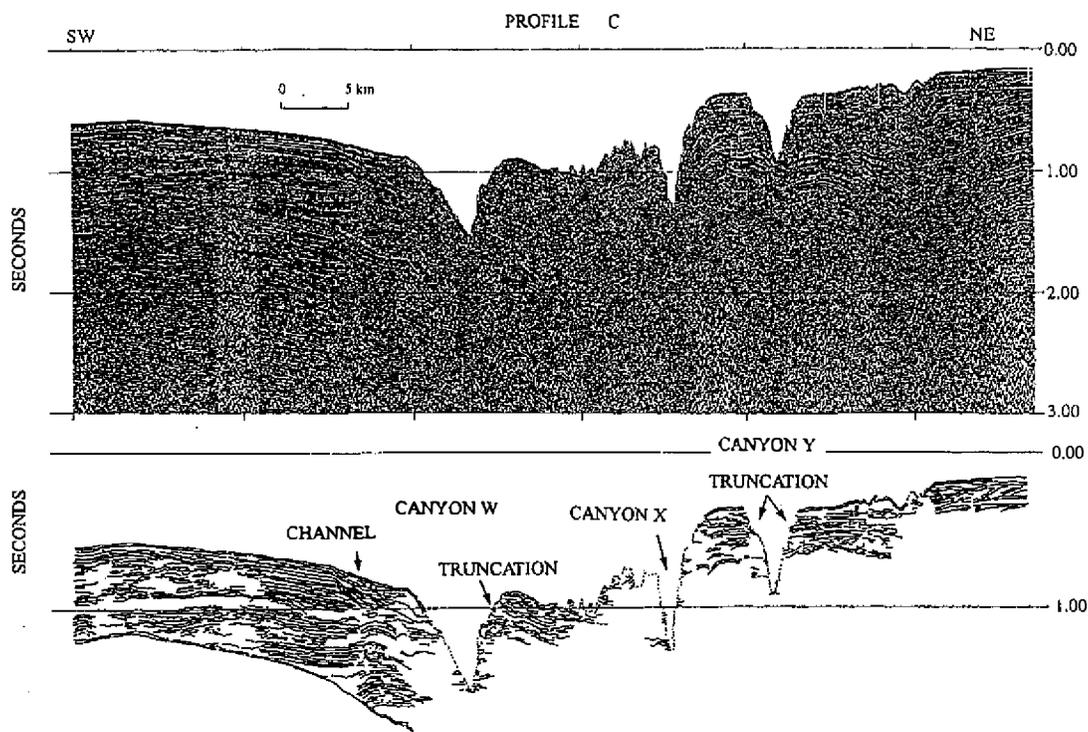


Fig. 8. Seismic section and line drawing interpretation of Profile C illustrating termination of parallel reflectors against canyon walls. Thicker sequences of slope sediments are eroded away, suggesting greater intensity of canyon erosion.

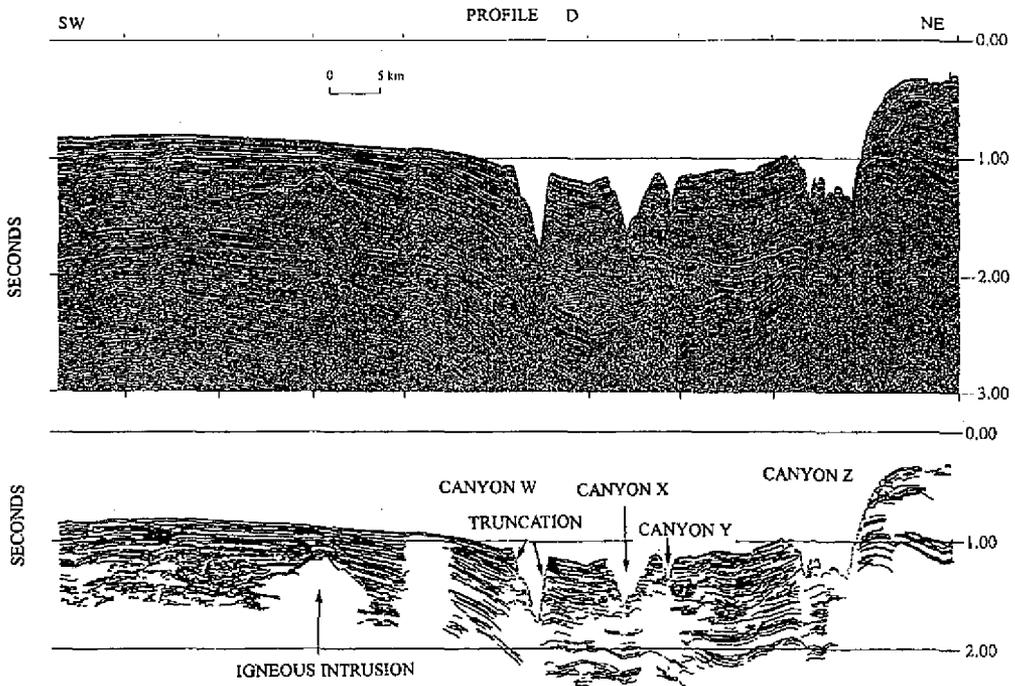


Fig. 9. Seismic section and line drawing interpretation of Profile D showing truncation of reflectors against canyon walls together with slumping/sliding features, indicating continued down-cutting of canyon walls.

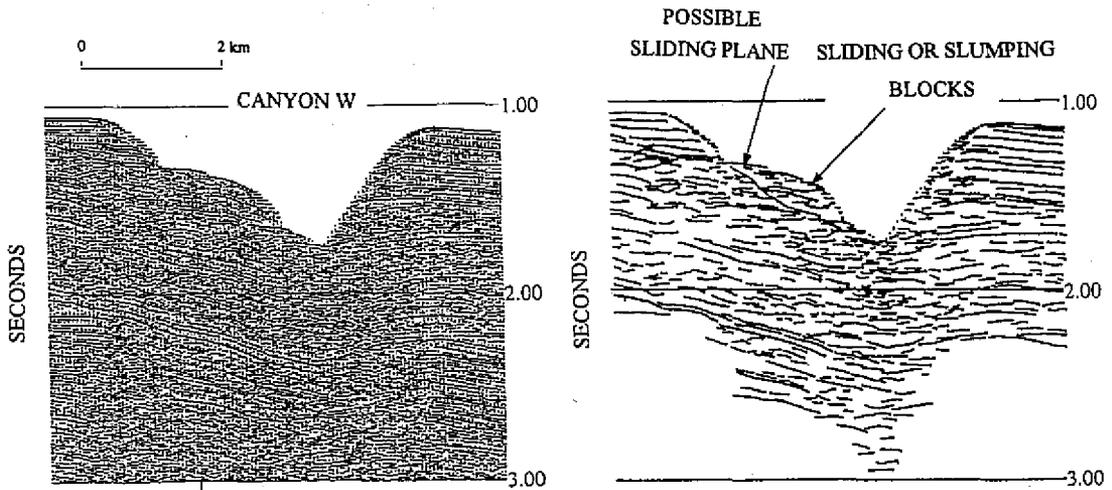


Fig. 10. Close-up view of west wall of canyon W appearing on Profile D shows a possible sliding plane and sliding/slumping blocks.

Later, these sediments could be carried downcanyon by strong sediment flows or turbidity currents along the canyon axis, and repeated deposition and erosion could result in the irregular bedform on the canyon floor.

Tributary canyons W, X, Y and Z merge into a single canyon as shown on profile E (Figure 11). Truncation of reflectors of slope sediments on the canyon walls is indicative of down-cutting deep into the underlying strata. Profile E reveals evidence for probable multiple episodes of canyon erosion and deposition. The close-up view of the canyon axis illustrates that multiple cut and fill features probably occur on the bottom of the North Mien-Hua Canyon (Figure 12). The cut and fill feature is a common erosional/depositional event throughout the evolution of a submarine canyon (e.g., McGregor, 1981, for Miocene Wilmington Canyon; Liu *et al.*, 1993, for modern Kaoping Canyon). Further downcanyon, profile F also shows truncation of sediment layers against the canyon walls (Figure 13) and probably a cut and fill feature on the bottom of the canyon (Figure 14).

Seismic reflection profiles provide no evidence of fault zones along or across the courses of the North Mien-Hua Canyon. Therefore, the origin of the North Mien-Hua Canyon is probably not related to strike-slip motion, as suggested by Hsu *et al.* (1996). Seismic data provide

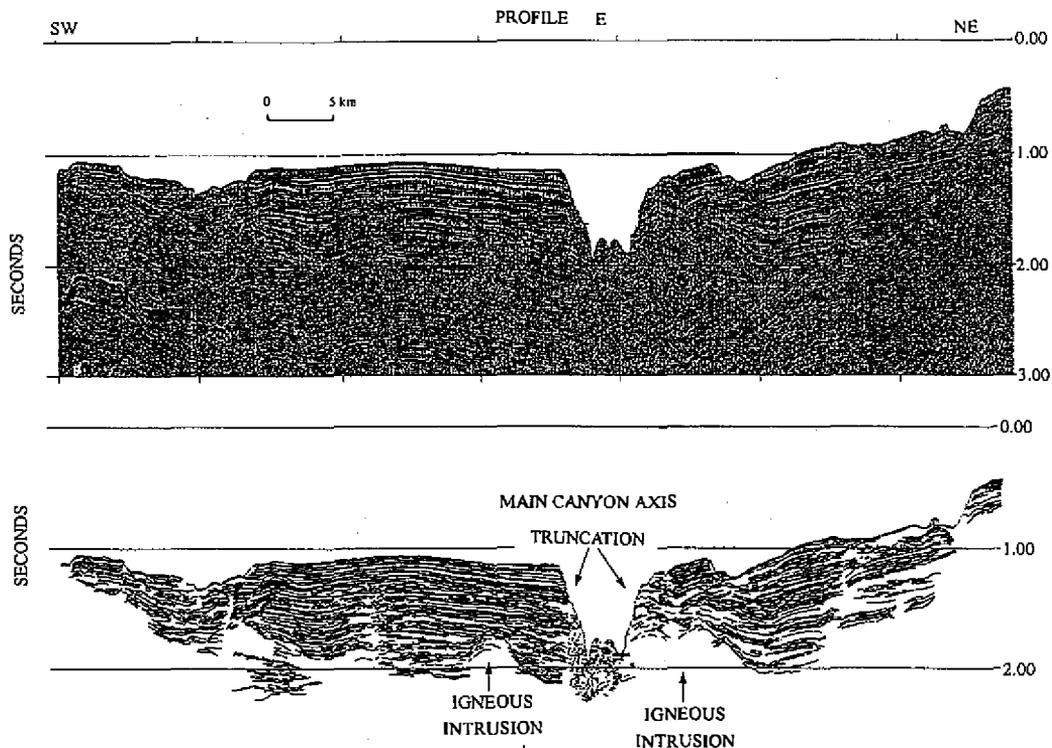


Fig. 11. Seismic section and line drawing interpretation of Profile E. Truncation of reflectors of slope sediments on the canyon walls of the main canyon is indicative of down-cutting deep into the underlying strata.

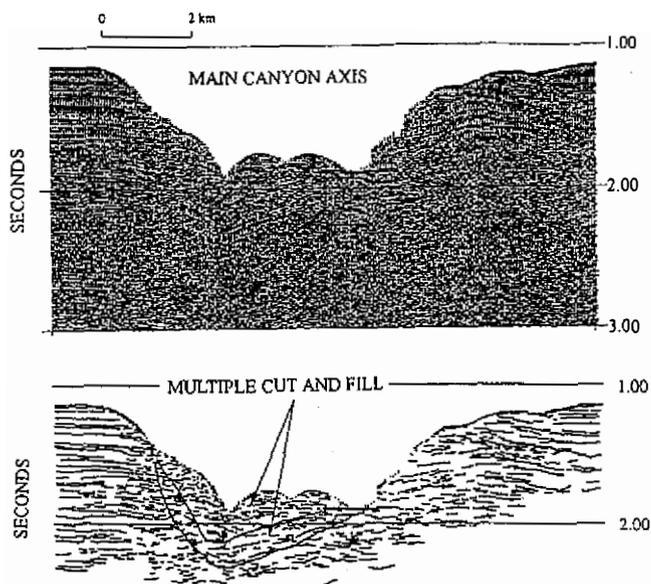


Fig. 12. Close-up view of canyon bottom from Profile E illustrates that multiple cut and fill features probably appear on the canyon bottom.

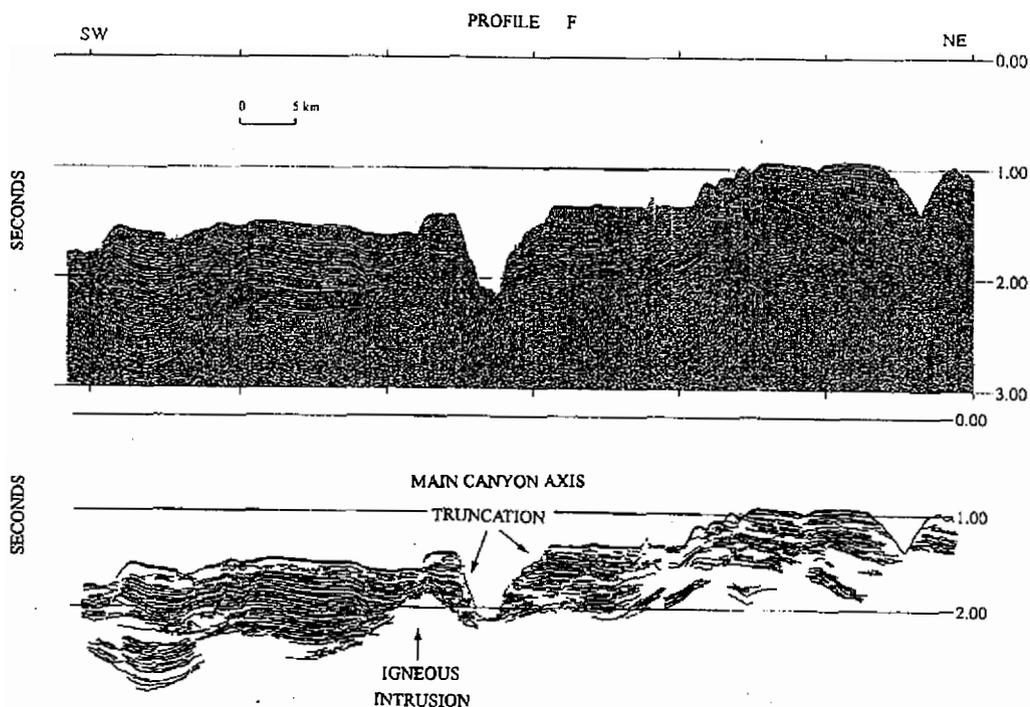


Fig. 13. Seismic section and line drawing interpretation of Profile F showing down-cutting along canyon walls as indicated by truncation of reflectors against the canyon walls.

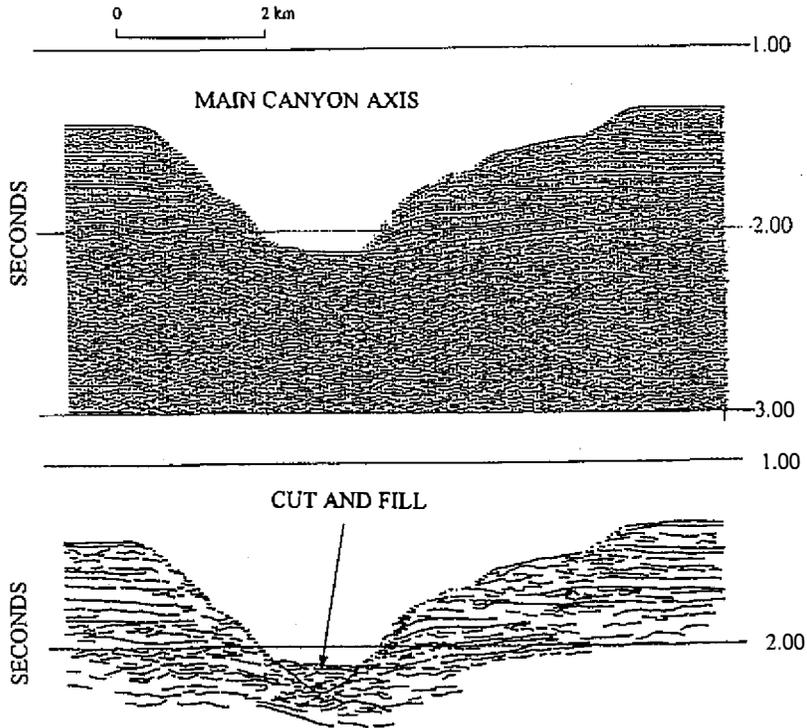


Fig. 14. Close-up view of canyon floor from Profile F showing a possible cut and fill feature.

evidence that submarine erosion of down-cutting is the major factor in the formation of the North Mien-Hua Canyon with multiple episodes of cut and fill. On the basis of morphological characteristics and seismic interpretations, the North Mien-Hua Canyon began as submarine incisions or gullies on the upper part of the East China Sea Slope. Upslope instability, which was probably caused by over-steepness of the slope (Twichell and Roberts, 1982, Farre *et al.*, 1983) and inferred tectonic activities of back-arc rifting (Lee *et al.*, 1980, Sibuet *et al.*, 1987), initiated the incisions or gullies immediately below the shelf edge. Later, downslope excavation deepened and widened the gullies into tributary canyons which in turn flowed downslope and joined together to form a single canyon.

5. CONCLUSIONS

Bathymetric data show that the North Mien-Hua Canyon is a multi-headed canyon which developed on the East China Sea Slope near Taiwan. This canyon consists of four tributary canyons which join together to form a single canyon near the 900 m isobath in lower slope region. The North Mien-Hua Canyon is characterized by a fan-shaped erosional feature. In cross-section, the canyon shows V-shaped troughs and steep-sided walls with varying incision depths.

Seismic profiles show submarine excavation along the canyon walls that is considered to be the major factor in the formation of North Mien-Hua Canyon. Seismic data provide no evidence of the presence of faults associated with the North Mien-Hua Canyon, suggesting the origin of the canyon might not be fault-related.

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