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The Huapinghsu Channel/Canyon System off Northeastern Taiwan: Morphology, Sediment Character and Origin

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ABSTRACT

A study of the Huapinghsu Channel/Canyon System was conducted with bathymetric profiles, 3.5 kHz echograms and box cores, to investigate morphology and sedimentary features. This channel/canyon system consists of two distinct units: (1) a broad trough-shaped channel which cuts into the shelf, and (2) a narrow V-shaped canyon with steep walls on the upper slope, which merges shoreward with the first channel. It extends from the shelf to the slope and has a total length of about 120 Km.

Core samples indicate that coarse-grained sediments are the dominant surface sediments in the channel and adjacent shelves but muddy sediments occur in front of the canyon mouth and nearby slopes. Erosional processes of lateral widening predominated in the channel course on the shelf and intense downcutting was prevalent in the canyon on the upper slope.

This channel/canyon system probably was initiated by sediment failure at the paleo-shelf edge. The canyon head then began to extend shoreward and resulted in a broad channel on the shelf. After later submergence the channel/canyon system has been preserved and enlarged by marine processes and mass wasting.

The Huapinghsu Channel/Canyon System on the shelf and slope was a part of seaward sediment-transport systems during the late Pleistocene low-sea-level stand. The subsequent transgression, some 5,000 to 7,000 years ago, inhibited the landward erosion of the channel. Because of cut-off from its main sediment source during the transgression, this channel/canyon system can no longer act as a modern conduit transporting sediments to the sea. The inadequate sediment supply from the China mainland and Taiwan has also prevented modern sediments from filling the submerged Huapinghsu Channel/Canyon System.

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1. INTRODUCTION

1.1 Canyon Setting

The continental margin off northeastern Taiwan consists mainly of a broad East China Sea continental shelf, a narrow East China Sea continental slope and the deep southern Okinawa Trough (Figure 1). Submarine canyons and canyon-like incisions (narrow linear depressions) are recognized as the most prominent physiographic features on the shelf-slope region off northeastern Taiwan. Bathymetric contours indicate the presence of three major submarine canyons which indent the shelf, cross the slope and extend south-eastward into the southern Okinawa Trough (Figure 1). Two of these canyons were named the Chilung Canyon and the Huapinghsu Canyon by Yu (1992), after a nearby port city and an island near the head of the canyon on the shelf, respectively (Figure 1). The third canyon remained unnamed because of inadequate bathymetric mapping (Yu, 1992).

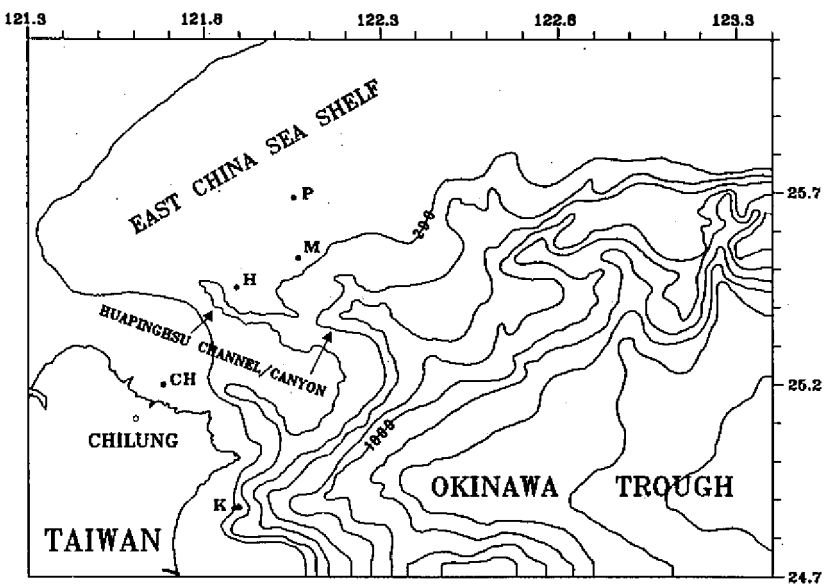

Fig. 1. Location map showing the major physiographic units and the principal canyons of the northeast coast off Taiwan. Small dots are volcanic islands. P=Pengchiahsu, M=Menhuahsu, H=Huapinghsu, CH=Chilung Tao and K=Kueishan Tao. (After Yu and Hong, 1992, Song, 1992).

1.2 Purpose

These submarine canyons have been known for twenty years (Wang and Hilde, 1973, Boggs *et al.*, 1979, Kimura, 1983, Marssett *et al.*, 1987, Song, 1992) but the morphology, sediment dispersal, and origin of these canyons have not been fully investigated. Up until 1992, not a single paper specifically describing these canyons has been published. This has resulted in limited understanding.

The purpose of this paper is to determine the area, describe the morphology, and discuss the possible origin of the Huapinghsu Channel/Canyon System . This study primarily presents a plane view and a cross-sectional examination along the course of the channel/canyon system. Selected 3.5kHz echograms and sediment samples are also integrated into the interpretation of its origin. This paper intends to result in a better understanding of the Huapinghsu Channel/Canyon System, and lead to an investigation of other aspects of the channel/canyon systems.

1.3 Data

The bathymetric data, high frequency (3.5 kHz) subbottom profiles and five box cores in areas off northeastern Taiwan were acquired during three cruises aboard R/V Ocean Researcher I during 1991-1992 (Figure 2). Bathymetric data were recorded by Simrad EK 500 Sonar. High frequency 3.5 kHz profiles were collected by ORE echo sounders. The survey line totalled about 2,000 km ,of which eleven transects across the Huapingshu Channel/Canyon System and surrounding areas were used in this study.

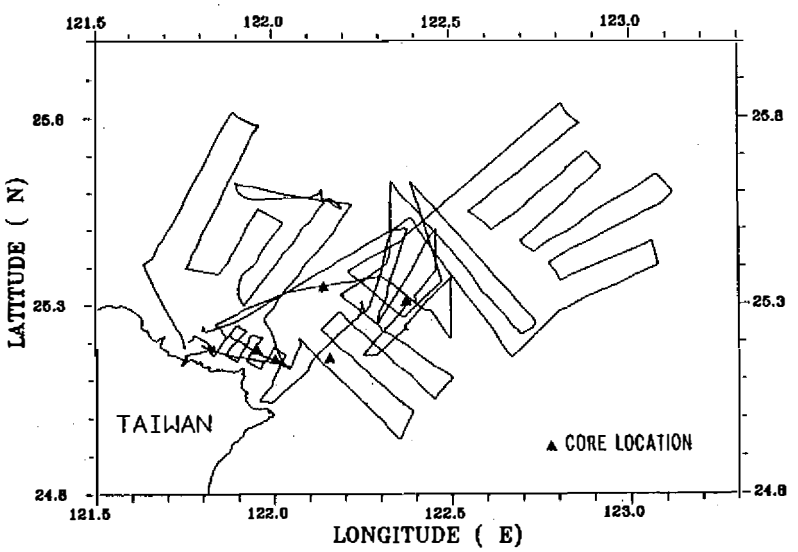

Fig. 2. Location of echo-sounding tracks, 3.5 kHz subbottom profiles and five box-cored samples. The surveys covered most of the areal extent of the Huapinghsu Channel/Canyon System.

2. MORPHOLOGY

The bathymetric chart (Figure 3) and cross-sectional morphology (Figure 4) indicate that this linear depression consists of two distinct units: (1) a broad trough-shaped channel which cuts into the shelf, and (2) a narrow V-shaped canyon with steep walls on the upper slope which merges shoreward into the channel. This submarine depression is herein named Huapinghsu Channel/Canyon System.

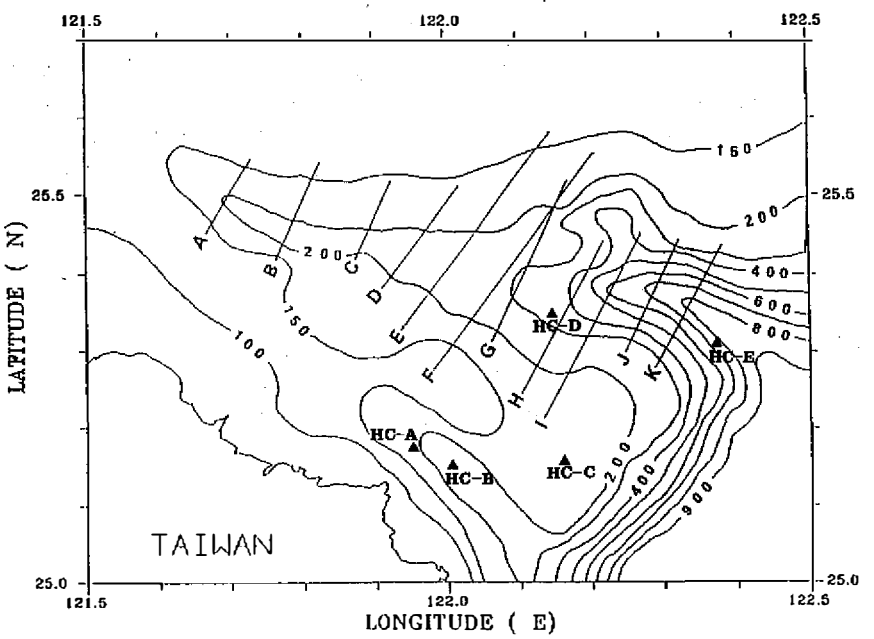

Fig. 3. The bathymetric chart shows a linear depression extending on the shelf-slope region in an east-west direction and ending approximately at the isobath of 900 m on the slope. The solid triangle indicates the box-cored samples.

The head of the Huapinghsu Channnel/Canyon System is located close to the Huapinghsu island where the water depth is approximately 120 m (Figure 3). This channel/canyon system follows a relatively straight course extending across the shelf and the upper slope in a nearly E-W direction. It then changes its course at around 25°37′N and 122°30′E, and continues its path southeastward and finally ends approximately at the isobath of 900 m on the continental slope. The Huapinghsu Channel/Canyon System, with its length of about 120 km, has a relief exceeding 580 m. The width of the channel/canyon system is approximately 5 km close to the head, and increases to about 26 km in the middle and then narrows to about 16 km around the canyon mouth.

Morphological characteristics, depth, width, relief and gradient of this channel/canyon system, are summarized in Table 1. There are considerable variations in elevation of the channel/canyon rims and the floors. The depth of the floor ranges from 120 to 825 m, and the difference in depth between the rim and floor of the channel/canyon ranges from 110 to 580 m. The average slope of both flanks varies from 0.36 to 4.67 degrees. Clearly, the canyon segment has steep walls. The gradients of the channel/canyon floors ranges from 0.04 to 2.28 degrees and the floor of the canyon is steeper than that of the the channel. Thus the basic channel/canyon shape is that of a broad trough-shaped channel cutting into the broad continental shelf and a narrow well-defined V-shaped thalweg of the canyon downcuts the upper slope region.

The cross-sections of the Huapinghsu Channel/Canyon System are presented in Figure 4. Profile A, running approximately in a NE-SW direction, shows that the head of the channel

Table 1. Morphological variables of the Huapinghsu Channel/Canyon System.

Line	Channel/Canyon Floor Depth (m)	Water Depth to the Rim (m)	Relief* (m)	Width (km)	Wall Slope (°)	Axis Slope (°)
A	222	112	110	5.5	1.54	
						0.155
B	250	122	128	6.0	1.59	
						0.037
C	242	126	116	4.2	1.55	
						0.072
D	250	134	116	16.6	0.62	
						0.035
E	246	122	124	22.0	0.84	
						0.159
F	274	139	135	26.8	0.36	
						0.406
G	336	172	164	19.8	2.79	
						0.543
H	417	201	216	19.9	1.08	
						2.285
I	658	196	462	18.1	2.91	
						0.750
J	765	245	520	13.9	4.07	
						0.569
K	825	245	580	16.1	4.67	

* Relif is the depth difference between the channel/canyon rim and the channel/canyon floor

is a relatively small V-shaped trough. The width of the channel head is around 5 km and the depth of the channel floor is about 220 m. As shown in Profiles B, C, D, and E in a downchannel direction, the channel increases its width to about 22 km, but the channel floor maintains its depth of about 250 m. The cross-section of the channel changes from a single V-shaped trough to a shallow and relatively wide depression with irregular floor surfaces. Further downchannel, it then bifurcates into two depressions with irregular floor surfaces and reaches the maximum cross-sectional area. The channel increases its depth slightly over 300 m as shown in Profiles F and G. These two depressions then merge into a V-shaped trough and continue along its course eastward as shown in Profiles H and I. The segment between Profiles I and J is the transitional zone where the channel-dominated system evolved into a narrow (15 km) and deep (600 m) canyon with decreasing cross-sectional area. The canyon then changes its course at Profile J from a E-W direction to a southeast direction. This SE-NW segment of the canyon is characteristically a sharp V-shaped trough with steep walls and a relief exceeding 580 m, as represented by Profiles J and K.

2.1 Longitudinal Profile and Channel/Canyon Relief

The axial slope of the channel changes gradually and maintains around 0.16 degree (Figure 5). A sharp increase of the slope up to 2.28 degrees occurs at the canyon segment and thereafter there is a decrease to 0.75 degree or less along the canyon course on the upper

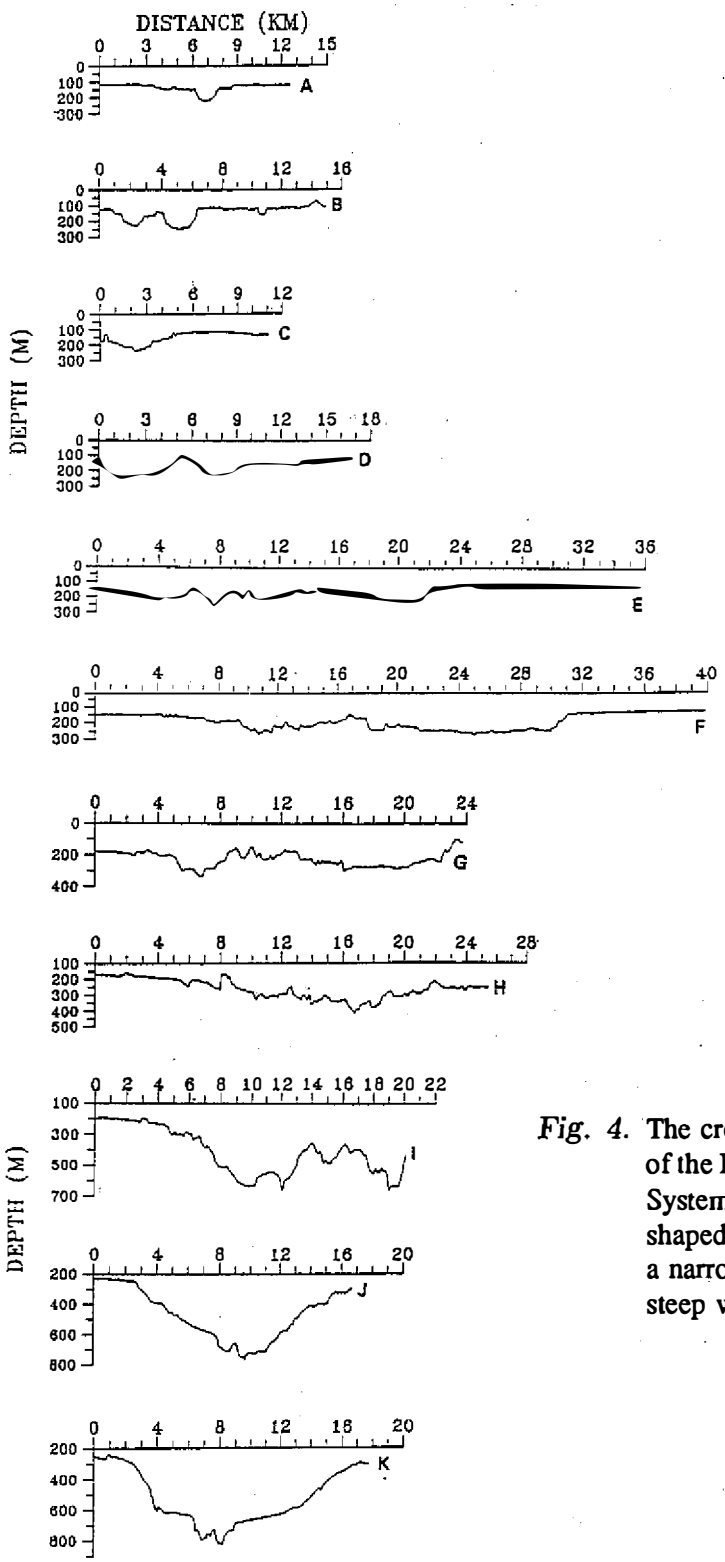

Fig. 4. The cross-sectional morphology of the Huapinghsu Channel/Canyon System comprises a broad trough-shaped channel on the shelf and a narrow V-shaped canyon with steep walls on the upper slope.

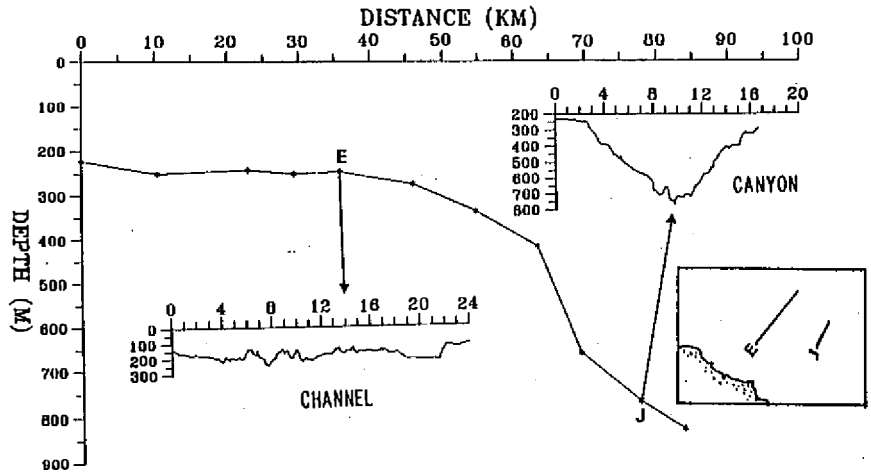

Fig. 5. Axial profiles of the Huapinghsu Channel/Canyon System on the shelf-slope off the northeast Taiwan coast. Note U-shaped and V-shaped cross-sections of the channel and the canyon, respectively. The presence of significant knick points in the gradient profiles indicates entrenchment has not reached an equilibrium with depositional processes.

slope. The variations of axial slope along the channel are generally in accordance with the surrounding shelf floor, which has an average gradient of about 0.07 degree (Yu and Hong, 1992). The greater gradients of the canyon segment also reflect the steepness of the East China Sea slope off northeastern Taiwan which has gradients ranging from 1/50 to 1/100 (Wang and Hilde, 1973), in places exceeding 10 degrees (Yu and Hong, 1992).

It is suggested that a boundary can be placed between profiles H and I to separate the channel from the canyon. The slope between profiles A and H has gradients ranging from 0.04 to 0.54 degree and is represented by a broad shallow depression while the slope between profiles H and K has greater gradients (0.6 to 2.3 degrees) and is characterized by a sharp V-shaped trough. Apparently, lateral erosion of the channel course on the shelf and downcutting into the upper slope during its development have shaped and modified the linear trough into its present form.

A plot of the incision depth of the channel/canyon system against its course indicates that the incision depth changes very little on the shelf and greater incision depth takes place at the lower reaches of the channel and the canyon segment (Figure 6). Variations of the incision depth, together with the longitudinal profile, also suggest that the erosional processes of lateral widening predominated in the channel but the downcutting was prevalent at the canyon on the upper slope.

3. SEDIMENT PROPERTIES AND DISPERSAL

Five box-cored samples in and around the channel/canyon, supplemented by the bottom sediment facies maps (Boggs *et al.*, 1979) and the echo character map (Hong *et al.*, 1992), were used to delineate the sediment distribution and dispersal around the channel/canyon region.

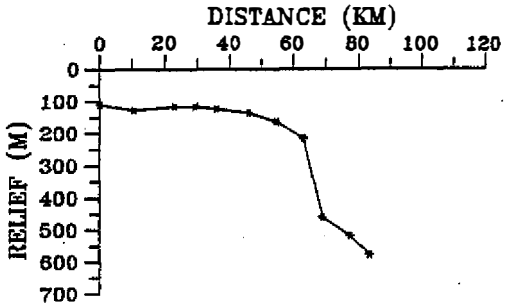

Fig. 6. Relief plotted against distance from the channel head area to the canyon mouth. Note the Huapinghsu Channel maintains a uniform incision of 100-200 m, increasing rapidly to over 600 m at the canyon mouth.

Core samples (Figure 7) indicate that coarse-grained sediments are dominant at the channel surface and on the adjacent shelf, whereas muddy deposits occur around the canyon mouth and nearby slopes. Sediments deposited on the shelf immediately off northeastern Taiwan are characterized by coarse-grained gravel and pebbles, usually larger than 2 cm in diameter (Figures 7A & 7B). Further northeast, the shelf sediments (Figure 7C) are primarily composed of coarse-grained shell fragments. These biogenic sediments consist principally of mollusk shells and fragments and foraminifera tests. The sediments in the Huapinghsu Channel/Canyon are characterized by coarse-grained rock fragments and mud clasts (Figure 7D). These coarse-grained shelf sediments have been interpreted as relict sediments (Boggs *et al.*, 1979). However, sediments at the canyon mouth are mainly silts and clays (Figure 7E).

Our findings of the sediment distribution are compatible with previous studies in this region (Boggs *et al.*, 1979, Chen *et al.*, 1992, Hong *et al.*, 1992). For instance, 3.5 kHz echograms covering the channel/canyon system and adjacent shelves were dominated by prolonged echoes (Figure 8). Numerous studies (e.g. Damuth, 1980, McClennen, 1989) have shown that prolonged echoes usually indicate coarse-grained sediments.

Eustatic change of sea level was the main factor controlling the dispersal and nature of the sandy sediments on the shelf around Taiwan (Niino and Emery, 1961, Boggs *et al.*, 1979). During the late Pleistocene (15,000 years B.P.), sea level was probably about 140 m below present level, exposing most of the Taiwan continental shelf. Rivers on the broad shelf deposited sediments of gravels, sands and muds. The sea level rose later and reached its present level some 5,000 to 7,000 years ago (Boggs *et al.*, 1979). Niino and Emery (1961) found widespread sandy and gravelly sediments on the broad shelf west and north of Taiwan and interpreted them as relict sediments which have not been covered by younger sediments since the late Pleistocene. In contrast, the bottom sediments in the inshore area within about 40 km of Taiwan consist mainly of fine-grained Holocene to modern sediments (Boggs *et al.*, 1979).

We interpreted the coarse-grained sediments in the channel to be reworked relict sediments. Current velocities along the channel course are not available at present. However, near-bottom currents around the channel area generally flow from shelf edge toward shelf with a velocity averaging around 20 cm/s and the near-surface currents, in turn, flow seaward

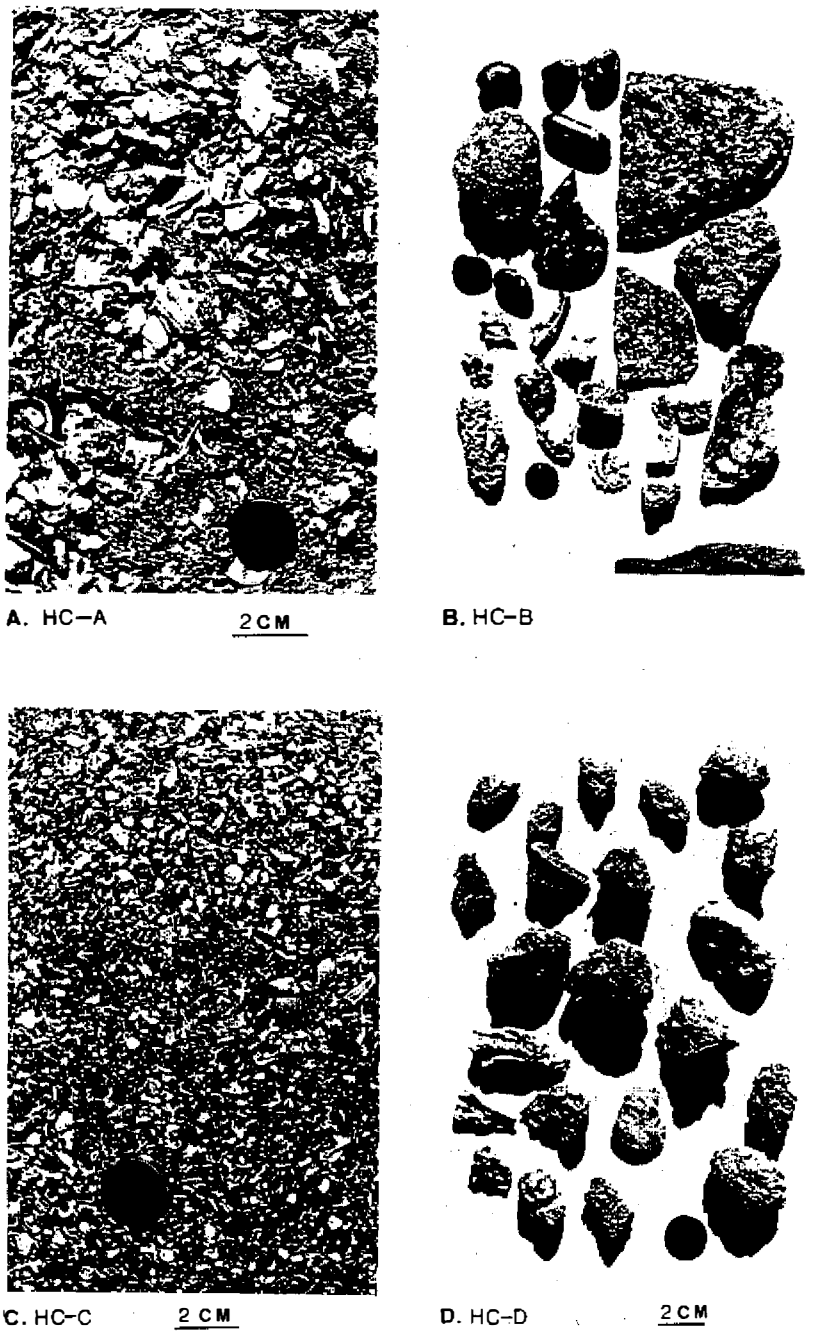

Fig. 7. Five box-cored samples indicate that coarse-grained sediments are the dominant surface sediments in the channel and adjacent shelves and muddy deposits occur around the canyon mouth and nearby slopes. (HC-A) and (HC-B) Pebbly sands and gravels, (HC-C) Coarse-grained shell fragments, (HC-D) Gravelly mudclasts and rock fragments and (HC-E) Fine-grained silts and clays. Locations of the cores are shown in Fig. 3.

E. HC-E

Fig. 7 (Continued.)

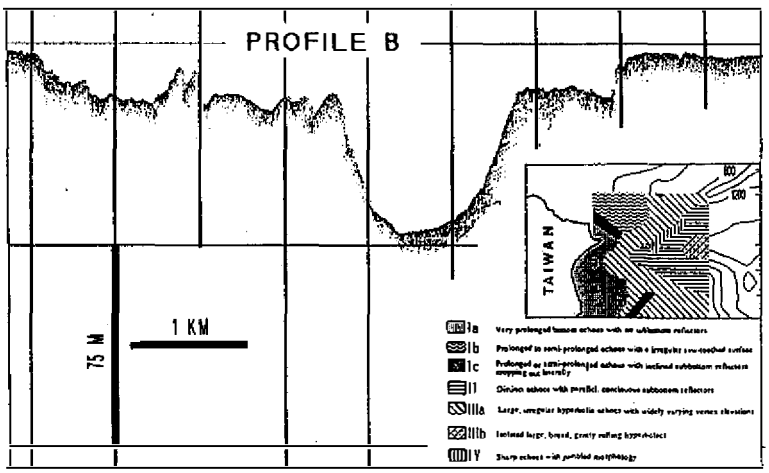

Fig. 8. The 3.5 kHz record of profile B shows that the channel areas are dominated by prolonged echoes which indicate coarse-grained (from silt to gravel) sediments. The inserted echo character map at the right shows that the areas surrounding the Huapinghsu Channel/Canyon System are characterized by prolonged to semi-prolonged echoes. (After Hong *et al.*, 1992).

(Chern, personal communication). The currents pattern suggests that the flow seems not to be capable of transporting coarse-grained sediments in the channel seaward. We suggest that the coarse-grained sediments, either relict or eroded from the channel edges, were reworked and confined in the channel, but the clays were removed and laid down in the canyon segment. This suggests that the channel is no longer a conduit for transporting coarse-grained materials seaward.

4. ORIGIN

The submarine canyons in the shelf-slope region off northeastern Taiwan have been interpreted to be glacially eroded, submerged valleys developed in the late Pleistocene (Boggs *et al.*, 1979). However, Shepard (1981) cautioned that the origin of submarine canyons is of multiple causes and their development history may be long. Based on bathymetry, morphology, sediment characteristics and regional geology, the origin of the Huapinghsu Channel/Canyon System may be inferred.

Since the Huapinghsu Channel/Canyon System is related neither to the present river drainages of Taiwan nor to those of the China mainland directly, it does not belong to the river-extension type (Shepard, 1981). However, morphological characteristics suggest that the erosional process of lateral widening dominated in forming the channel (profiles A to H) on the shelf, as evidenced by the wide and shallow troughs and low gradients of the channel floor and lack of steep walls. Apparently, the intensity and duration of downcutting of headward erosion in the shelf areas were not strong and long enough to cut the shelf strata into a canyon form. It is apparent that steep canyon walls begin to appear at profile I, which marks a turning point in the channel course near the transition from submarine channel to true submarine canyon. The canyon segment (profiles I to K) is characterized by higher gradients (0.57 to 2.28 degrees) than those of the channel (0.04 to 0.5 degree). The trough on the upper slope is a relatively narrow, linear, deep depression with steep sides which fit Bouma's 1990 definition of the submarine canyon.

During the late Pleistocene (15,000 years B.P.) the broad shelf north of Taiwan was exposed subaerially and the Pleistocene shoreline was probably located along Longitude 120 E (Boggs *et al.*, 1979). Following the models of submarine canyon evolution (Shepard, 1981, Farre *et al.*, 1983), we speculate that the infant Huapinghsu canyon was initiated at the paleo-shelf edge where significant sediment failure and mass-wasting occurred. Once initiated, the canyon head acted as a sediment conduit, where erosion took place and indented the shelf landward. The canyon head erosion did not penetrate deeply into the shelf. Instead, it formed a broad channel probably due to the low gradient of the shelf. On the other hand, substantial submarine mass-wasting processes cut the slope into steep walls and deepened and widened the canyon course downslope. The subsequent rising of sea level stopped the landward erosion of the channel. The fine clays in the channel were removed and coarse-grained sands and gravels remained. Based on the finding that Holocene and modern sands from nearby Tawian drainages were restricted to the nearshore areas (Boggs *et al.*, 1979), we suggest that very few sediments were deposited in the Huapinghsu Channel/Canyon System and those found there are relicts. Inadequate sediment supply prevented the infilling of the submerged troughs of the Huapinghsu channel/canyon system.

5. CONCLUSION

The postulation of submerged valleys for the origin of the canyons off northeastern Tawian (Boggs *et al.*, 1979) was partly incorrect due to insufficient bathymetric data. We present an alternative model for the development of the submerged linear depressions. Our

results suggest that the narrow linear, trough on the shelf-slope region comprises a channel/canyon system. Morphologically, the canyon head portion on the shelf shows typical channel features which have resulted genetically from the headward erosion of the canyon.

The axial gradient of the channel generally is 0.15 degree or less. This channel generally has an irregular floor with a maximum width of about 26 km. The canyon segment on the upper slope has an axial gradient about 0.8 degree higher than that of the channel. The canyon walls have a steep slope of about 4.5 degrees. The relief of the canyon ranges from 160 to 580 m. The width of the canyon averages about 15 km.

The Huapinghsu Channel/Canyon System apparently originated on the East China Sea shelf-slope region as a part of a seaward sediment -transport system during the late Pleistocene low-sea-level stand. The subsequent transgressive sea drowned the channel/canyon system and cut off its sediment source. This channel/canyon system can no longer act as a modern sediment conduit to the sea. The limited sediment supply from the China mainland and Taiwan prevents the filling of the channel/canyon system.

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