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Physiographic Characteristics of the Continental Margin, Northeast Taiwan

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ABSTRACT

The continental margin off northeastern Taiwan consists of five major physiographic units which are the East China Sea continental shelf, the East China Sea continental slope, the Southern Okinawa Trough, the Ilan continental shelf and the Ilan Ridge. This physiographic framework is provisional and may be revised if better physiographic names are proposed.

The East China Sea continental shelf is relatively wide with a smooth surface marked locally by low-relief features resulting from sea-level fluctuation during the late Pleistocene and by volcanic activities of the back-arc rifting.

The East China Sea continental slope varies laterally in slope gradient and topography. The continental slope is marked by a variety of slumping or sliding scars, erosional gullies, and debris flow deposits or turbidites. The submarine canyons are another prominent topographic feature occurring on the slope. The submarine canyons indent the continental shelf and modify the linear shelf-slope transtition region into an irregular shape. The western end of the Southern Okinawa Trough has curvelinear bathymetric contours at the maximum depth of about 2,000m. The trough is mainly confined by the continental slope to the north and by slopes off the Ryukyu volcanic islands.

The Ilan continental shelf is the seaward continuation of the Ilan Plain along the northeastern coast of Taiwan. The shelf is fan-shaped, and the width varies from about 10 km off the Lan Yan Hsi River to about 2km at the coastal cities of Touchen and Suao. This shelf protrudes onto the slope seaward with the accumulation of the sediments transported by the Lan Yan Hsi River.

The Ilan Ridge is a long and narrow ridge extending seaward from the Ilan shelf. The ridge separates the forearc basin of the Nanao basin to the south from the backarc basin of the Okinawa Trough to the north. The Ilan Ridge is confined by the Ryukyu volcanic islands to the east and is relatively narrow in areal extent as compared to the Ryukyu island chain.

The shelf-slope transition region where the water mass exchange process takes place between the East China Sea and the Kuroshio Current is characterized by an irregular topography. This topographic effect on the Kuroshio edge exchange process is worthwhile to be investigated in greater detail.

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1. INTRODUCTION

The East China Sea is one of the marginal seas along the rim of the western Pacific. It is bordered by the Yellow Sea to the north. The boundary line between the East China Sea and the Yellow Sea extends from the location of 33°17′ lat. at the coast of China to the western end of Cheju Island, Korea. The East China Sea is separated from the Taiwan Strait by a line connecting from the Fukueichiao at northernmost Taiwan to Haitan island off Fujian Province, China (Ma, 1986). The Ryukyu islands are the eastern boundary of the East China Sea (Figure 1). It covers an area of about 770,000 square km and has an elongated shape trending northeast-southwest. It has a length of about 1,300km from northeast to southwest and the average width from east to west is around 540km (Zhou *et al.*, 1989).

The continental margin off northeastern Taiwan is characterized by the shallow broad East China Sea shelf, the relatively narrow and steep continental slope and the deep Okinawa Trough. In general, the shelfbreak around Taiwan occurs at a depth of about 200m (Boggs *et al.*, 1979). It has been noted that off the eastern and northeastern coast of Taiwan,the Kuroshio Current flows northeasterly along the shelf edge towards Japan (Figure 2). The Kuroshio Current is a major western boundary current with warm (20-27°C), saline(33‰) water and originates east of Luzon Island around 15°N, 125°E. The importance of shelf edge exchange processes of the Kuroshio Current flowing along the segment off northeast Taiwan has been recognized in recent years, especially the significance of water-mass exchange between the Kuroshio Current and the East China Sea (Chu, 1976).

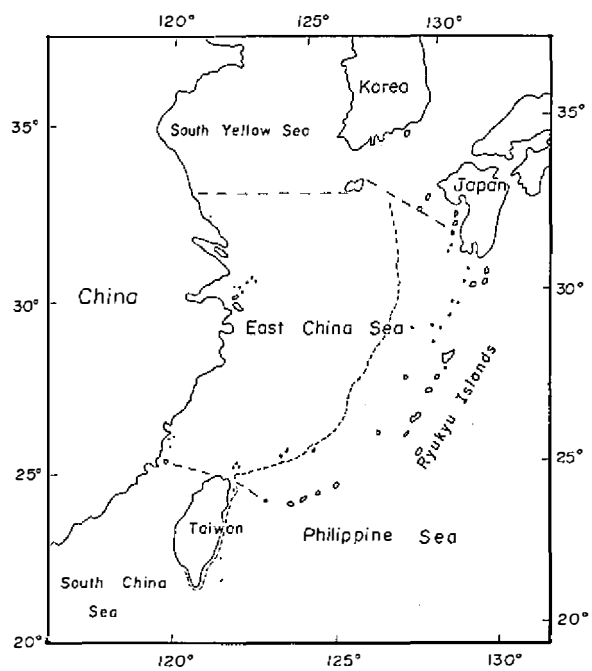

Fig. 1. Map showing the areal extent of the East China Sea which is characterized by relatively shallow (100m) and wide (400 to 500m) continental shelf. Note that the Ryukyu volcanic islands serve as the boundary to the east. Dashed line is the shelf break at approximately 200 meters depth.

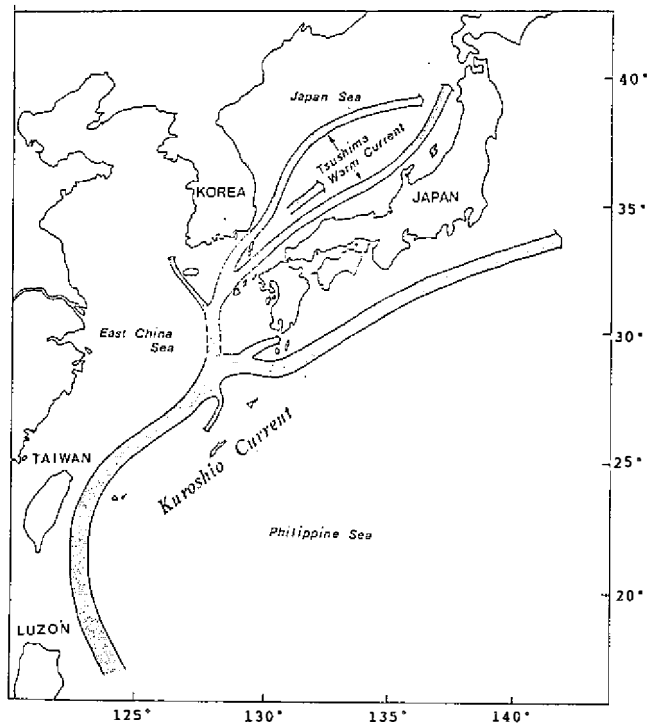

Fig. 2. Schematic flow pattern of the Kuroshio current (After Yin *et al.*, 1987).

1.1 Purpose and Scope

This study is a geological part of the joint research project of Kuroshio edge exchange processes (KEEP) which is an integrated research of marine sciences including physical oceanography, marine chemistry, biology, and geology sponsored by the National Science Council of Taiwan (Chu, 1989).

The movement of the Kuroshio Current is closely related to the topography of the shelf-slope region off eastern Taiwan (Chung and Yu, 1988), and the topography of the sea floor around Taiwan has resulted from the hydrologic conditions on the shelf and slope and partly from Late Pleistocene lowstands of sea level (Boggs, *et al.*, 1979). The need for further information about the topography for the KEEP project is apparent and leads to investigation of the bathymetry and physiography of the region which affects the shelf-edge exchange processes of the Kuroshio Current in the areas off northeast Taiwan. The main purpose of this paper are twofold: (1) to emphasize prominent topographic features which may be related to the hydrodynamics along the shelf-slope region and (2) to present a physiographic framework for the KEEP study in the region off northeastern Taiwan. The advantage of having a physiographic framework is to set the references for specific locations with distinct topographic and bathymetric characters in the KEEP study areas. Hopefully, these proposed physiographic names could be followed by the marine scientists participating in the KEEP project and the topography information can be useful for other disciplines. This research emphasizes the prominent topographic features for each major physiographic unit. There is no intention of discussing the geomorphic characters of each individual feature in detail.

The study area is located at the shelf-slope region off northeastern Taiwan (Figure 3). The site for investigations is bounded to the north at 26°N, to the east at 123°E and to the south at 24°N.

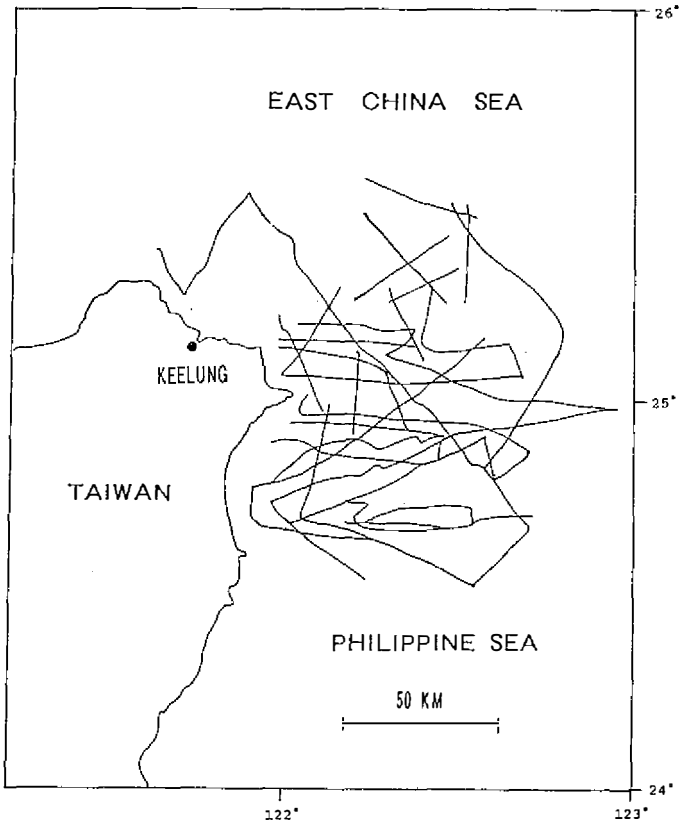

Fig. 3. Location of echo-sounding tracks and high frequency (3.5KHz) subbottom profiles. The study area is restricted at the north of 26°N, at east of 123°E and at the south of 24°N.

1.2 Data

Surface-ship echo-sounding tracks and high frequency (3.5KHz) subbottom profiles and, where available, multichannel seismic reflection profiles in the areas off northeast Taiwan were acquired during three cruises aboard R/V *Ocean Rese rcher I* during 1990-1991. Bathymetric data were determined with a Simard EK 500 Sonar. High frequency (3.5KHz) transects were collected by using Ocean Researcher Equipment transducers. In total, about 3,000km lines were collected, of which three multichannel seismic profiles are also included (Figure 3). Ten selected 3.5KHz profiles were used to illustrate the characteristic sea floor topography in the shelf-slope transition region off northeastern Taiwan (Figure 4). The 3.5KHz profiling is an effective tool to reveal the topography and surface sediments of the sea floor (Kennett, 1982).

2. BATHYMETRY

The bathymetric maps around Taiwan commonly used include the maps of Boggs *et al.* (1979), Suppe (1984), Marssett *et al.* (1987) plus bathymetric charts compiled by the

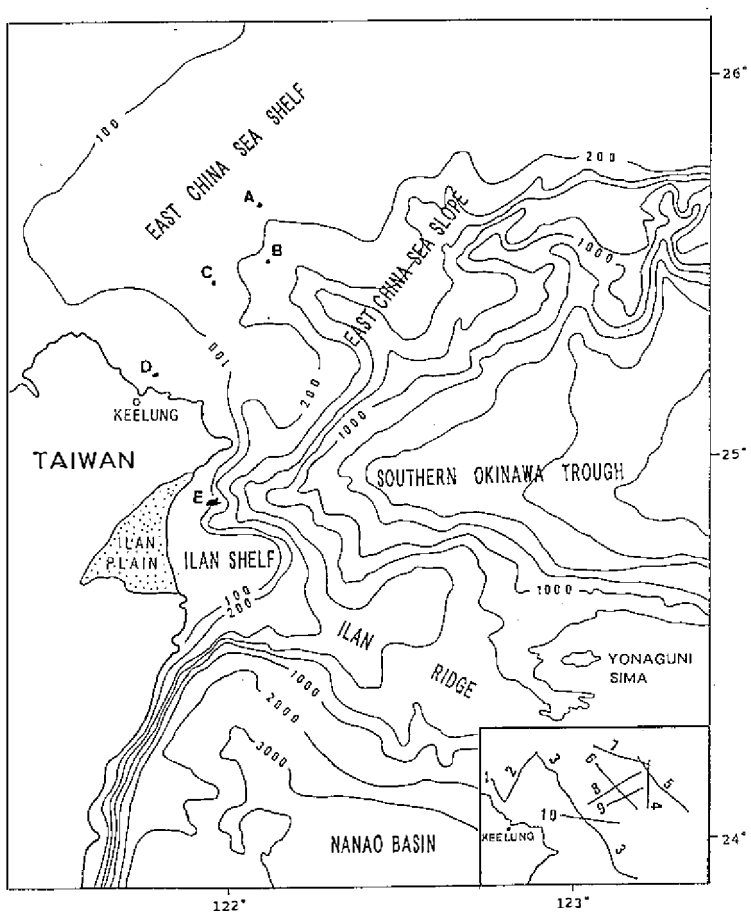

Fig. 4. Bathymetric map of the survey area, showing the major physiographic units. Bathymetry is from Marssett *et al.* (1987). Bathymetric contours are in meters. Small dots are volcanic islets. A=Pengchiahsu, B=Menhuahsu, C=Huapinghsu, D=Keelung Tao and E=Kueishan Tao.

Chinese Navy and the Institute of Oceanography, National Taiwan University (IONTU). There are discrepancies between these maps and charts. In order to provide an update and accurate bathymetric map covering the KEEP study areas off northeastern Taiwan, G.S. Song from IONTU has carried out a three-year plan to survey the KEEP study areas sponsored by the National Science Council of Taiwan. Song (1992) has presented a preliminary result of the topographic survey off northeastern Taiwan. He expects a standard bathymetric map for the KEEP study to be ready by 1994. We would not duplicate Song's work, and hence used the bathymetric map of Marssett *et al.* (1987) in this paper (Figure 4). The bathymetric map in the study area mainly covers the East China Sea shelf and slope and the western part of the Southern Okinawa Trough; the water depths range from approximately 100 to 2,200m below sea level. The bathymetry shows a regional trend in an NEE direction. Apparently, the water depth increases seaward in a SSE direction.

The sea floor of the continental shelf, shallower than 150m, is generally smooth and flat. However, many small islands, ridges, channels or canyons interrupt the smoothness of the sea floor of the continental shelf. About 15,000 years before the present time, in the glacial period of Late Pleistocene, the sea level was about 140m below present sea level and caused the continental shelf to be subjected to subaerial erosion (Emery *et al.*, 1971). When the shelf was submerged again, partly due to the melting of Quaternary glacier, some relict features such as river valleys or rocky banks were preserved. However, these relict geomorphologic features do not seriously change the mean relief of the shelf. For instance, profile 1 shows the typical flatness of the shelf morphology (Figure 5A), the relict features such as channels and ridges are shown on the profile 2 (Figure 5B). We realize that high resolution seismic profiles can better demonstrate these relict features than the 3.5KHz profiles do. The average gradient of the East China Sea shelf is about 0.07.

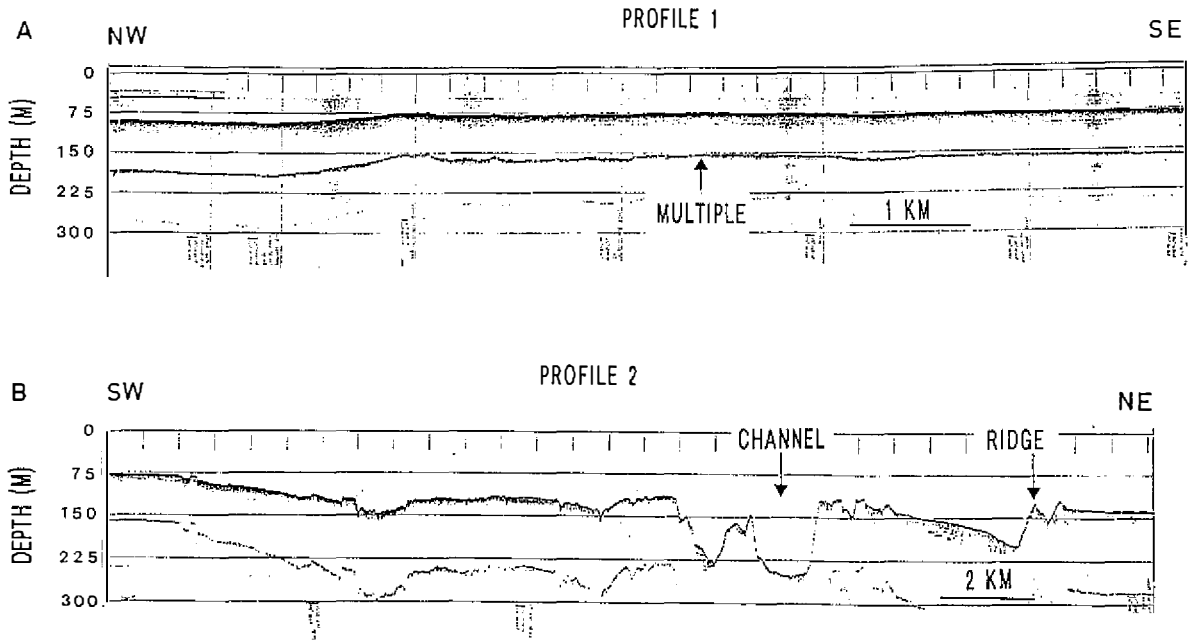

Fig. 5. Profile 1 showing the typically smooth and flat nature of the East China Sea shelf (A). However, the relict features such as channels and ridges resulting from the late Pleistocene glaciation on the shelf are shown by profile 2 (B).Location of the profiles is shown in Figure 4.

Maximum relief is found on the continental slope. The water depth to the top of the slope ranges from 150 to 300m, and the depth to the toe of the slope ranges from 1,800 to 2,200m. The average angle of the slope is between 2 and 5 with local slopes of greater than 30 as indicated by the 3.5KHz echo records.

The bathymetric contours between 200 and 1,200m are closely spaced which illustrate that the upper slope is steeper than the lower slope (Figure 4). The bathymetric chart also indicates indentation of bathymetric contours in the upslope areas. These convex contours

suggest the presence of submarine canyons at the upper slopes as reported by Wang and Hilde (1973) and Boggs *et al.* (1979).

The bathymetric chart indicates that the floor of the Southern Okinawa Trough is confined to below the 2,000m isobath. The bathymetric contours shallower than 2000m converge landward at the Ilan Plain. Bathymetric contours indicate that the shelf areas off Ilan Plain are relatively wide as compared to the rest of the shelves off the eastern coast of Taiwan to the south which are relatively narrow (2km) and linear.

3. PHYSIOGRAPHY

Three major physiographic units are recognized in the offshore region of northeast Taiwan: East China Sea shelf, East China Sea slope and basin floor of the Southern Okinawa Trough. In addition, two less prominent topographic features are distinguished: the Ilan continental shelf and the Ilan Ridge (Figure 4).

3.1 East China Sea Continental Shelf

Structurally, the East China Sea continental shelf is the seaward continuation of the extensive coastal plain along the coastal provinces of southeast China. Geomorphologically, the East China Sea shelf (200km) is relatively wide as compared to the continental shelves around the world with an average width of around 70-80km (Boillot, 1981). At the shelf edge (shelfbreak), there is a marked increase in gradient (Vanney and Stanley, 1983; Bouma, 1990). The depth of the East China Sea shelf edge around northeastern Taiwan is delineated by the 200m isobath (Boggs *et al.*, 1979). This is an approximation for the sake of convenient separation between the shelf and slope. Our study indicates that the depth of the shelf edge off northeast Taiwan has great lateral variations and ranges from 140 to 220m deep. For instance, profile 7 shows that there is a marked increase in gradient at the depth of about 140m along the outer margin of the East China Sea shelf (Figure 6). At profile 10 the shelf is

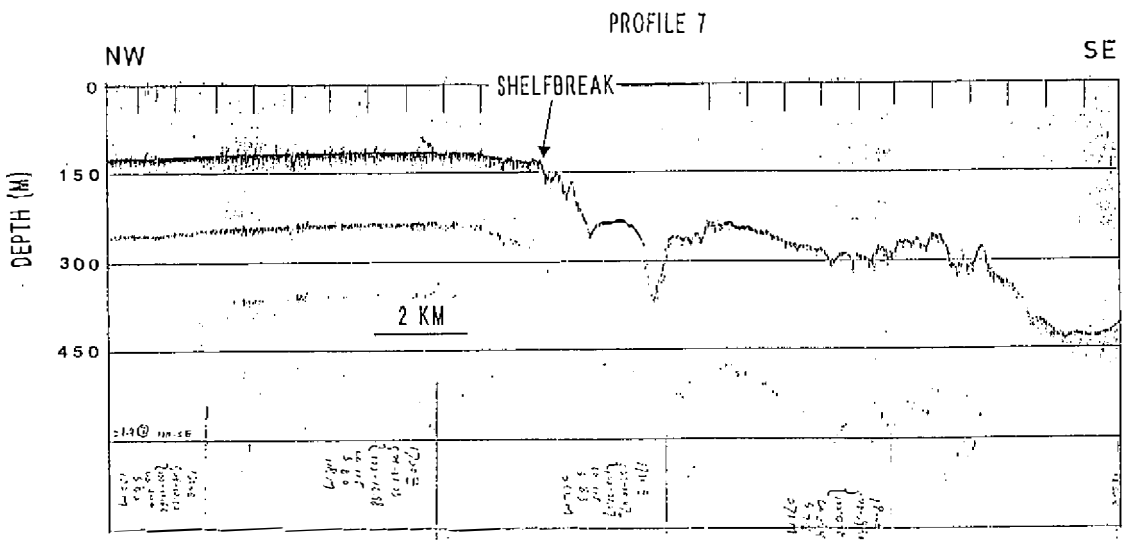

Fig. 6. A dip line (profile 7) across the shelf onto the slope showing that there is a marked increase of slope angle at the depth of about 140m at the outer margin of the East China Sea shelf. Location of the profiles is shown in Figure 4.

terraced (Figure 7) with the inner shelf of the East China Sea shelf shallower than 150m and the outer shelf about 220m in depth. However, the depth of shelf edge mainly is around 150m which may reflect the paleo-shoreline during the Late Pleistocene about 15,000 years ago. Note that the shelf-slope transition region around 200m is crooked which apparently reflects the indentation of the submarine canyons (Figure 4). The crooked topography of the shelf-slope zone may affect the water mass exchange between the Kuroshio Current and the East China Sea. It has been recognized that a cold water mass of upwelling is located adjacent to the Menhuahsu island and the head of one of the canyons (KEEP & WOCE Conference, Shito, Taiwan, 1992).

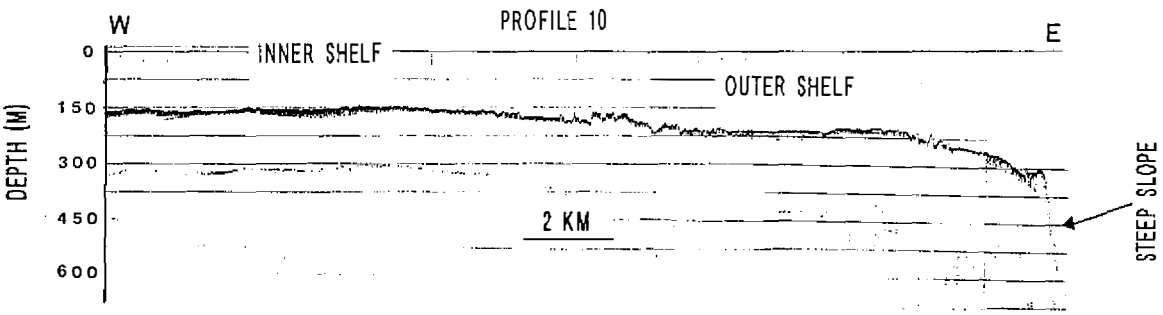

Fig. 7. A dip line (profile 10) showing that the broad continental shelf is terraced. The inner shelf is confined to depths shallower than 150m, but the outer shelf shows a marked change of slope angle at the depth about 220m at the outer margin of the shelf. Notice that the continental slope is very steep, and the slope angle is greater than 30. Location of the profiles is shown in Figure 4.

Several small islands, Pengchiahsu, Menhuahsu, Huapinghsu and Keelung Tao, occur on the broad and flat East China Sea shelf (Figure 4). These islets are about 30 to 60 km northeast of Taiwan and each have areas of fewer than several square kilometers. They are approximately 50 to 180 meters above sea level, and are mainly composed of andesites with tuff and agglomerates (Lin and Chou, 1974). They are Pleistocene volcanic islands and belong to the Tatung andesitic volcanic group of northern Taiwan (Yen, 1971).

3.2 East China Sea Continental Slope

The East China Sea continental slope begins at the shelf edge and descends downslope towards the floor of the Southern Okinawa Trough at the 2000m isobath. Structurally, the East China Sea slope is the northern flank of a young back-arc basin (Okinawa Trough). The continental slope, therefore, terminates at the axis of basin center without the presence of continental rise, abyssal plain or trench. Bathymetric profiles across the East China Sea slope vary greatly in terms of slope gradient and topography. Some sections of the continental slopes have gradients exceeding 30 (Figure 7). This very steep feature could be related to faulting at the shelfbreak. Other sections of the continental slopes are gently inclined and have average gradients less than 4 degrees (Figure 8). Wang and Hilde (1973) reported that

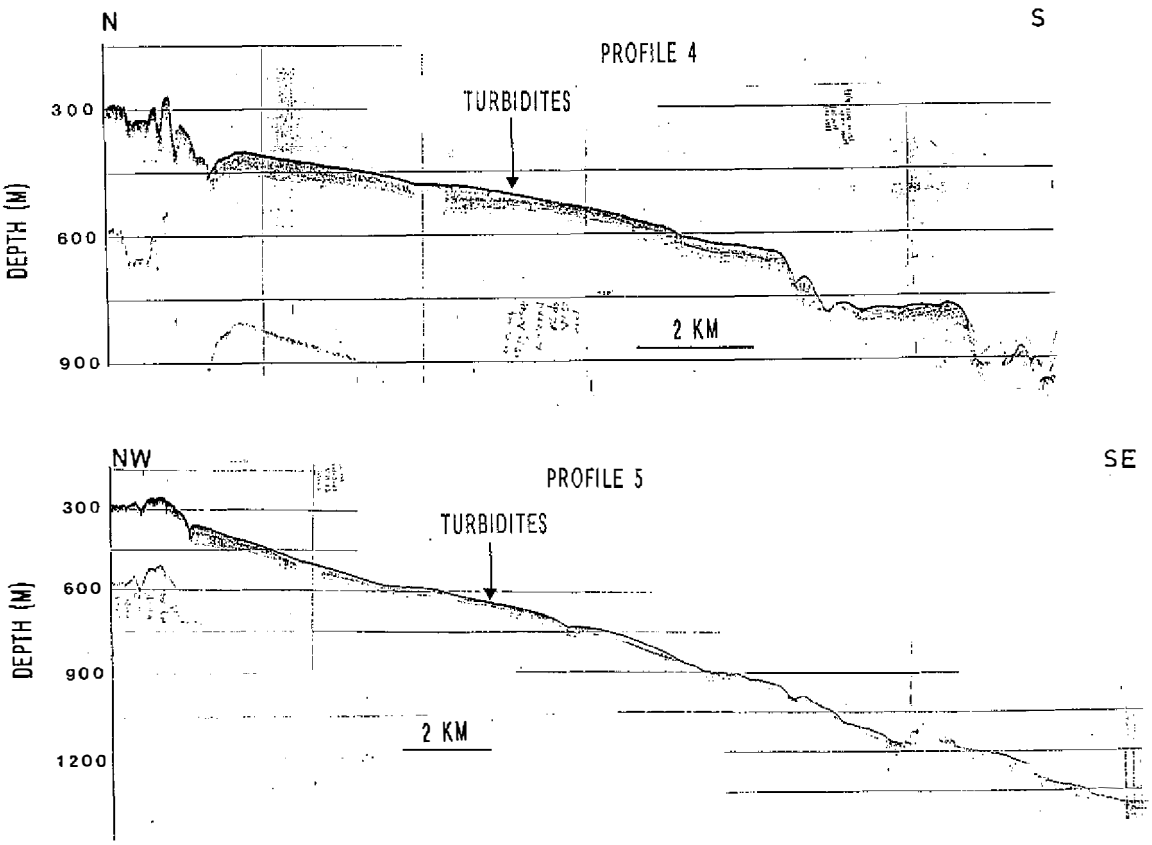

Fig. 8. Profiles 4 and 5 showing that the gently inclined slopes which are characterized by slope angles smaller than 4 degrees. Notice that the slopes may result from the accumulation of the turbidites and/or debris flow deposits. Location of the profiles is shown in Figure 4.

the East China Sea continental slope defining the northern side of the Southern Okinawa Trough has an average gradient of 1/100 to 1/50. Our observations of the slopes in the study areas seem to be compatible with their finding. In addition, Chou (1987) also reported that the East China Sea slope is characterized by an average angle of greater than 10 degrees. The profiles studied indicate that the continental slope has both smooth sloping surface and relatively irregular topography. For instance, profiles 4 and 5 both show relatively smooth surfaces and underneath the smooth sea floor may be the turbidites or debris flows with stratifications (Figure 8). On the other hands, profiles at different localities are characterized by slumping scars and channels (Figure 9). The relationships between the bedforms, sediment properties, near-bottom sedimentary processes and microtopography of the sea floor and certain specific 3.5KHz echoes reflected from the sea floor are well documented (Damuth, 1980; Klaus and Ledbetter, 1988; Laine *et al.*, 1986; McClennen, 1989 and Pratson and Laine, 1989). Based on the comparison between the 3.5KHz echograms on the East China Sea slope and that of the published studies , the sedimentary/topographic features such as the turbidites (Figure 8) and sliding scars (Figure 9) were determined. The slope topography has

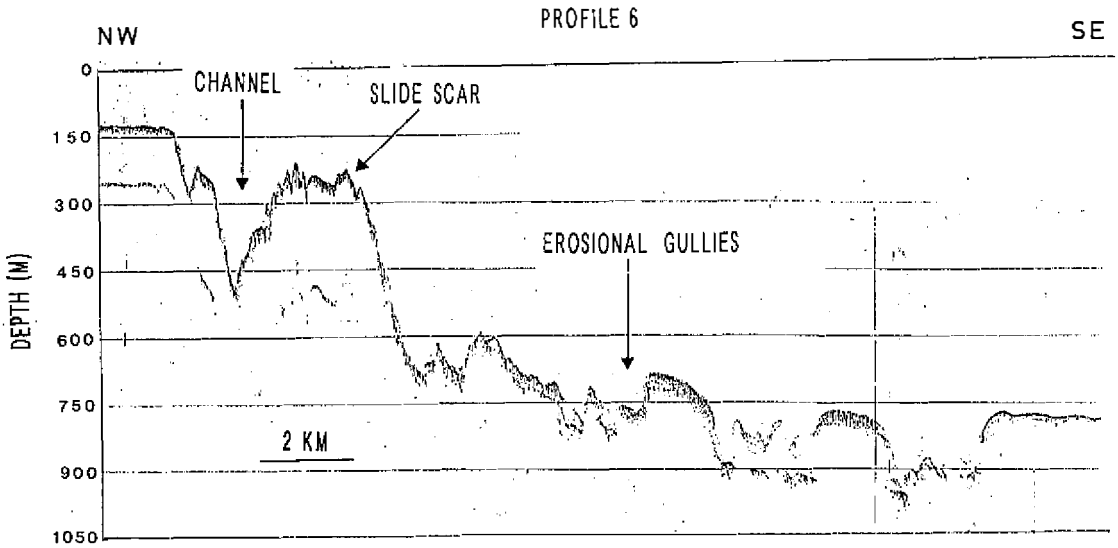

Fig. 9. Profile 6 across the slope showing the typical topographic expressions such as slide scars and channels. Location of the profiles is shown in Figure 4.

resulted from the combining effect of the progradational and/or erosional processes, sediment input, slope stability and faulting (Pickering *et al.*, 1989).

The submarine canyon is another prominent topographic feature occurring on the East China Sea slope (Figure 10). Profile 8, trending approximately in a EW direction across the submarine caynon shows that the uppercanyon part is characterized by a V shape with relatively steep slope extending from walls of two sides. The maximum width of the canyon is around 6km. The canyon floor is about 500 meters deep (Figure 10A). In a short distance downcanyon, profile 9 across the canyon shows the similar cross-sectional morphology to that of profile 8 but the canyon becomes wider (10km) and deeper (600m) as shown in Figure 10B. The cross-sectional morphology and dimensions of the canyon surveyed in the study area are similar to those found in the slope areas off southwestern Taiwan (Yu and Wen, 1991).

3.3 Southern Okinawa Trough

The Okinawa Trough is a back-arc basin located behind the Ryukyu Trench and the Ryukyu Island Arc (Lee *et al.*, 1980). It extends from the shelf edge off the Ilan Plain in northeastern Taiwan to the shallow sea southwest of Kyushu, Japan. According to Letouzey *et al.* (1987), Marsset *et al.* (1987) and Sibuet *et al.* (1987), the Okinawa Trough is subdivided into three subbasins: Southern Okinawa Trough, Middle Okinawa Trough and Northern Okinawa Trough. Morphologically, the Okinawa Trough is characterized by long depressions with flat bottom and steep sides. It is 60-100km wide in the south and reaches a maxmium width of 230km in the north. The deepest basin floor, 2270m in depth, is found

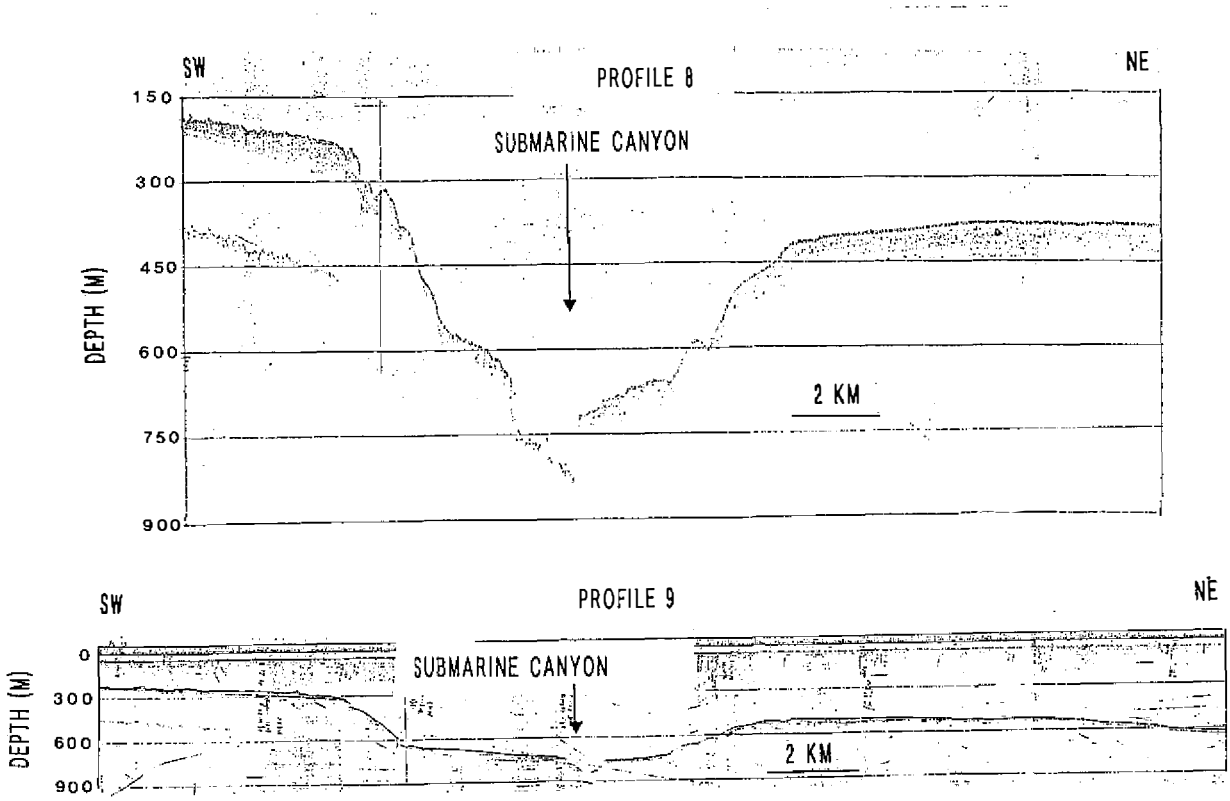

Fig. 10. Cross-sectional morphology of the segments of uppercanyon which is characterized by V-shaped configuration and high and steep walls. Location of the profile is shown in Figure 4.

in the Southern Okinawa Trough about 100km north of Ishigakijima volcanic island of the Ryukyu chain. The basin floor of the Okinawa Trough becomes shallow towards Kyushu, Japan. There is no consensus on the boundary separating the East China Sea slope from the Okinawa Trough. The sloping region of the northern side of the Okinawa Trough structurally is a high-angle faulted terrane overlain by Pliocene and younger sediments. Genetically, this slope is a part of the rift basin (Okinawa Trough). However, the bathymetric expression of the northern side of the Southern Okinawa Trough is classified as the continental slope based on the nomenclature of the continental margin. In fact, this rock body of the northern sloping region of the Southern Okinawa Trough structurally is the wall of a rift basin and morphologically belongs to a continental slope. We suggest that the boundary between the East China Sea slope and the Southern Okinawa Trough at the 1000m isobath because this paper is mainly concerned with the physiography along the continental margin of northeast Taiwan rather than the structure of the Okinawa Trough. Kobayashi (1985) and Marsset *et al.* (1987) also placed the boundary between the East China Sea slope and the Okinawa Trough at the 1000m isobath. In the study area, only the western part of the Southern Okinawa Trough is included. Profile 3 trending NW/SE shows that the relatively flat continental shelf with local low-relief features crosses the narrow and steep slope and extends onto the deep Okinawa Trough (Figure 11).

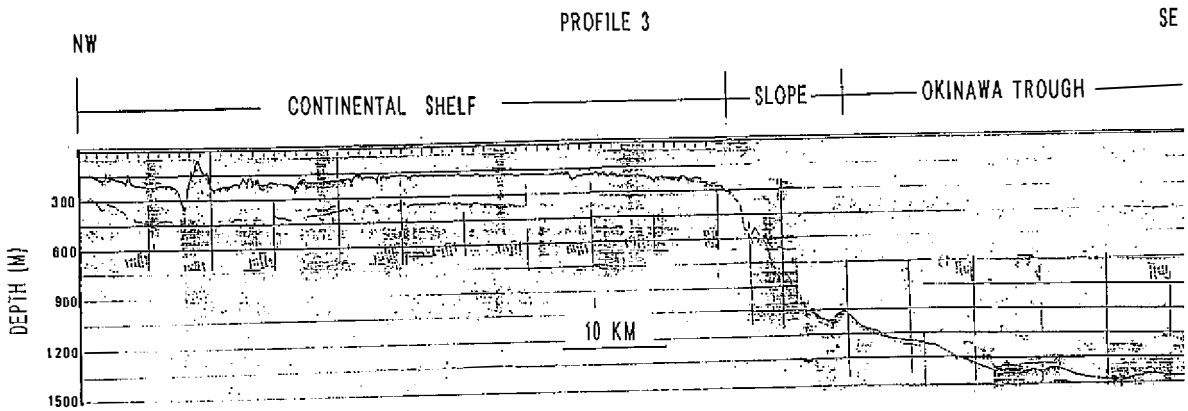

Fig. 11. Profile 3 trending NW/SE shows that the relatively flat continental shelf with locally low-relief features crosses the narrow and steep slope and extends onto the deep Okinawa Trough. Location of profile 3 is shown in Figure 4.

The western part of the Southern Okinawa Trough is surrounded by the East China Sea slope to the north, the Ilan Plain continental shelf to the west, the Ilan plain continental slope to the southwest and the slope off the Ryukyu volcanic island of Yonagunisima to the south (Figure 4).

3.4 Ilan continental shelf

The continental shelf off the northeastern corner of Taiwan is a relatively narrow platform which extends from the protrusion of about 122°E and 25°N southward and ends up at the coastal city, Suao (Figure 4). This shelf is named here as the Ilan continental shelf after the Ilan Plain. The shelf is fed by sediments from Taiwan via the Lan-Yan Hsi River. Apparently, the Ilan Plain continental shelf is the natural continuation of the Ilan Plain under the sea as revealed by the geologic map of Taiwan (1986). The width of the Ilan shelf varies from about 2km off the northeastern protrusion to more than 10km east of the lan-Yan Hsi and becomes narrow again towards the city of Suao. The fan-shaped shelf areas off the Lan-Yan Hsi is called Lan-Yan Fan by Chen (1991). Sediments derived from the Lan-Yan Hsi may prograde outward and accumulate on the shelf in a lobate form (see Hong, *et al.*, this volume). Kueishantao is a prominent volcanic island that appears on the Ilan Plain shelf. The island is located at 121°55′E, 24°53′N and has an area of about 2.7 square kilometers. Radiometric dating indicates that the volcanic island formed about 200,000 years ago as reported by the 1990 yearbook of the Central Geologic Survey of Taiwan. Kueishantao island consists mainly of andesite and is considered the western extension of the Ryukyu Arc.

3.5 Ilan Ridge

The Ilan Ridge is a long and narrow ridge extending seaward from the Ilan continental shelf. The Ilan ridge extends seaward and terminates at the Yonagunisima island of the Ryukyu island chain. The Ilan Ridge is relatively small in areal extent as compared to the Ryukyu island chain.

The word RIDGE has several meanings, and one of them is defined as a long, narrow elevation often separating ocean basins (Bouma, 1990). Morphologically, the Ilan Ridge is an elevation that rises steeply from the Okinawa Trough to the north and the Nanao basin to the south. Tectonically, the ridge is a part of the Ryukyu volcanic islands and separates the backarc basin of the Okinawa Trough from the forearc basin of the Nanao basin to the south. Therefore, we assign the term of ridge to the slope areas between the Ilan shelf and Ryukyu islands because it fits the definition as suggested by Bouma (1990).

4. DISCUSSION

The naming of these physiographic units is provisional and may be revised if better names are proposed. We are fully aware of the guidelines for naming undersea features recommended by such organizations as the Intergovernmental Oceanographic Commission (IOC), the International Hydrographic Organization (IHO) and the joint IOC/IHO Guiding Committee for the General Bathymetric Chart of the Ocean (GEBCO), as cautioned by Bouma (1990).

5. CONCLUSIONS

The continental margin off northeastern Taiwan can be divided into five physiographic units mainly by bathymetry and topography and secondarily by structure and tectonic setting. These physiographic features from north to south are the East China Sea continental shelf, the East China Sea continental slope, the Southern Okinawa Trough, the Ilan continental shelf and the Ilan Ridge. This physiographic framework is provisional and may be revised if better names are proposed.

The indentation of the submarine canyons onto the shelf and the protrusion of the Ilan shelf onto the slope have modified the linear shelf-slope transition region into an irregular shape. The shelf-slope zone is also characterized by great lateral variations in gradient and topographic characters. The relationships between the topography and hydrodynamics in the shelf-slope region off northeastern Taiwan are worthy of investigation.

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臺灣東北海域大陸邊緣地形區之特徵

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摘要

臺灣東北海域之大陸邊緣包括五個主要地形區，即東海大陸棚、東海大陸斜坡、南沖繩海槽、宜蘭大陸棚及宜蘭海脊。這個地形區架構是暫定的，如果有更好的的名稱提出則修改之。

東海大陸棚相當地寬，且其海床平坦，但局部有明顯的地貌起伏，這是受到晚更新世海水面升降及弧後盆地張裂的火山活動影響。

東海大陸斜坡的地形及坡度其側向變化極大，大陸斜坡上有明顯的崩塌或滑動斷崖、侵蝕槽谷、碎屑流或濁流沉積物。海底峽谷是大陸斜坡另一明顯的地貌，其頭部嵌入大陸棚，使棚坡區域形成不規則狀。

南沖繩海槽的西界以彎曲的2000公尺等深線爲準，此海槽範圍主要在北邊東海大陸斜坡及南方的硫球島弧斜坡之間。

宜蘭大陸棚爲陸上宜蘭平原向外海的自然延伸。此陸棚呈扇狀，陸棚寬度在蘭陽溪口附近寬約10公里，至頭城及蘇澳附近則變窄爲 2公里左右。宜蘭大陸棚突出於大陸斜坡之上，實乃大量宜蘭溪帶來的沉積物堆積而成。

宜蘭海脊由宜蘭陸棚向東南延伸形成一個長而窄的地形高區，此海脊分隔了南方的弧前南澳盆地與北面的弧後沖繩海槽。宜蘭海脊以東邊的硫球島弧爲界，其區域範圍有限，表現局部性的地形特徵。

東海海水與黑潮水在東海大陸棚坡區交換，而此地區的地形爲不規則狀，這種地形效應值得進一步探討其對黑潮邊緣交換過程的影響。