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Physiographic and Geologic Frameworks of the Shelf-Slope Region off Northeastern Taiwan

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ABSTRACT

The East China Sea Shelf and East China Sea Slope are the major physiographic provinces of the continental margin off northeastern Taiwan. The shallow and flat East China Sea Shelf has an average shelfbreak depth of 120 m and shows a simple type of convex-up profile form, reflecting the effect of Quaternary glaciation about 18,000 years ago.

The East China Sea Slope has a width ranging from 73 to 94 km. Its upper limit is at the shelfbreak, and its lower boundary ranges from water depth of 1700 to 2030 meters near the bottom of southern Okinawa Trough. Overall, it shows moderate lateral variation in gradient with an average slope angle of 1.31 degrees. This slope is transversely dissected by submarine canyons and many gullies which produce irregular sea floor topography. Structurally, the East China Sea Slope is the northern flank of Okinawa Trough. It is quite different in size and morphology from mature continental slopes due to its young back-arc basin related formation.

The shelf and slope region off northeastern Taiwan was formed by a sequence of extensional episodes that produced extensive normal faulting and massive terrigeneous deposition along the Eurasian continental margin. Rift faulting during the Late Cretaceous-Early Tertiary, together with subsequent subsidence and deposition of shallow marine sediments in the Late Tertiary and Quaternary resulted in today's East China Sea Shelf. In comparison, tilted normal fault blocks formed by back-arc extension during the Late

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Miocene to Quaternary and subsequent deposition of sediments from the nearby shelf have produced the present-day East China Sea Slope.

(Keywords: Taiwan, East China Sea, shelf, slope, physiography, geology)

INTRODUCTION

The island of Taiwan is located on the Eurasian margin at the junction of the Ryukyu Arc and the Luzon Arc in the western Pacific (Fig. 1). Morphologically, the sea floor surrounding Taiwan shows a distinct asymmetry with shallow shelf areas off northern and western Taiwan, and deep basins off the southwestern and eastern coasts. Tectonically, the East China Sea Shelf to the north and the Taiwan Strait Shelf to the west of Taiwan are underlain by the Eurasian continental plate, whereas the Philippine Sea oceanic plate underlies the deep-water region off eastern Taiwan.

The sea floor off northeastern Taiwan in the present study area (Fig. 1) consists of three major physiographic units: the East China Sea Shelf, the East China Sea Slope and the Okinawa Trough. In addition, there are two less prominent physiographic features, the Chilung Shelf and the Ilan Shelf (Fig. 1). Near northeastern Taiwan, the East China Sea Shelf is a relatively flat platform except for Pleistocene volcanic islets, sea valleys and submarine canyons (Yu and Song, 1993). The East China Sea Slope varies laterally in slope gradient as evidenced by irregularly spaced isobaths, and is cut by gullies and two major submarine canyons (i.e., Mien-Hua Canyon and North Mien-Hua Canyon) west of 123° E. (Fig. 2). South of the East China Sea Slope lies the floor of southern Okinawa Trough which has a water depth of about 1500 to 2200 m and becomes shallow towards Taiwan (Sibuet et al., 1987).

The shelf-slope region off northeastern Taiwan is where the exchange between East China Sea and Kuroshio Current water masses takes place and the path of the Kuroshio Current is influenced by this bathymetry (Chung and Yu, 1988, Tang, 1996). A detailed description of morphology in the shelf-slope region will improve the understanding of topographic effect on the Kuroshio edge exchange processes. Likewise, a detailed knowledge of the shelf-slope transition morphology is essential to understanding the area's sedimentary and tectonic history (Vanney and Stanley, 1983 and Gorsline, 1991).

This paper presents detailed descriptions of bathymetry of the shelf-slope region off northeastern Taiwan. The morphological data of shelfbreak depth, gradient and slope depth are tabulated. Factors controlling the morphology of the shelf and slope off northeastern Taiwan are discussed. In doing so, this paper gives a general review of the physiographic and geological features off northeastern Taiwan. The geologic framework presented here is based on published literature, together with proprietary seismic and well data provided by the Chinese Petroleum Company.

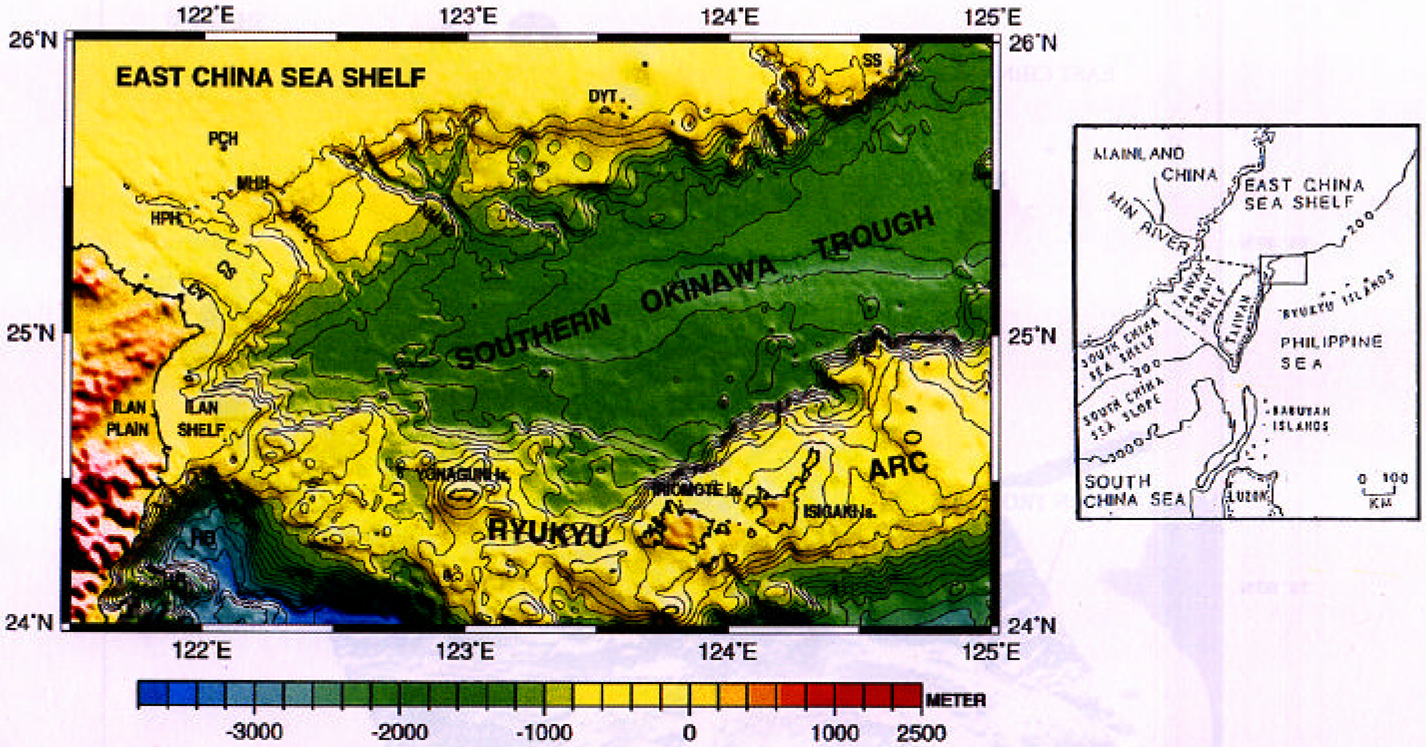

Fig. 1. Map showing the sea floor around Taiwan characterized by a distinct asymmetry with shallow shelf areas off northern and western Taiwan and deep basin floor off the southwestern and eastern coasts. Note the 200 m isobath with a NE-SW trend. The study area is outlined by the heavy-lined box. Bathymetric map of the northeastern Taiwan shows the major physiographic units: the East China Sea Shelf, the East China Sea Slope and Okinawa Trough. Bathymetric contours are in meters. Note that the shelf is dotted with three volcanic islets: Pengchiahsu (PCH), Mienhuahsu (MHH), and Huapinghsu (HPH). CV=Chilung Sea Valley, MHC=Mien-Hua Canyon, NMHC=North Mien-Hua Canyon. Modified from Liu et al. (1998).

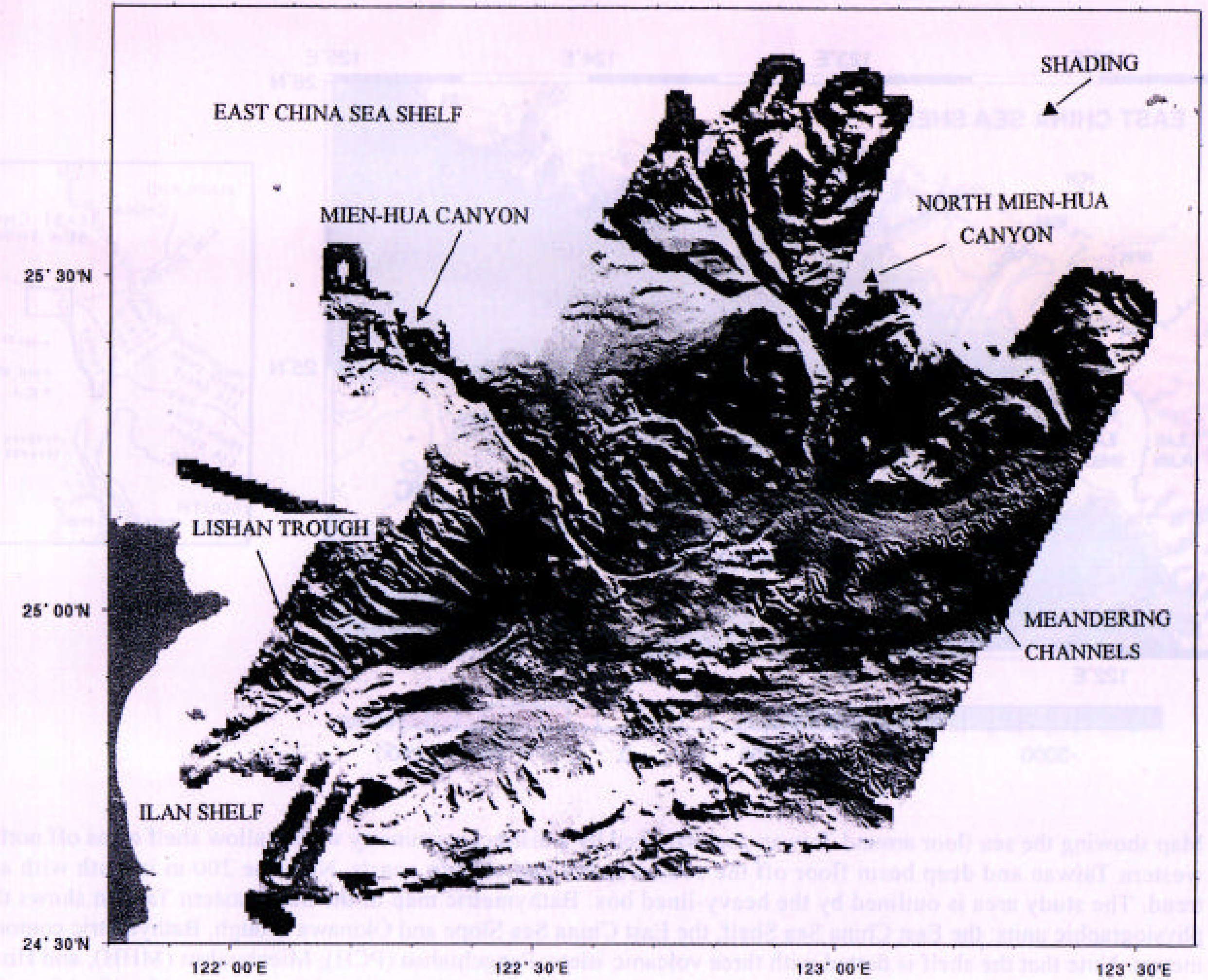

Fig. 2. NE shading bathymetric map showing two major canyons on the East China Sea Slope, the Lishan Trough on the north of the Ilan Shelf and meandering channels on the basin floor of the Okinawa Trough off northeastern Taiwan Modified from Sibuet et al. (1999).

PREVIOUS STUDIES

Regionally, the East China Sea Shelf has been known for its shallowness (100 m) and width (exceeding 400 km), describing a broad, flat and mostly featureless sea floor underlain by deep NNE-SSW trending sediment-filled basins (Emery et al., 1969, Wageman et al., 1970). However, the shelf narrows to 230 km wide near Taiwan. Early studies of the Taiwan shelf and slope by Boggs et al. (1979) indicated that it is characterized by low-relief submarine ridges and volcanic intrusions in addition to erosional features of sea velleys and canyons. Four volcanic islets (Ho, 1975), Pengchiahsu, Mienhuahsu, Huapinghsu and Chilungtao appear on the shelf near Taiwan (Fig. 1). These islets are mainly composed of andesites, tuff and agglomerates, with heights of from 50 to 180 m above sea level (Lin and Chou, 1974). The morphologic characteristics of Chilung Sea Valley and Mien-Hua Canyon have been described by Song and Chang (1993), Yu and Hong (1993) and Marr (1995). The general bathymetry of the shelf-slope region off northeastern Taiwan has been studied by Boggs et al. (1979),Yu and Hong (1992), Hong et al. (1992), Yu and Shyu (1994) and Yu and Song (1996). In particular, Boggs et al. (1979) pointed out that the shelf northeast of Taiwan was subaerially exposed in the Late Pleistocene time, when sea level dropped about 140 m below the present level. The bathymetry of the sea floor and the relict sands of the shelf northeast of Taiwan reflect the effects of Quaternary glaciation about 18,000 years ago.

Pioneering geologic and geophysical investigations in the East China Sea were carried out by Emery et al.(1969) and Wageman et al.(1970). The general geology of East China Sea has also been described by Jin (1992). Early local geologic and geophysical studies in the region off northeastern Taiwan were made by Lee et al. (1973) and Wang and Hilde (1973). Using industry seismic and drilling data, Sun (1982), Huang et al. (1992) and Yu and Huang (1994) presented the general stratigraphy, structure and geologic evolution of the continental margin off northeastern Taiwan.

The Okinawa Trough has been recognized as a back-arc basin (Wageman et al., 1970, Herman et al., 1978, Lee et al., 1980). Detailed descriptions of the structure of Okinawa Trough were given by Kimura (1985) and Letouzey and Kimura (1986). Subsequently, Sibuet et al. (1987) provided constraints for the models of back-arc extension using Sea Beam records and other geophysical data.

DATA AND METHOD

Bathymetric transects were acquired in the area northeast of Taiwan from 1990 to 1996 on board the R/V Ocean Researcher I using EK 500 Sonar together with the Global Position System. Bathymetric data were then integrated into the bathymetric data bank complied by Institute of Oceanography, National Taiwan University. The tracklines of bathymetry cover the study area are shown in Figure 3. Using this data bank and applying a digital elevation model for gridding and contouring, Liu et al. (1998) generated the most up-to-date regional bathymetric chart for the offshore areas around Taiwan. This chart has a grid spacing of 1.8 by 1.8 km, is able to reveal many detailed submarine features, and has been widely used as a reference for submarine topography. The current paper uses a part of this regional bathymetric chart (Liu et al., 1998) to display the bathymetry off northeastern Taiwan (Fig. 1). A NE simulated hill-shading of the shelf-slope region west of 123° 30′ E in the study area is made from the same bathymetric data bank with gridding of every 75 m to show the sea floor features (Fig. 2).

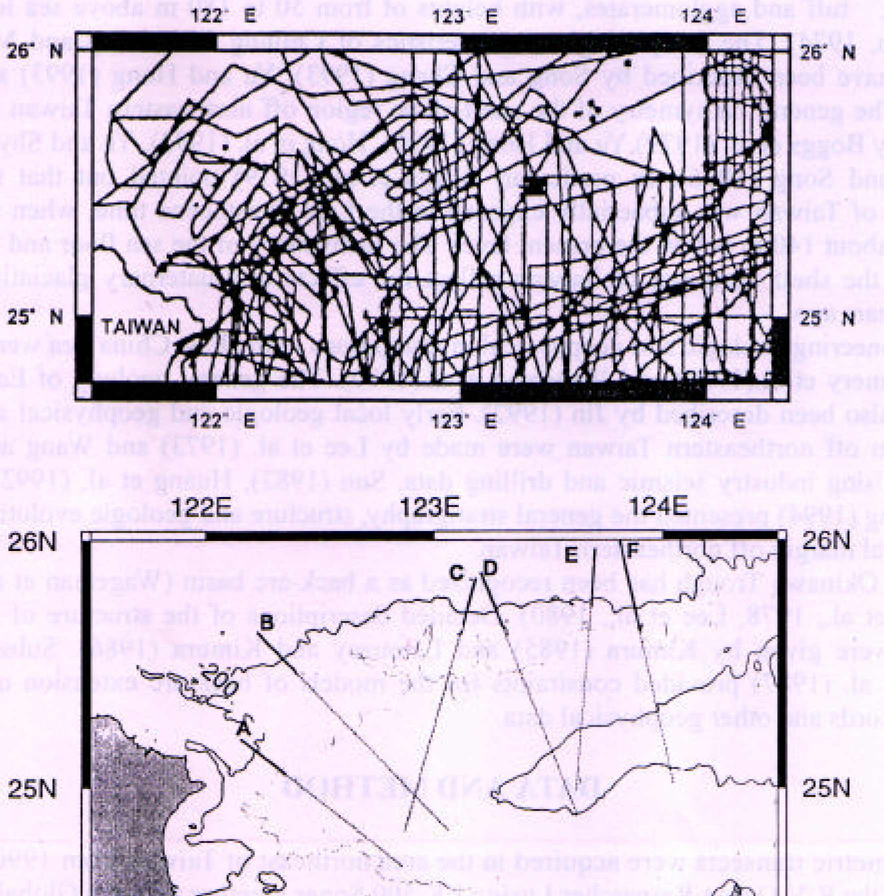

Fig. 3. The tracklines of bathymetry in the study area off northeastern Taiwan (Top). The locations of six selected bathymetric profiles are shown in the bottom.

Table 1. Morphological Data of the East China Sea Slope near northeastern Taiwan.

PROFILE	UPPER BOUNDARY (SHELF BREAK)			LOWER BOUNDARY (TROUGH AXIS)			SLOPE ANGLE	WIDTH (km)	GRADIENT
	LONG.	LAT.	DEPTH. (m)	LONG.	LAT.	LEPTH. (m)			
A	122.26	25.12	-234	122.56	24.91	-1535.9	1.928	38.475	1/30
B	122.33	25.53	-122	122.97	24.92	-1908.8	1.086	94.110	1/53
C	123.15	25.74	-142	122.91	24.95	-1794.7	1.033	94.644	1/55
D	123.25	25.77	-116	123.58	24.99	-2098.5	1.264	92.697	1/45
E	123.70	25.84	-85	123.63	25.05	-2103.3	1.320	87.171	1/43
F	123.87	25.77	-137	124.00	25.20	-2250.8	1.861	73.737	1/31

The position and depth of shelfbreak of the East China Sea Shelf off northeastern Taiwan were first examined graphically using the methods of Vanney and Stanley (1983), and then measured numerically by the method of Chang (1997). The six bathymetric profiles of this study were constructed across the East China Sea shelf-slope region. These six bathymetric profiles were aligned as closely as possibly normal to the isobaths in order to determine the maximum slope angle of the shelf-slope transition. The profile locations are shown in Figure 3 and morphological data are given in Table 1.

PHYSIOGRAPHY

East China Sea Shelf

South of 25° 45' N, the sea floor of East China Sea Shelf is generally smooth and flat, although it is dotted with three volcanic islets near the head of Mien-Hua Canyon (Fig. 1). Our study indicates that the shelfbreak of the East China Sea Shelf in the study area occurs in a water depth ranging from 85 m to 142 m with an average shelfbreak depth at about 120 m (Table 1). Jin (1992) reported that shelfbreak depth of the East China Sea Shelf ranges from 140 to 160 m, reaching a maximum depth of 181 m, which is not significantly different from our results. The East China Sea Shelf near Taiwan can be regarded as a typical continental shelf because most present-day shelves in the world have the shelfbreak occurring at a depth of 130-200 m (Boillot, 1981, Kennett, 1982).

Figure 4 shows that five of six representative bathymetric profiles across the shelf-slope transitions in the study area reveal a smooth and curviliner shape without the presence of depressions or elevations on the sea floor. This belongs to the simple type of shelfbreak in terms of classification of Field et al. (1983). These five bathymetric profiles displayed with x10 vertical exaggeration appear as convex-up arcs, a common shelfbreak configuration (Vanney and Stanley, 1983). It can be noticed that these profiles were selected not to cross canyons or faults in order to show the form at the shelf-slope transition without being overprinted by other geologic processes such as locally downward erosion.

In general, this paper suggests that the morphology of East China Sea Shelf mainly reflects the Quaternary glaciation effect of about 18000 years ago, as indicated by depth of shelfbreak and profile form.

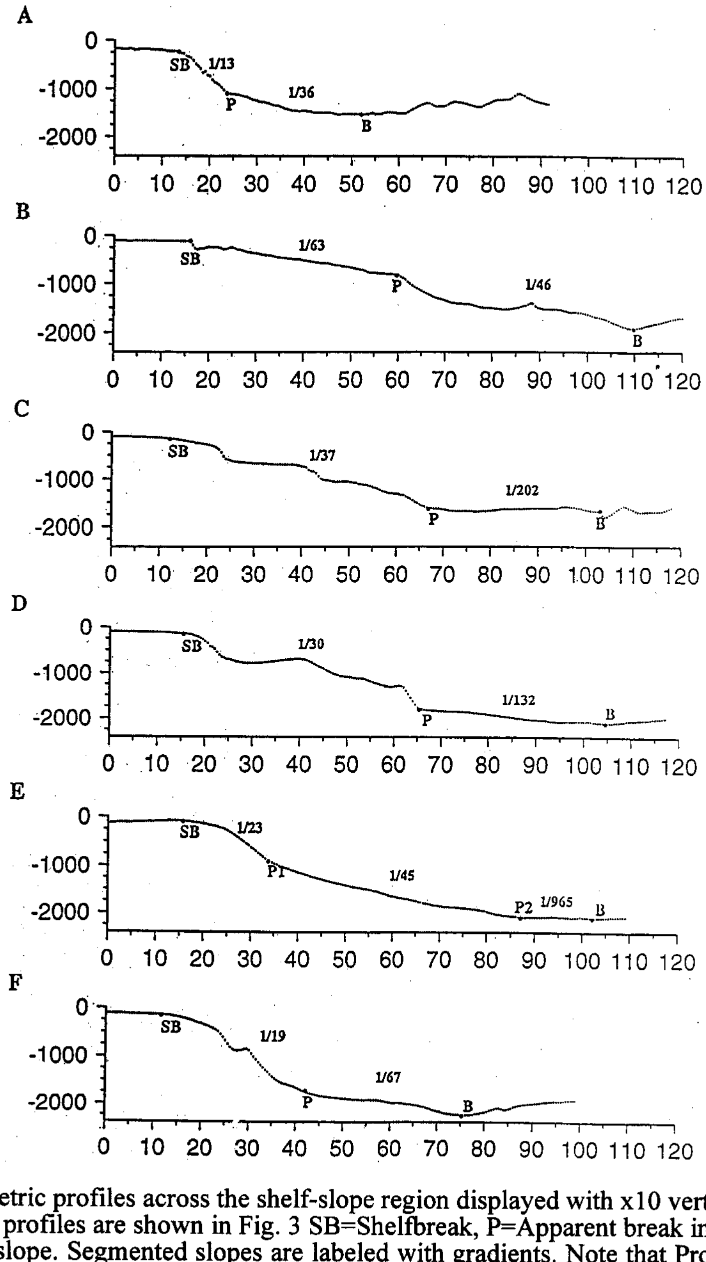

Fig. 4. Six bathymetric profiles across the shelf-slope region displayed with x10 vertical exaggeration. Location of profiles are shown in Fig. 3 SB=Shelfbreak, P=Apparent break in slope continuity, B=Base of slope. Segmented slopes are labeled with gradients. Note that Profile E shows two apparent slope breaks which are marked with P1 and P2, respectively. Vertical scale is in

Chilung Shelf

The shelfal area between northern Taiwan and Mien-Hua Canyon is referred to as the Chilung Shelf (Song and Chang, 1993, Song, 1994). The shelfbreak depth of the Chilung Shelf denoted by profile A is determined to be 234 m (Fig. 4, Table 1), which is about 110 m deeper than that of the adjacent East China Sea Shelf. The Chilung Shelf shows a slope angle of about 1.5 degrees, which is much greater than that of typical continental shelves (about 0.05) (Kennett, 1982). Morphologically, the Chilung Shelf may not be regarded as a typical continental shelf because of its deep shelfbreak and high slope angle.

The general form of the shelfbreak across the Chilung Shelf shows a simple convex-up arc (Fig. 4). In plan view, the shelfedge extends NNE-SSW as a straight line for a short distance of 50 km, and the northeastern end of the shelf edge is offset along the Mien-Hua Canyon for a distance of 60 km. The southern margin of the Chilung Shelf is marked by a major right-lateral strike-slip fault zone of Pliocene-Pleistocene age which has developed the Chilung Sea Valley (Huang et al., 1992, Marr, 1995). Hsu et al. (1996) suggested that a major left-lateral strike-slip fault exists along the axis of Mien-Hua Canyon. If the argument of strike-slip faults is correct, then the offset of the Chilung Shelf relative to the East China Sea Shelf might be due to left-lateral motion along the strike-slip faults.

Chilung Sea Valley is a prominent submarine valley separating the Chilung Shelf from the Ilan Shelf area to the south (Fig. 1). This sea valley is located about 10 km north of Taiwan with a northwest-southeast trend. It is a relatively shallow (270 m) and wide (around 10 km) linear depression with a length of about 65 km. The slope along the valley axis is less than 0.5 and the relief between valley edge and valley axis is about 20 m (Song and Chang, 1993, Marr 1995).

Ilan Shelf

The Ilan Shelf is the seaward continuation of the Ilan Plain along the northeastern coast of Taiwan (Fig. 1). The shelf is fan-shaped, and the width varies from about 2 km off the northeastern protrusion to more than 10 km at its eastern edge, becoming narrow again towards the southern end. Because of its fan shape and its being close to a major river in the Ilan Plain (i.e., Lan-Yang Hsi), Chen (1991) inferred the Ilan Shelf to be a fan deposit. Subsequently, Hong et al. (1992) suggested that sediments derived from the Ilan Plain prograded seaward and accumulated on the shelf to form a lobate deposit on the basis of the echo characteristics of 3.5 kHz profiles across the shelf.

The Ilan Shelf is bounded on the north by the Lishan Trough (Figs. 1 and 2). The trough extends from the shelf-slope transition about 200 m nearly eastward to the near 1500 m isobath on the deep floor of Okinawa Trough. Structurally, this trough can be connected to the Lishan Fault on the Ilan Plain in Taiwan (Hsu et al., 1996). It is the boundary separating the Eurasian continental margin to the north from the Ryukyu Arc to the south (Sibuet et al., 1998).

Examining proprietary bathymetric tracks and 3.5 kHz profiles across the Ilan Shelf, we determined the depth of shelfbreak of the Ilan Shelf. Depths of the this shelfbreak range from 165 to 430 m with a large scatter and an average shelfbreak depth of 270 m. Note that present-day shelves world-wide are characterized by depths of shelfbreak ranging from 130 to 200 m (Boillot, 1981, Kennett, 1982). The shelfbreak depth of the Ilan Shelf is much deeper than values from the nearby East China Sea Shelf (120 m) and other shelves around the world. Morphologically, the Ilan Shelf cannot be considered a typical continental shelf in terms of its fan shape and deep depth of shelfbreak. Apparently, the tectonic activities of volcanism of the Ryukyu Arc and back-arc opening of the southern Okinawa Trough overwhelm the effects of depositional/erosional processes in forming the shelf. Discussions of the relationship between morphology and tectonics of the Ilan Shelf are not elaborated here.

East China Sea Slope

The East China Sea Slope extends eastward from the Mien-Hua Canyon throughout the study area. Along this E-W trend the slope width averages 88 km (range of 73-94 km), comprises an area of about 20,000 square kilometers and generally has a base-of-slope depth about 2030 m (Fig. 4). The upper boundary of this slope is at the shelfbreak with water depths ranging from 85 to 142 m. The lower boundary is at the basin floor of the bordering Okinawa Trough. Note that there is a progressive eastward deepening of basin floor of Okinawa Trough from the Ilan Shelf and this is the main cause of deepening trend of the slope base to the east from profiles A to F (Fig.4). Slope width, therefore, probably depends on the base-of-slope datum for each slope.

The East China Sea Slope shows moderately eastward lateral variations in gradient, ranging from 1/55 to 1/30. The average slope angle is 1.31 degrees, which is much smaller than that of others in the world. The average slope angle of continental slopes off stable coasts is about 3 degrees, off mountainous coasts about 4.6 degrees and off faulted coasts about 5.6 degrees (Shepard, 1973). However, continental slopes globally average a relatively steep slope angle of about 4 degrees (Shepard, 1973, Kennett, 1982). Therefore, the continental slope in the study area is characterized by a gentle submarine sloping surface, despite this margin's development being of recent tectonic origin.

In Figure 4, five bathymetric profiles across the East China Sea Slope can be visualized in three profile forms: straight, terraced and concave-up. Profile B shows a nearly straight form, although an apparent break in continuity (P) at 817 m deep occurs around the middle point of the profile.

Profiles C and D show terraced form. The apparent breaking points may be placed at depths around 1700 m, separating the profiles into an upper segment and a lower section. The upper segments are much steeper (1/30) than those of lower sections (1/200). Profiles E and F have similar concave-up forms, as indicated by the fact that the upper segments are steeper than those of lower sections.

The terraced forms of profiles C and D are most probably formed by normal faulting, as noted by Sibuet et al. (1987). They reported that 3.5 kHz records on sea floor of northern margin of the southern Okinawa Trough show the displacement of normal faults varying from a few meters to about 50 meters. On the other hand, there is no surface geological evidence to explain the formation mechanism of straight and concave-up forms of the profiles. However, it is reasonable to suggest that the form of the slope can be related by rifting faulting, syn-tectonic sedimentation and lateral strike-slip faults. For example, Liu et al. (1998) recognized that the East China Sea Slope west of 124° E can be differentiated as a slope of steep fault scarps from a slope of tilted subsiding fault blocks.

The East China Sea Slope off northeastern Taiwan is extensively dissected by large submarine canyons and by many small gullies which incise inter-canyon areas, producing irregular sea-floor surfaces (Fig. 1). Located at the western end of the East China Sea Slope, the Mien-Hua Canyon shows the headward erosion that cuts into East China Sea Shelf to form a broad trough-shaped channel. The main canyon developed on the East China Sea Slope has a narrow V-shaped form and steep walls (Yu and Hong, 1993). This canyon branches into two tributaries at the upper slope. One tributary indents shoreward and passes south of the Huapinghsu islet and the other cuts the shelf and ends around the Mienhuahsu islet (Song and Chang, 1993). This canyon extends from the head on the shelf to its end on the slope with a length of about 120 km and a relatively straight course (Yu and Hong, 1993). However, the shaded bathymetric map with low elevation view points in the study area (Fig. 2) shows the detailed canyon course of the lower reach of the Mien-Hua Canyon, indicating an abrupt eastward turn at its end.

The North Mien-Hua Canyon is a multi-head canyon consisting of four distinct heads that indent the shelf slightly (Fig. 5). These four heads coalesce downslope to form a single canyon near the 1200 m isobath. This canyon ends near the 1600 m isobath at the lower slope. Profiles transversing canyon courses show characteristic high relief, steep walls and a V-shaped cross-sectional configuration (Fig. 5).

Using multi-channel seismic reflection profiles across the North Mien-Hua Canyon Yu and Lee (1998) pointed out that termination of parallel reflectors of slope sediments against the canyon walls and slumping features on canyon walls provide evidence of downward excavation. The canyon floors are slightly filled by sediments with irregular surfaces, suggesting that sediments from up-canyon and both walls are carried down-canyon by strong sediment flows or turbidity currents along the canyon bottom. Thus, the North Mien-Hua Canyon is an active canyon transporting sediments from the shelf-slope region to the deep Okinawa Trough.

Sibuet et al. (1999) pointed out that sediments transported by canyons on the East China Sea Slope and the Lishan Trough accumulated in the deep basin of Okinawa Trough, and were subsequently eroded into meandering channels as shown in Figure 2.

Chilung Slope

Within a small area offshore the corner of northeastern Taiwan, the seaward slope beyond Chilung Shelf is referred to here as the Chilung Slope. Bathymetric profile A (Fig. 4) shows that the Chilung Slope begins at the shelfbreak (234 m deep) and decends rapidly to a depth of 1092 m with a steep gradient of 1/30, and ends at the deep floor of Okinawa Trough (1536 m). In general, the Chilung Slope has a slope angle of 1.93 degrees and shows a concave-up form. The Chilung Slope is a very small part of the northwestern flank of southern Okinawa Trough near its southwestern end (Fig. 1). Its morphology is mainly controlled by the strike-slip motion and subsidence due to the tectonic interaction between the opening of the southern Okinawa Trough and the nearby indentation of Taiwan island into the passive Chinese margin (Song et al., 1997). In fact, tectonics is a major control of all the slope areas discussed in this paper.

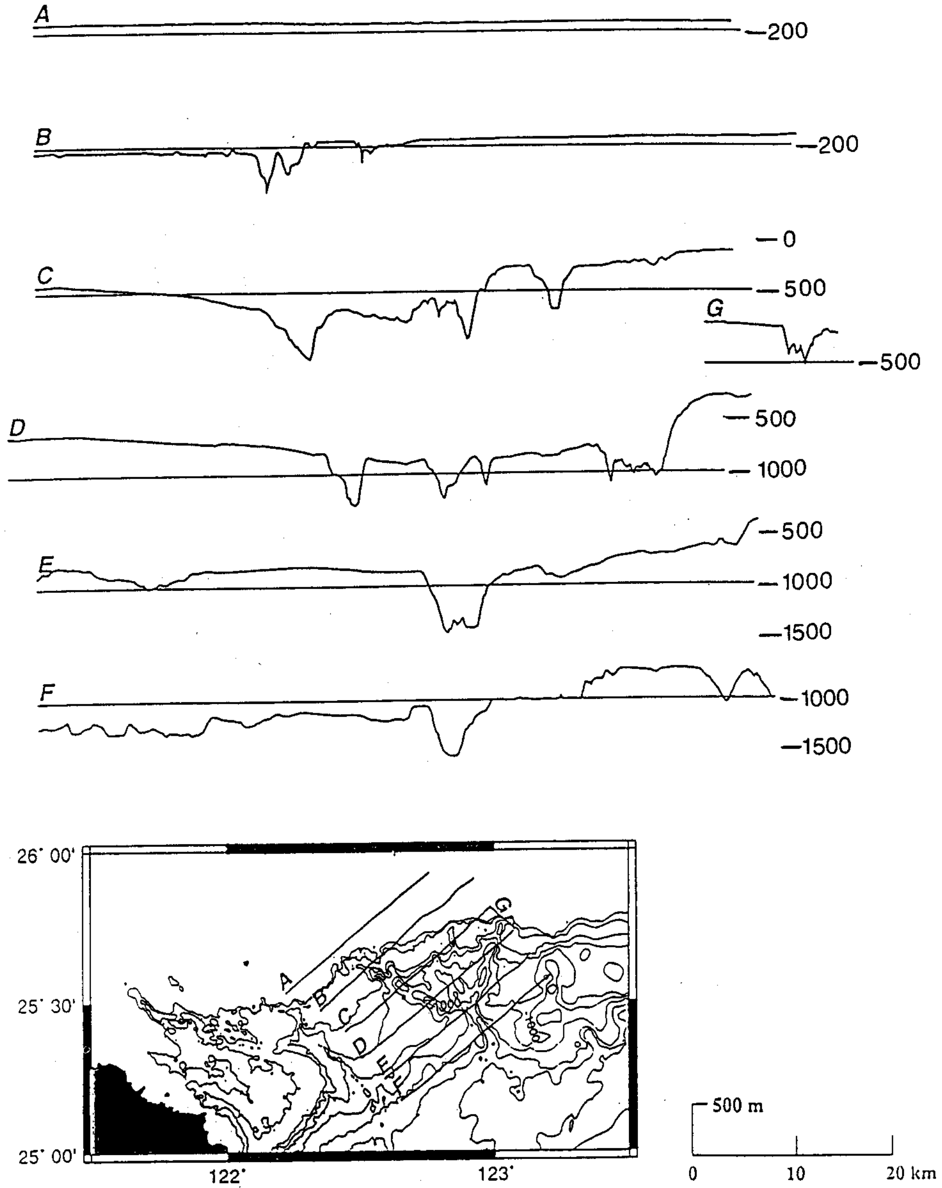

Fig. 5. Cross-sectional morphology of the North Mien-Hua Canyon showing typical features of steep walls and V-shaped troughs. Vertical scale is in meters below sea level.

GEOLOGY

Stratigraphy

The rock sequences underlying the East China Sea Shelf northeast of Taiwan in the study area consist mainly of Cenozoic clastic sediments up to 8000 m thick (Sun, 1982, 1985).The basement , overlain uncomformably by thick Cenozoic strata, is assumed to be a Mesozoic magmatic-volcanic complex, i.e., the eastward extension of the eastern Fujian basement complex although a small number of exploration wells have penetrated a basement of Proterozoic age (Chou, 1991, Zhou et al., 1989, Jin, 1992).

The lithology of the Cenozoic strata is dominated by clastic facies including sandstones and mudstones. Rifting volcanic facies of lava flows and pyroclastics occur mainly in Late Paleocene, Eocene and Middle to Late Miocene. A widespread regional unconformity from the Middle Oligocene separates the Cenozoic strata into Paleogene and Neogene sequences (Sun, 1982). Early Tertiary sediments consist mainly of non-marine to marine facies, whereas Late Tertiary and Quaternary strata are characterized by flat-lying shallow marine facies. The Lower Tertiary strata are structurally disturbed, commonly tilted, and are deposited in both half and full grabens. In contrast, the Upper Tertiary sequences are generally undeformed and overlie the infilled half grabens (Fig. 6).

The data base for our construction of a stratigraphic framework of the Cenozoic strata off northeast Taiwan is mainly derived from published seismic stratigraphic studies using industrial seismic data and exploration wells (Huang, 1982, Sun, 1985, Chou, 1991, Yu and Huang, 1994,Shaw, 1996).

Structure

A northwest-southeast trending geologic profile across the southern East China Sea Shelf near northeast Taiwan shows typical rifting features of high-angle normal faults, uplifted fault blocks and half grabens (Fig. 6). The east-west zonation of alternating structural ridges and basins was reported by Wageman et al. (1970). Using industrial seismic data, Sun (1982) named these structural highs and lows successively from northwest to southeast as follows: Tungyintao Basin, Tungyintao Ridge, North Pengchiahsu Basin, North Taiwan Ridge and Taiwan Basin (Fig. 6). Furthermore, Huang et al. (1992) found that the age of formation of these rifting basins changes sequentially, becoming progressively younger towards the southeast. For Tungyintao Basin, the age of formation began in the Paleocene, for the North Pengchiahsu Basin in the Eocene, and for the Taiwan Basin in the Oligocene. In general, normal faulting occurred in Late Cretaceous and Early Tertiary with substantial fault displacements, although the intensity of normal faulting decreased with time during the Late Tertiary, as evidenced by accumulation of thicker Early Tertiary sediments.

Tectonically, the Lower Tertiary sequences are fault-controlled rifting sediments whereas the Upper Tertiary and Quaternary strata are passive subsidence deposits. The structural style characteristic of tilted fault blocks, half grabens and accompanied sedimentation suggest that the areas off northeastern Taiwan have been dominated by rifting

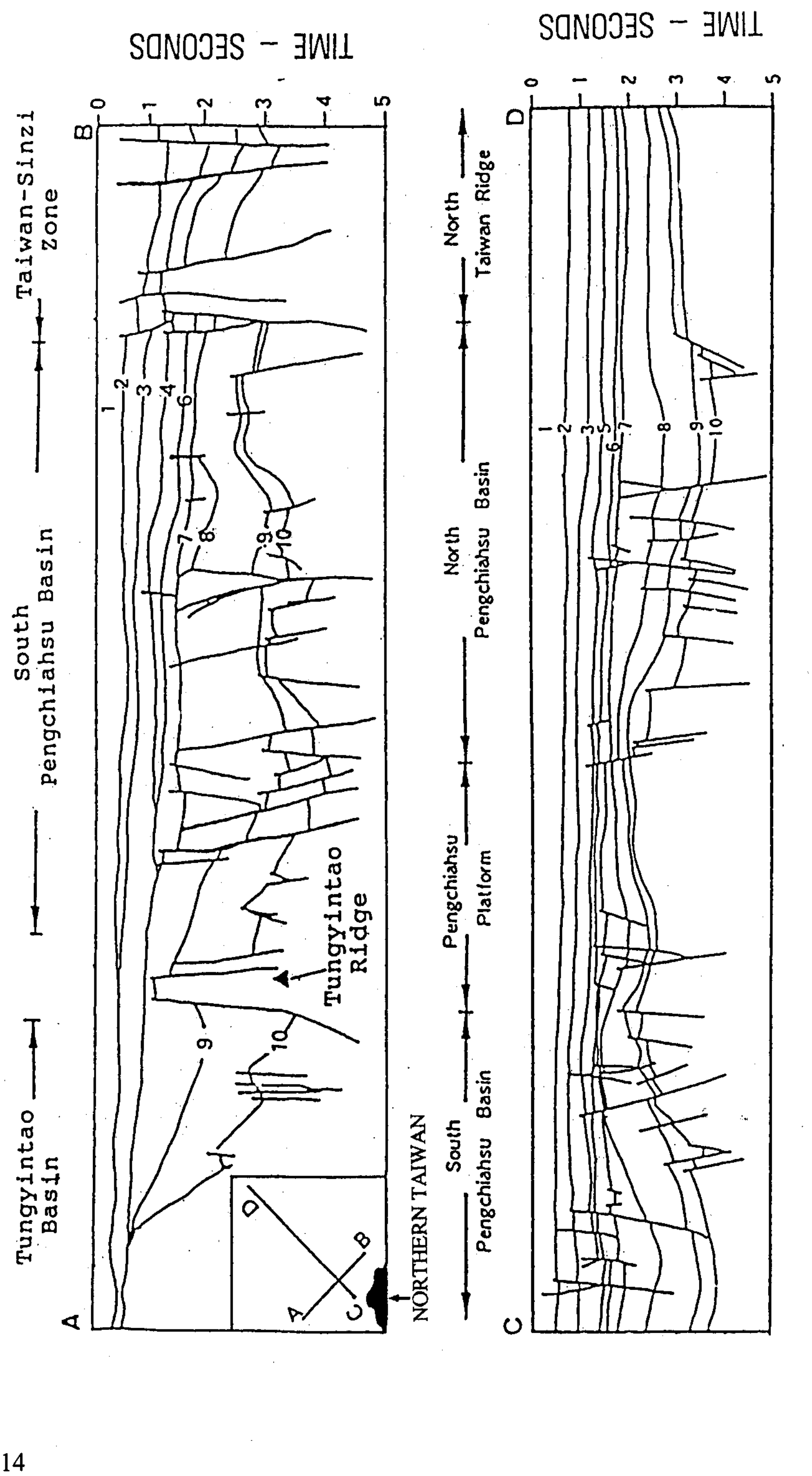

Fig. 6. Profiles underneath the East China Sea Shelf near Taiwan showing typical rifting features of high angle normal faults and tilted fault blocks. Note that Lower Tertiary strata are intensely faulted whereas Upper Tertiary sequences are flat-lying sediments and are mildly deformed. 1 = Pleistocene, 2 = Top of Pliocene, 3 = Top of Middle Miocene, 4 = Base of Middle Miocene, 5 = Top of Mushan Formation (NN1), 6 = Top of Oligocene, 7 = Horizon with Oligocene, 8 = Top of Eocene, 9 = Top of Paleocene, 10 = Top of Cretaceous. (After Huang et al., 1992).

from the Late Cretaceous to the Pleistocene (Sun, 1982, Huang et al., 1992, Jin, 1992). However, a major right-lateral strike-slip fault zone of Pliocene-Pleistocene age developed along the Chilung Valley, resulting from the indentation of Taiwan island into the Chinese passive margin (Huang et al., 1992, Lu, 1993 and Marr, 1995).

Lying east of Taiwan Basin, the southern Okinawa Trough has been interpreted as a Late Miocene back-arc extension basin, characterized by extensional normal faults, rotated fault blocks and associated magmatic intrusions (Lee et al., 1980, Letouzey and Kimura, 1986 and Sibuet et al., 1987). The north side of the southern Okinawa Trough (East China Sea Slope) near Taiwan was formed by a series of normal faults covered mainly by terrigenous sediments (about 2 km thick) from the adjacent East China Sea Shelf (Wageman et al., 1970, Lee et al., 1980, Sibuet et al., 1987).

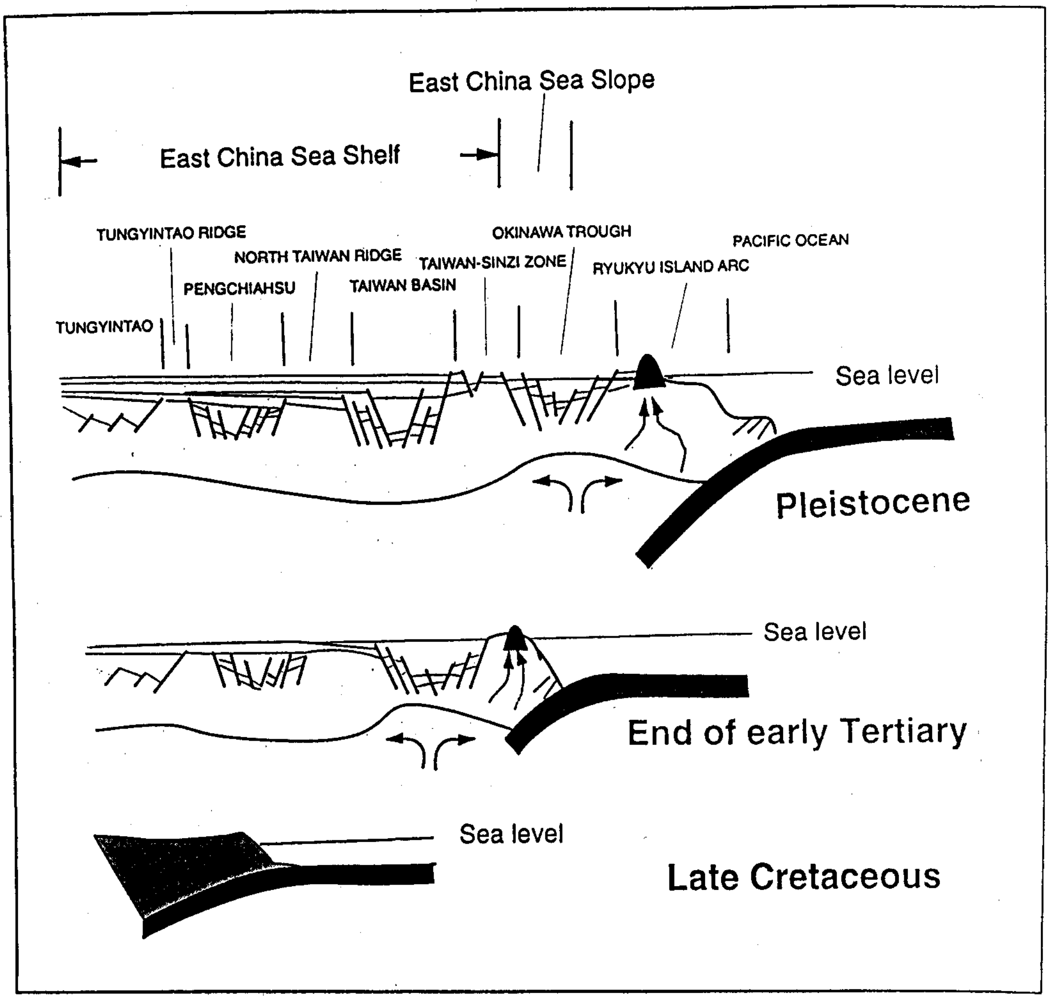

Fig. 7. A schematic diagram showing the development history of the East China Sea Shelf and Slope.

DEVELOPMENT OF THE EAST CHINA SEA SHELF AND SLOPE

Combining back-arc extension models of Huang et al. (1992), Lee et al. (1980), Letouzey and Kimura (1986) and Sibuet et al. (1987) in the eastern Asian continental margin in Late Cretaceous-Quaternary time, we present a simplified schematic illustration for the development of East China Sea Shelf and Slope near Taiwan (Fig. 7).

During Late Cretaceous and Early Tertiary, the region along eastern Asian margin was uplifted due to thermal expansion and was followed by extensive crustal extension. Normal faulting and accompanied sedimentation developed the rifting basins of Tungyintao, North Pengchiahsu and Taiwan progressively towards east. Towards the end of Miocene, crustal extension started to form the Okinawa Trough behind the Ryukyu Arc. As the rifting activity shifted to the Okinawa Trough in the Pliocene and Quaternary, the continental margin underlain by these Early Tertiary basins (northeast of Okinawa Trough) was dominated by regional tilting, subsidence and depositional fills of shallow marine sediments (about 2000 m thick) to form today's East China Sea Shelf. On the other hand, south of East China Sea Shelf, a sloping surface dipping towards the axis of Okinawa Trough was formed by normal faulting and syn-tectonic slope sedimentation, producing the present-day East China Sea Slope.

CLASSIFICATION OF MARGIN TYPE

Continental margins consist of three major physiographic units: continental shelf, slope and rise. We apply the genetic sequential classification of continental margins (Emery, 1977,1980) to the shelf-slope region northeast of Taiwan in order to determine the stage of development and type of the continental margin.

Beneath the broad and flat East China Sea Shelf, rifting basins and troughs have become completely filled by thick (8,000 m) terrigenous sediment. The East China Sea Shelf is characterized by a broad blanket of sediments overlying the entire thick Tertiary sedimentary sequences in association with extensional faults. Therefore, the East China Sea Shelf is at the mature stage (type A) of continental margin development (Emery, 1980).

The East China Sea Slope is a sloping surface underlain by a series of faulted blocks partly and thinly (about 2000 m or less) covered by terrigenous sediments. Using the criteria of Emery (1980) we classify the East China Sea Slope (the northern flank of southern Okinawa Trough) to be at the youth stage (type B) of continental margin development. On the basis of the classification of continental slopes (Emery, 1977) the East China Sea Slope can be classified as a transitional between type A and type B. Note that a continental rise does not exist at the foot of the East China Sea Slope, as would be expected for the youth stage.

SUMMARY AND CONCLUSIONS

The continental shelf and slope off northeastern Taiwan comprise the major physiographic provinces of the southern East China Sea. Depth for shelfbreak and profile forms along the margin off northeastern Taiwan indicate that the East China Sea Shelf is a typical continental shelf, characterized by morphology resulting from the Quaternary glaciation about 18,000 years ago. In contrast, the local Chilung Shelf shows a deep shelfedge (234 m) and a greater slope angle, suggesting the Quaternary glaciation effect is overprinted by subsequent tectonic activity, such as faulting.

The Chilung Slope and East China Sea Slope are actually the north side of southern Okinawa Trough. Morphologically, they are characterized by shallowness (2000 m) and an average slope angle of 1.31 degrees. Therefore, they are quite different in size and morphology from those of the mature Atlantic type continental slopes.

The shelf-slope region off northeast Taiwan was formed by a series of normal faulting episodes due to crustal rifting along eastern Asian continental margin which were later covered by thick terrigenous sediments from the Late Cretaceous to the present.

The East China Sea Shelf underwent a long history of syn-rifting (Late Cretaceous to Early Tertiary), and post-rifting subsidence/deposition (Late Tertiary to Recent) events. In contrast, the East China Sea Slope has a shorter development history and is the product of back-arc extension and accompanied slope sedimentation from Late Miocene to the present.

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