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A Preliminary Study of the Echo Characters and Sedimentary Processes along the Continental Margin, Northeast of Taiwan

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ABSTRACT

The regional mapping of the 3.5kHz echo characters in the areas off northeastern Taiwan provided valuable information about sedimentary processes on the sea floor. Seven distinctive echo types were recognized. These echo types were grouped into four major classes: indistinct, distinct, hyperbolic and irregular echoes. Indistinct echoes had three sub-classes: prolonged, prolonged with irregular saw-toothed surface and prolonged or semi-prolonged with inclined sub-bottom reflectors cropping out laterally. Besides, the hyperbolic class included the large irregular hyperbolae and the broad gently rolling hyperbolae. The irregular echoes were similar to the distinct type but with a jumbled morphology.

The echo character map showed that each of the physiographic provinces was characterized by a distinctive echo type. The very prolonged echo occurring on the narrow Ilan continental shelf indicated that strong current activities prevailed in this region. The upper part of the continental slope, characterized by large irregular hyperbola, was dominanted by slumping and/or sliding processes. Meanwhile, the turbidity currents and mass-wasting processes had apparently been the primary agents shaping the lower part of the slope as indicated by the distinct echoes.

1. INTRODUCTION

Off the northeast of Taiwan, the Kuroshio current crosses the Ilan Ridge and then turns northeastwards along the East China Sea continental slope. The crossing over and the turning have caused the Kuroshio to change tremendously in its flow regime. Therefore, the northeast offshore region of Taiwan (Figure 1) has long been the focus of studies of many oceanographic disciplines. However, only a few studies deal with the geological aspect (Niino and Emery, 1961; Emery *et al.*, 1969; Wangeman *et al.*, 1970; Wang and Hilde, 1973; Chen, 1979; Lee *et al.*, 1980; Chern, 1983; Lin and Chen, 1983; Shyu and Chiao, 1983).

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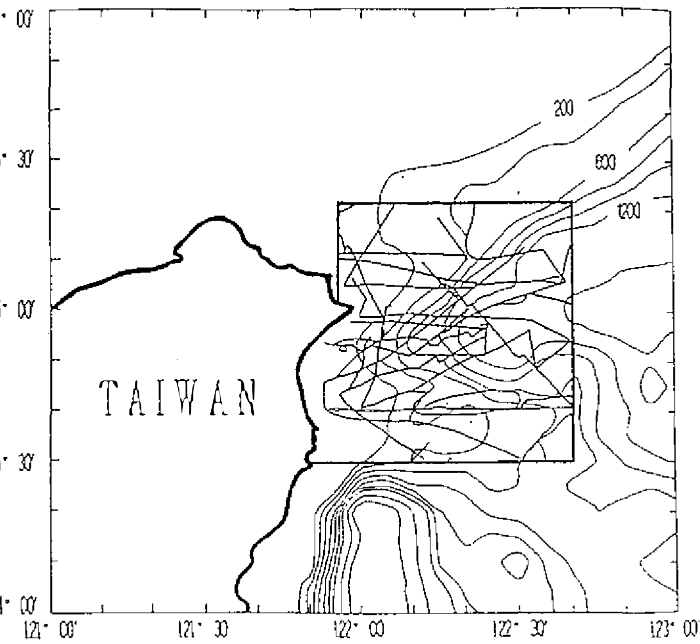

Fig. 1. Bathymetric map of the northeastern offshore of Taiwan. The contour interval is 200 meters. The box shows study area. Solid lines indicate locations of echogram profiles.

This region includes seven physiographic provinces : the Ilan continental shelf, the East China Sea continental shelf, the East Taiwan continental shelf, the East China Sea continental slope, the Ilan continental slope, the Ilan Ridge and the basin floor of the Okinawa Trough (Figure 2). The echo character of the upper-most seafloor throughout the region was recorded using 3.5kHz short ping (< 5ms) reflection profiler(Figure 1). The echo types were identified, classified, and mapped from these recorded echograms following the guidelines established by previous echo-character studies (Damuth, 1975, 1978, 1980; Klaus and Ledbetter, 1988; McClennen, 1989; Pratson and Laine,1989).

The purpose of this study is to interpret the sedimentation processes in the northeastern offshore region of Taiwan. Since previously studies (Damuth, 1975, 1978, 1980; Klaus and Ledbetter, 1988 ; McClennen, 1989 ; Pratson and Laine, 1989) can potentially reveal the bedforms responsible for specific echo characters and the near bottom processes which create these bedforms, certain preliminary conclusions could be drawn from the echo character map of the study area.

2. CLASSIFICATION OF 3.5kHz ECHOES

Seven distinctive echo types were recognized in the study area. The echo types were grouped into four major classes: indistinct, distinct, hyperbolic and irregular echos.

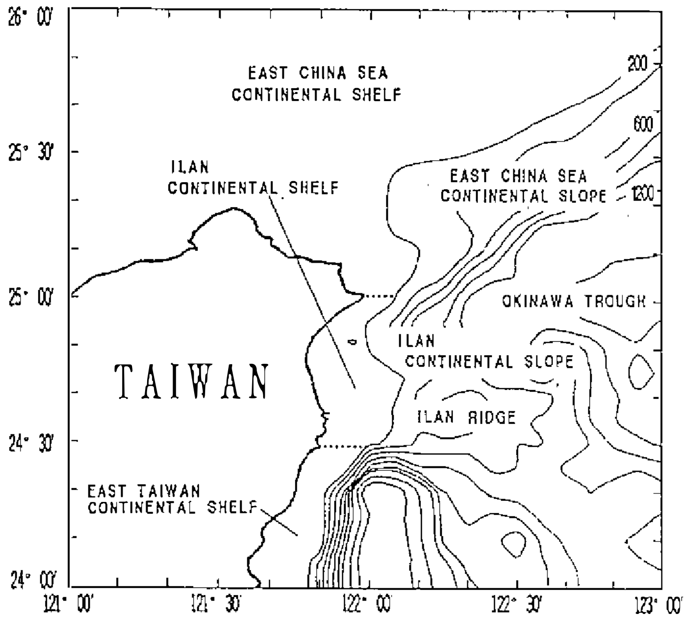

Fig. 2. Physiographic provinces around the northeastern offshore of Taiwan.

2.1 Indistinct echoes

Indistinct echos have a prolonged or sometimes semiprolonged bottom echo, and occur in areas of flat and locally rugged sea-floor. There are three subclasses that have been distinguished as follows:

Type Ia. Very prolonged bottom echoes with no sub-bottom reflectors (Figure 3a). These echoes occur at most parts of the Ilan continental shelf.

Type Ib. Prolonged to semi-prolonged echoes with a irregular saw-toothed surface (Figure 3b). Amplitudes generally range from 5 to 30 meters and wavelengths are less than 15 meters. These echoes occur only in the areas off northeastern Taiwan around 200 meters depth contour.

Type Ic. Semi-prolonged echoes with inclined sub-bottom reflectors cropping out laterally (Figure 4a). These echoes are returned exclusively from the rugged terrain of Ilan Ridge, submarine troughs and channels.

2.2 Distinct echoes

Distinct echoes are characterized by a sharp, continuous, smooth bottom echo.

Type II. Distinct echoes with parallel, continuous sub-bottom reflectors (Figure 4b). The main region returning this type of echoes is from the lower part of the continental slope.

2.3 Hyperbolic echoes

Two different types of hyperbolic echoes are gathered in this category.

Type IIIa. Large, irregular hyperbolic echoes with widely varying vertex elevations (Figure 5a) characterize the upper part of the continental slope.

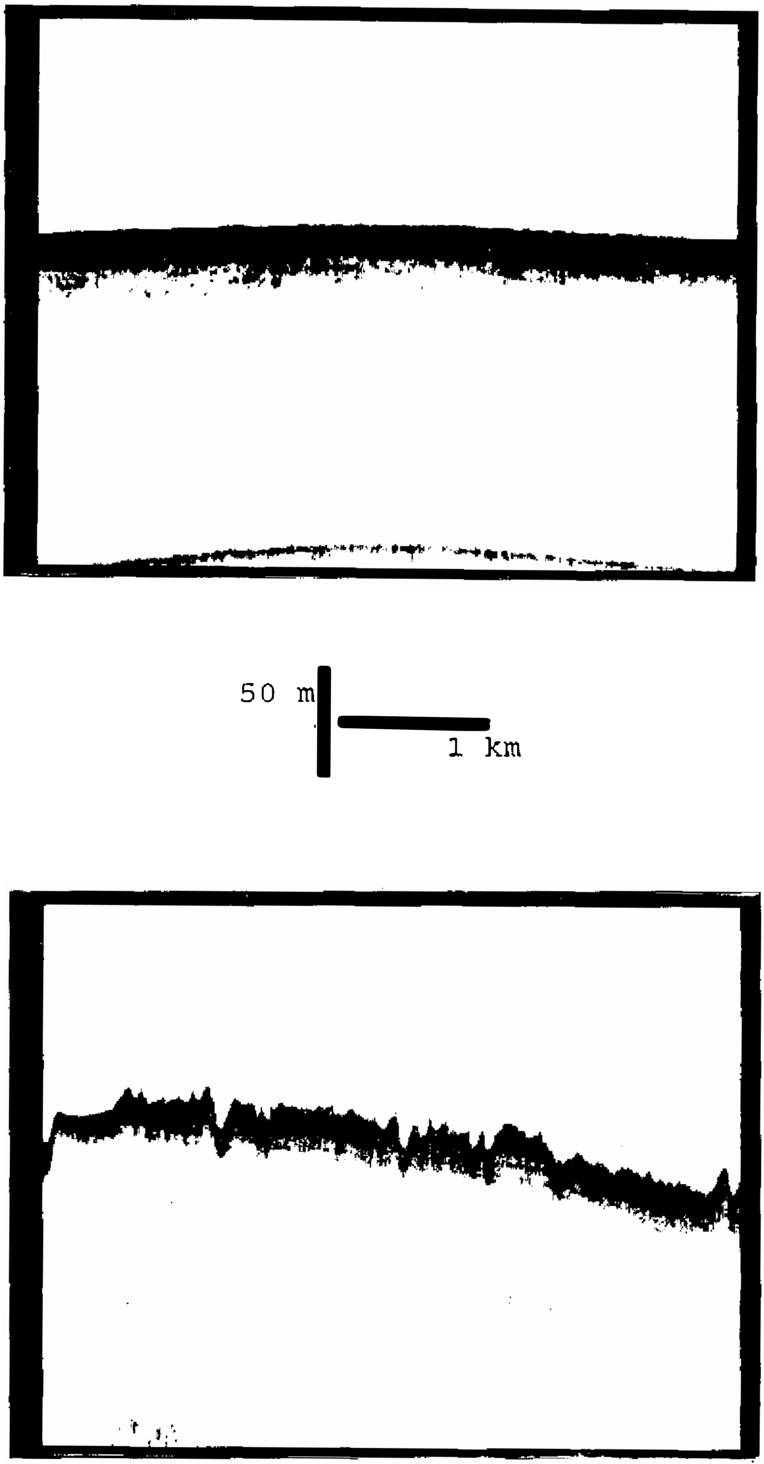

Fig. 3. Examples of echo types: (a) Ia. Very prolonged bottom echoes with no sub-bottom reflectors. (b) Ib. Prolonged to semi-prolonged echoes with a irregular saw-toothed surface.

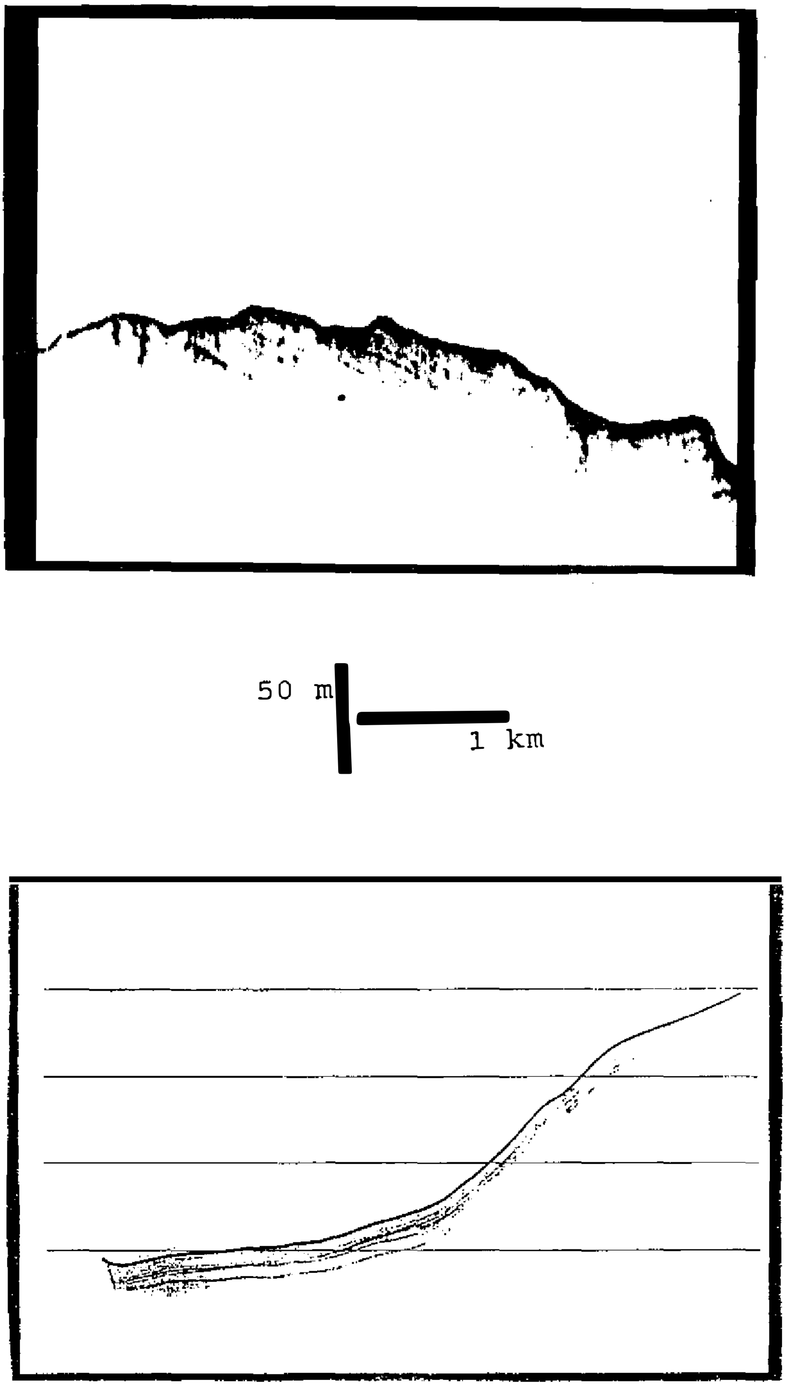

Fig. 4. Examples of echo types: (a) Ic. Prolonged or semi-prolonged echoes with inclined sub-bottom reflectors cropping out laterally. (b)II. Distinct echoes with parallel, continuous sub-bottom reflectors.

Type IIIb. This type is a kind of isolated large, broad, gently rolling hyperbolae with conformable parallel sub-bottom reflectors (Figure 5b). These echoes are observed from the lowermost part of the continental slope adjacent to the western tip of the Okinawa Trough.

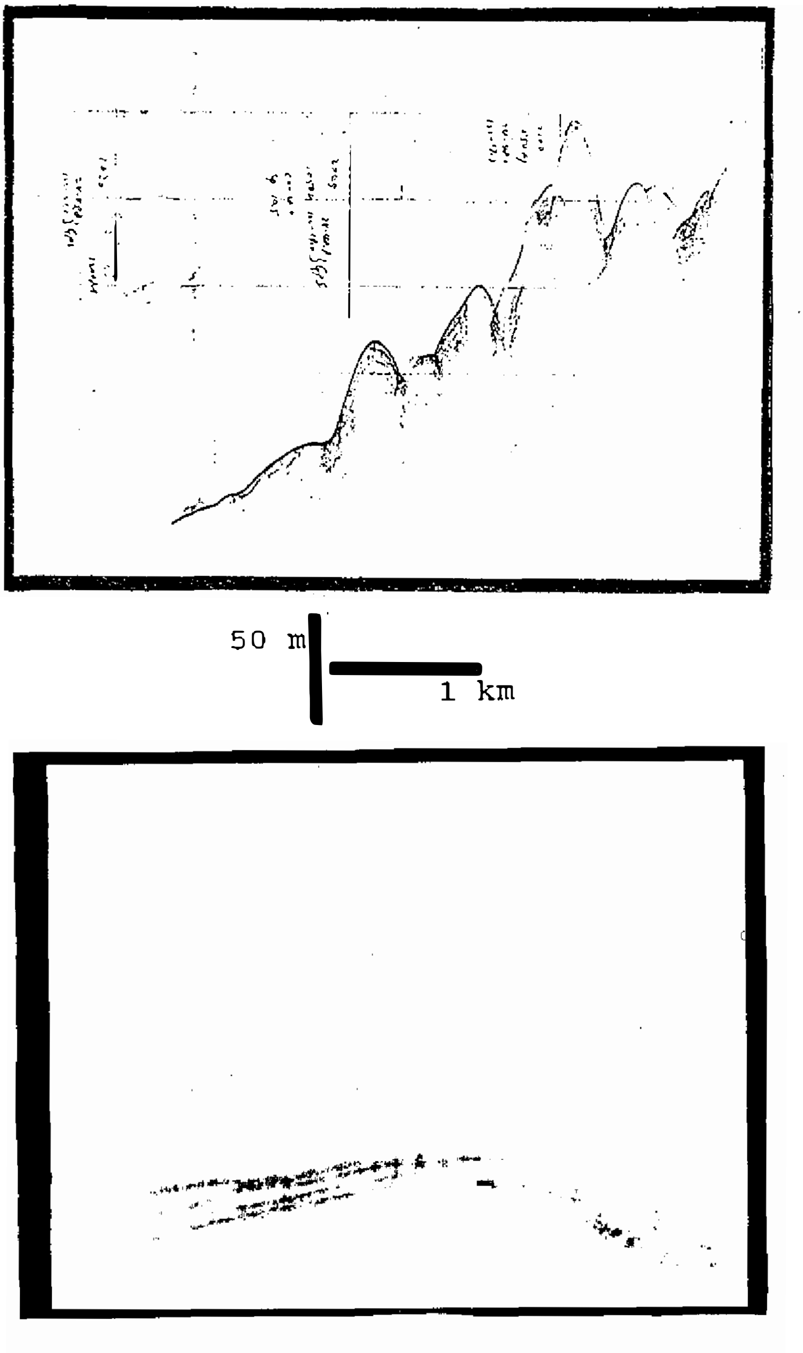

Fig. 5. Examples of echo types: (a) IIIa. Large, irregular hyperbolic echoes with widely varying vertex elevations. (b)IIIb. Isolated large, broad, gently rolling hyperbolae with conformable parallel sub-bottom reflectors.

2.4 Irregular echoes

Type IV. The echo character is similar to Type II having continuous, sharp, bottom echoes with continuous, sharp, parallel sub-bottom reflectors. However, it has a jumbled morphology (Figure 6). This type is confined in a narrow zone, extending roughly along the 1400 meters depth contour , at the middle part of the East China Sea continental slope.

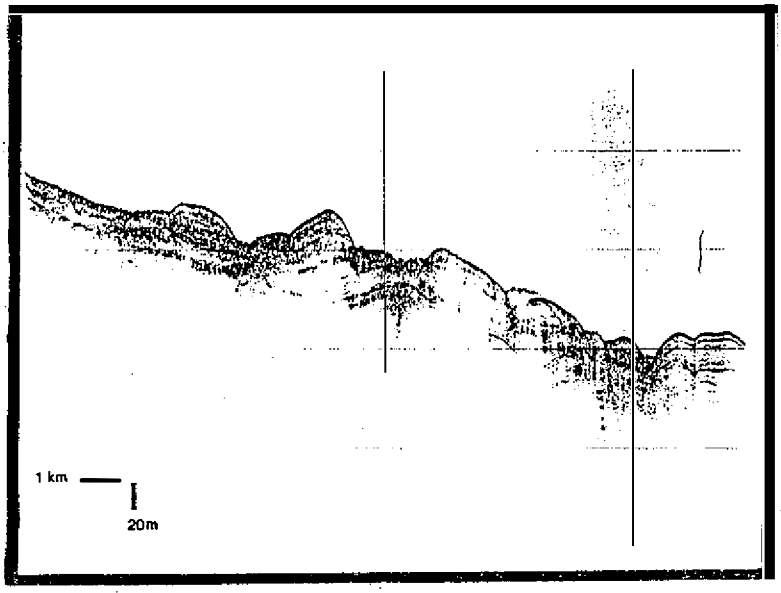

Fig. 6. Echo type IV. is similar to type II but with a jumbled morphology.

3. INTERPRETATION OF THE ECHO-CHARACTER MAP

3.5kHz echoes were first identified, classified and then mapped. During mapping, the regional bathymetry was used to constrain echo-type distribution. Construction of the echo-character map was mainly based on guidelines of Damuth (1980). The interpretation of depositional processes operating in the study areas is inferred mainly from the echo characters and their aerial distribution.

It appears that different physiographic provinces exhibit their own distinct echo types (Figure 7). Accordingly the associated sedimentary processes will be discussed physiographically province by province.

3.1 Ilan continental shelf

The shelf is mainly characterized by very prolonged echoes with no sub-bottom reflectors (Type Ia). Recent studies utilizing near-bottom sound sources suggest that the prolonged nature is the result of reflections from small erosional/depositional bedforms which have wavelengths that are too small to be resolved into discrete hyperbolae (Ewing *et al.*, 1973; Damuth, 1978). Sub-bottom reflections are not recorded because there are high concentrations of bedded silt/sand in the upper meters of the sea floor (Damuth, 1980; Addy *et al.*, 1982).

It had been reported that the Ilan continental shelf is covered by fine-to medium-grained sandy sediments (Boggs *et al.*, 1979). Above these, the velocities of tidal current and the Kuroshio current are measured up to 100 cm/sec (Chen and Lin 1990). The region is also often disturbed by seasonal storm activities. These observations are consistent with the interpretation of the prolonged echo type in previous studies (Ewing *et al.*, 1973; Damuth and Hayes, 1977; Damuth, 1980; Addy *et al.*, 1982).

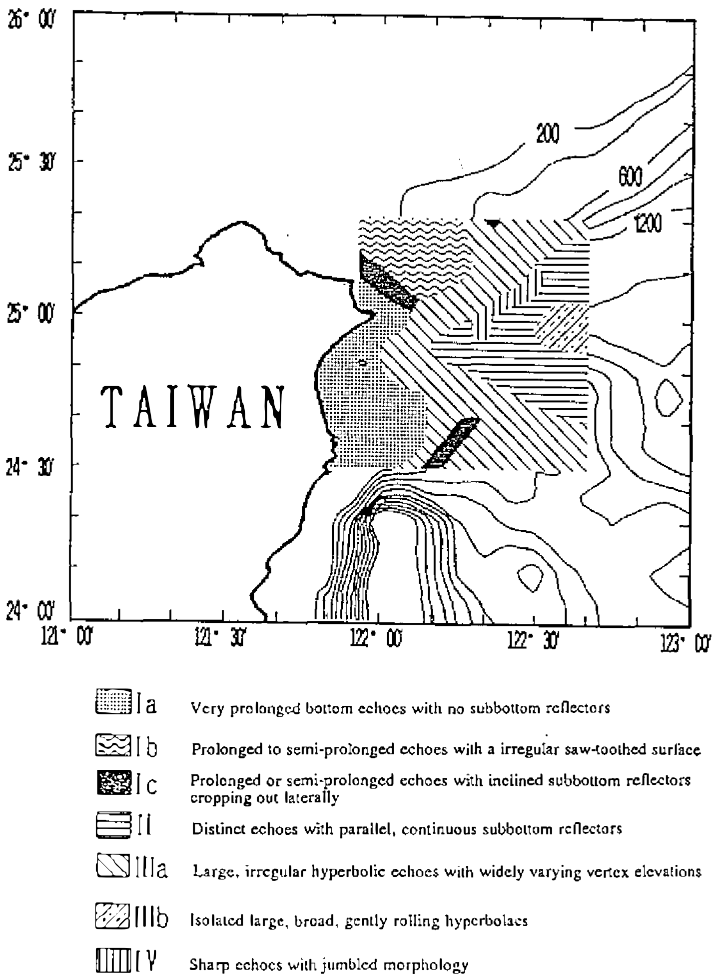

Fig. 7. Echo character map of the study area.

3.2 East China Sea continental shelf

Only the southern end of the East China Sea continental shelf was covered in this study. This area, around 200 meters in depth, is characterized mainly by prolonged to semi-prolonged echoes with a irregular saw-toothed surface (Figure 3b ; Type Ib). Based on mutually crossed seismic profiles these saw-toothed features seem to be dune-like bedforms Their amplitude is ranged from 5 to 30 meters with wavelength generally less than 15 meters.

The sediments of the saw-toothed bed forms were mainly composed of very coarse shell debris and a few quartzose sands and pebbles as recovered by three box cores. There were two possibilities for developing such kinds of bed forms. First, the current velocities should be significantly larger than those in the Ilan continental shelf. Alternatively, these features were probably the relict bed-forms sculptured by sedimentary and/or erosional processes during low-stand of eustatic sea-level in the Pleistocene (Boggs *et al.*, 1974, 1979; Niino and Emery, 1961).

3.3 Continental slope

This region involves the southeastern part of the East China Sea continental slope and the Ilan continental slope provinces. The gradient is greater in the upper part of the slopes (1 to 6 degrees) than that of the lower part of the slopes(0.5 to 4 degrees).

(a) Upper continental slope

These slopes are characterized by large, irregular hyperbolic echoes with widely varying vertex elevations (Figure 5a; Type IIIa). These type of echoes have been reported from very rugged terrains such as the steep sides of seamounts and plateaus, continental slopes, canyon walls, as well as rugged mid-ocean ridges (Damuth and Hayes, 1977; Damuth, 1980; Pratson and Laine, 1989; Satterfield and Behrens, 1990). The other studies (Jacobi, 1976; Klaus and Ledbetter, 1988) also indicate that the echo character could also be return from regions with slide and slump blocks.

As mapped by Song (1992), the upper continental slope in part of the study area was characterized by steep and rugged topography. This is compatible with the irregular hyperbolic nature of the observed 3.5kHz echoes.

(b) Lower continental slope

The distinct echoes with parallel, continuous subbottom reflectors (Figure 4b ; Type II) characterized the lower slope areas. Studies by previous investigators indicated that the areas returned by this echo type contained mainly fine sediments with or without bedded sand or silt(Damuth, 1975 , 1980; Mayer, 1980; Addy *et al.*; Pratson and Laine, 1989).

So far, our knowledge is still not sufficiently advanced to permit positive correlations between specific echo character and specific sediment property. However, regions characterized by the above echoes were often found to be dominated by weak waning turbidity currents and/or by pelagic sedimentation processes (Damuth, 1980). Consequently, the lower continental slopes in these areas were most likely shaped by turbidity currents and pelagic depositions.

A same type of reflector but with jumbled morphology (Figure ;Type IV) was observed from the upper part of the lower East China Sea continental slope. A few seismic reflection profiles were taken parallel and perpendicular to the continental margin. From these seismograms, the region looked like to be irregular surfaces of slide or slump blocks cutting by small valleys. This interpretation was encouraged for the same type of surface morphology and acoustic reflection had been well documented from many other parts of the world ocean (Jacobi, 1976; Embly and Jacobi, 1977; Mcgregor, 1977; Pratson and Laine, 1989).

3.4 Okinawa Trough

The seismic lines only slightly cover the western tip of the basin floor of the Okinawa Trough. A small portion of the lower most continental slope and this part of the basin floor (Figure 5) return a kind of isolated large, broad, gently rolling hyperbolae (Type IIIb). Rolling hyperbolae looks like sediment waves reported in many parts of the oceans (Jacobi *et al.*, 1975; Embley and Langseth, 1977; Damuth, 1979; Normark *et al.*, 1980; Flood and Shor, 1988; Klaus and Ledbetter, 1988; Carter *et al.*, 1990). However, it needs further study to verify what the echoes really are.

Finally, the prolonged or semi-prolonged echoes with inclined sub-bottom reflectors cropping out laterally (Type Ic) are returned exclusively from the rugged terrain of Ilan Ridge or areas adjacent to the submarine trough or channel. The lateral crop-out sub-bottom reflectors seem to be formed by the erosion and truncation of the sediment gravity flows during low stand of eustatic sea level in Pleistocene time. Further sedimentary and paleontologic data are required in the future studies.

4. CONCLUSIONS

3.5kHz echograms have been applied successfully to study the near-bottom sedimentation processes world-wide for more than 20 years. The same type of echograms recorded from the northeast off Taiwan were classified and mapped in an attempt to study the regional sedimentation. Preliminary conclusions have been drawn as follows:

1. Seven echo types were recognized on 3.5kHz profiles from the areas off northeastern Taiwan. Each of the physiographic provinces was characterized by its own distinct echo types indicating different sedimentary processes prevailed.
2. Prolonged bottom echoes were recorded from the Ilan continental shelf. Strong tidal and storm currents prevailed as evidenced by medium to coarse sandy sediments and current data. The correlation between sediments and echo type is consistent with other studies.
3. Very coarse shell debris, along with a few rounded quartzose sands and pebbles, were recovered from the southern end of the East China Sea continental shelf. Distinct saw-toothed reflectors had been found here. The causes for this echo type need further study.
4. The upper parts of the continental slopes were characterized by very steep and rugged topography which returned large irregular hyperbolic echoes.
5. Distinct sharp echoes with parallel sub-bottom reflectors and those with jumbled morphology distributed over the lower part of continental slopes. The gentle rolling hyperbolae were only recorded from the western tip of the Okinawa Trough. The appearance of these different types of echoes indicated that the gravity-induced down slope processes were probably the main agents shaping the lower slopes and the western tip of the Okinawa Trough.

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臺灣東北部大陸邊緣回聲特徵和沉積作用之初步研究

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摘要

3.5 kHz 單頻道聲納回聲特性之區域分佈對於臺灣東北部海域之沉積作用提供了許多非常有價值的資料。從所有記錄之震測剖面中一共可以辨認出七種不同的波譜型態，而此七種波譜型態則分別歸屬於不清晰型、清晰型、拋物線型和不規則型等四大類。其中，不清晰型包含有三種波譜型態，依次爲：一、濃密狀，二、濃密且表面呈鋸齒狀，三、濃密至次濃密狀，且其次層反射在側向上遭到截切或出露。此外，大而不規則之拋物線型以及大且寬緩之拋物線型，兩者均屬於拋物線型類。至於不規則類型則與清晰型相似，只是在外型上呈不規則之團塊狀。

從回聲波譜型態之區域分佈圖顯示，各個海底地形區分別呈現出不同的回聲特徵。例如在狹窄的宜蘭陸棚上所記錄到的是濃密狀的波譜，顯示區域中應有較強的水流作用。而以大且不規則之拋物線型波譜爲特徵之上部大陸斜坡，則是以崩移和崩滑作用爲主要之塑形營力。此外，薄且清晰之波譜型態指示出濁流以及各種碎屑流主宰了下部大陸斜坡之沉積。