Geol. Soc. Malaysia, Bulletin 18, November 1985; pp. 151–166.

Seismic evidences of relative changes of sea level in the Tertiary depositional sequences near Taiwan

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Abstract: It is generally conceived that the tectonic evolution of Taiwan can be attributed to interaction of crustal plates. In this tectonic model, the island of Taiwan is situated on the juncture between the continental Eurasian plate on the west and the oceanic Philippine Sea plate on the east. The foreland basin formed on the Eurasian plate to the west of the Central Range, covering foothills, coastal plain and offshore areas, has been considered a most petroliferous province consisting of a thick sequence of Tertiary to Pleistocene clastic sediments.

The Miocene basin to which this study is referred is a fine example of a combined structural-stratigraphic development. Deposition has occurred concurrently with intermittent structural movement, which in turn has had substantial influence on the migration and accumulation of hydrocarbons. The primary hydrocarbon migration and accumulation was probably determined in late Miocene time, but the hydrocarbons remained trapped only if subsequent Pliocene/Pleistocene movements did not move the trapping mechanism.

The sandstone members within the Talu Formation proved to be the most prolific producers of hydrocarbons in northwestern Taiwan. Although excellent production is obtained from them onshore, efforts to extend the production offshore into the study area have not been so successful. However prolific production was obtained from one well, which suggests that the sequence offshore is capable of producing hydrocarbons provided proper conditions for entrapment existed.

This paper is mainly concerned with the interpretation of the Miocene depositional sequences in the offshore area of Hsinchu from viewpoint of seismic stratigraphy. Taking correlative reflections as formation boundaries, we describe the seismic facies for the various formations encountered in the study area. During the course of deposition, the relative rise of sea level as determined by the rate of terrigenous influx gave rise to the associated reflection configurations and variations in amplitude, frequency and continuity of reflections. By using these criteria, the environmental setting and estimation of lithology of each formation is interpreted as an aid for the further appraisal of the prospect.

INTRODUCTION

The tectonic evolution of Taiwan can be attributed to interaction of crustal plates (Ho, 1982). In this plate tectonic model, the island of Taiwan is situated on the juncture between the continental Eurasian plate on the west and the oceanic Philippine Sea plate on the east. The foreland basin formed on the Eurasian plate to the west of the Central Range, covering foothills, coastal plain and offshore areas of Taiwan, has been found to be filled with a thick sequence of Tertiary to Pleistocene clastic sediments.

Based on the conventional 2D seismic reflection data a number of anticlinal

Presented at GSM Petroleum Geology Seminar 1983.

structures were mapped in the offshore area of Hsinchu. It was thought that the oil bearing formations found basinward on the Taiwan island would also be found in the offshore area, possibly with varying degrees of thickness reduction. A number of drillings on these offshore structures revealed that the producing formations occurred in the structures drilled on land were also encountered in these offshore wells, with varying amount of hydrocarbons found in each of them. Unfortunately, only one well hit the Talu Formation having hydrocarbons of commercial value. However prolific production was obtained from one well which suggests that the sequence offshore is capable of producing hydrocarbons provided proper conditions for entrapment existed.

To map these offshore structures in more detail, additional seismic surveys with closer line intervals were conducted in the study area. The seismic field data were recorded with multi-channels and processed through sophisticated procedures, such as wavelet processing, F-K migration, etc., in an effort to ensure the data quality to be satisfactory for the seismic stratigraphic study as well as for the structural interpretation.

The Seismic Reflection Parameters Used for Seismic Stratigraphy Study

Mitchum *et al.*, (1977) have given a list of seismic facies parameters which are used in geologic interpretation as follows:

Seismic Facies Parameters	Geologic Interpretation
Reflection configuration	Bedding patterns Depositional processes Erosion and palaeotopography Fluid contacts
Reflection continuity	Bedding continuity Depositional processes
Reflection amplitude	Velocity-density contrast Bed spacing Fluid content
Reflection frequency	Bed thickness Fluid content
Interval velocity	Estimation of lithology Estimation of porosity Fluid content
External form and areal association of seismic facies units	Gross depositional environment Geologic setting

Depending on the tectonic setting of the location and regional geology, it might be impossible to use all the parameters, or different interpretations can be made for some data.

SEISMIC STRATIGRAPHIC STUDY OF THE OFFSHORE AREA OF HSINCHU, TAIWAN

The general stratigraphic and sedimentologic framework of the Taihsi-Taichung Neogene basin has been properly defined or postulated because of the data available from drilling and geophysical prospecting (Sun, 1981; Huang, 1981). We tried to interpret the Miocene depositional sequences in the same basin from viewpoint of seismic stratigraphy. Figure 1 indicates the scope of the study area containing the seismic lines to which this paper refers.

There are three steps involved in the procedure of the seismic stratigraphic study: seismic sequence determination, seismic facies analysis, seismic facies map and palaeoenvironment estimation.

Seismic Sequences Determination

Surfaces of discontinuity in the study area are marked by reflection terminations and interpreted as unconformities or their correlative conformities. We also see some volcanic channels as evidence of discontinuity (Fig. 2). We marked four sequence

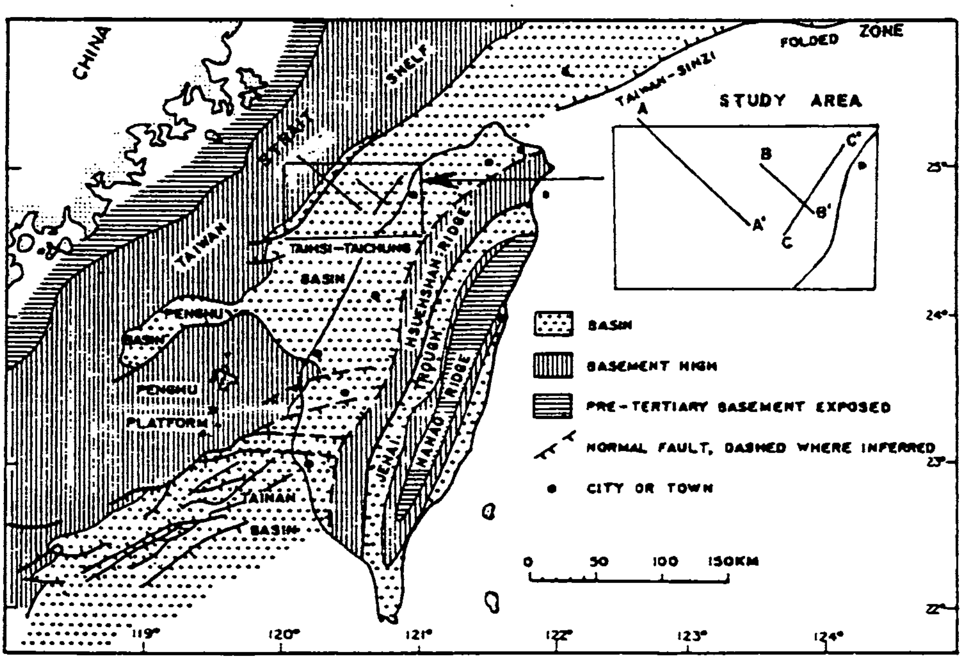
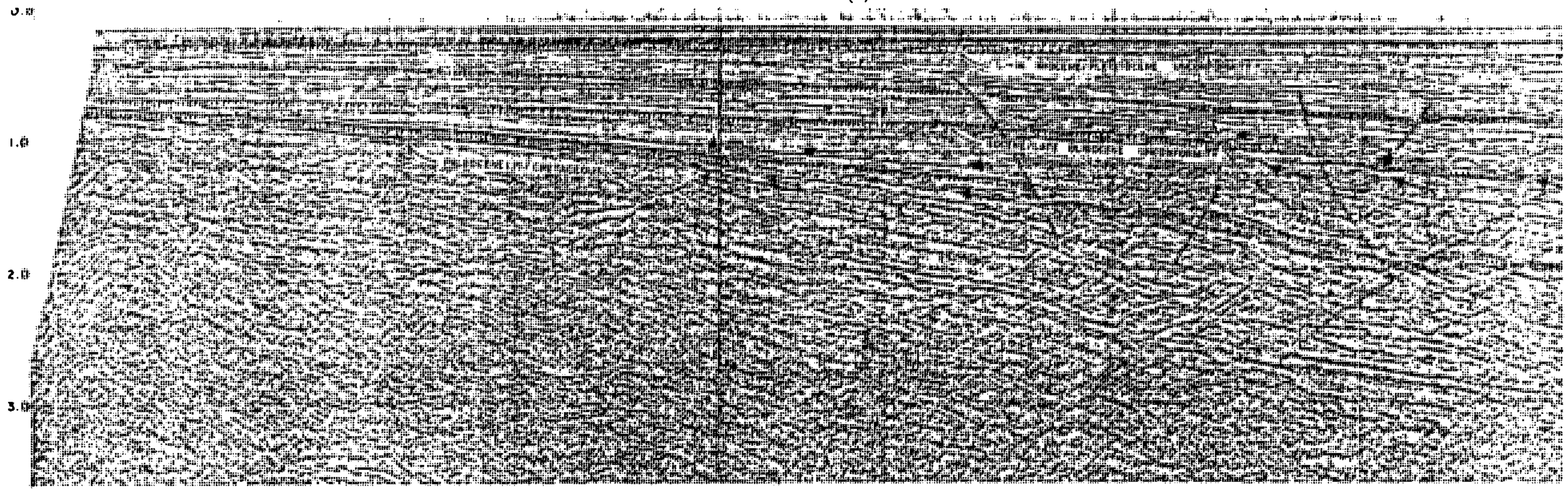


Fig. 1. Index map showing locations of study area and the three seismic profiles referred to (Neogene basins map from Sun, 1981).

SECTION AA′–(1)



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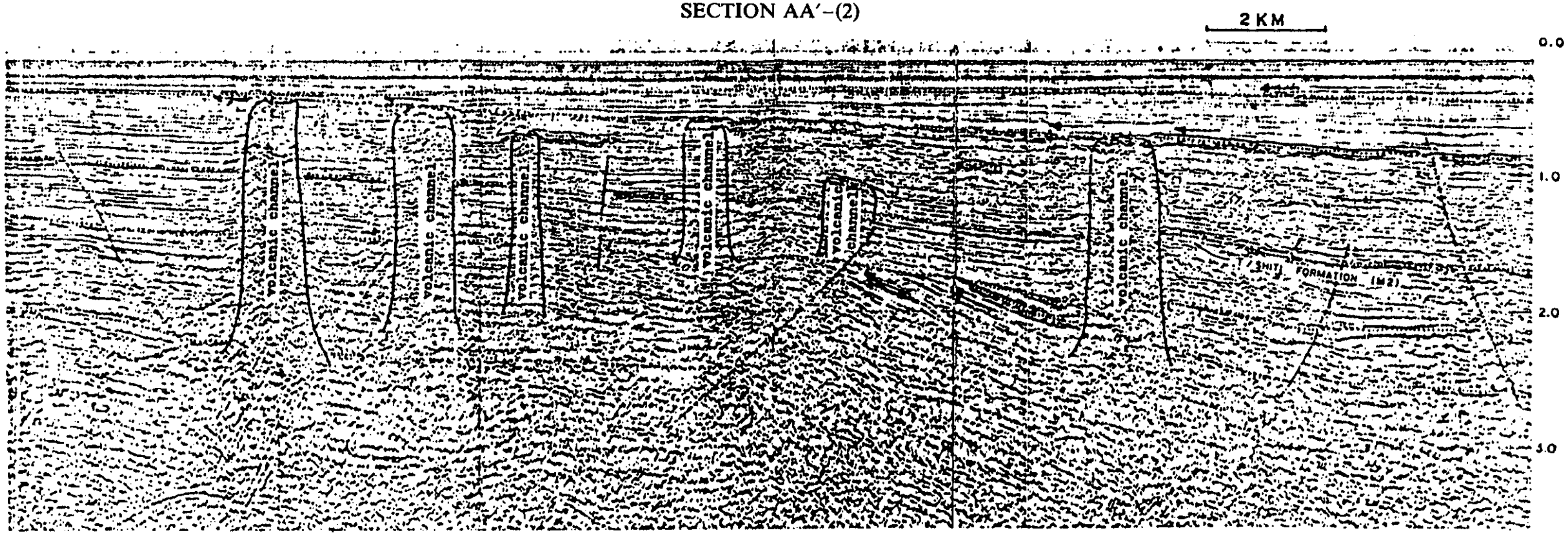

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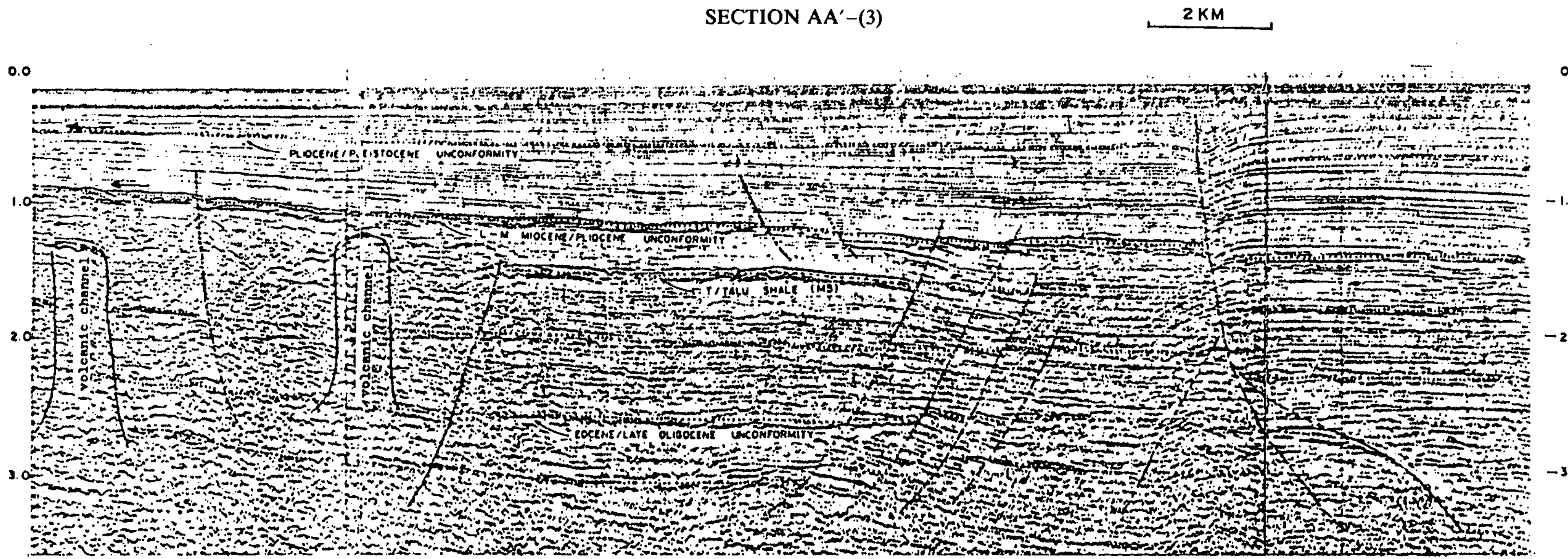

Fig. 2. Section AA (in three parts) showing major unconformities and associated seismic characters such as onlap, truncation, basaltic extrusion and volcanic channel.

boundaries on the seismic section A-A (Fig. 2) which are related to the crustal movements as described by Yen (1976):

(a) *Cretaceous/Palaeocene Unconformity*—This unconformity was widespread and formed by the Taiping movement which is characterized by tensional faulting and half graben structure (Sun, 1981). Coastal onlap and truncation of reflecting horizons are the main criteria for the determination of the unconformity. High amplitude and good continuity of reflections are also clues of a sharp velocity contrast existing between the associated seismic sequences.

(b) *Eocene/Late Oligocene Unconformity*—This unconformity resulted from the Puli movement. Large scale regression gave rise to a great amount of truncation of the Palaeogene sediments. We observe coastal onlap, truncation, good continuity and high amplitude reflections at the unconformity to the northwestern end of the section A-A (Fig. 2). However, the amplitude of the corresponding reflection decreases basinward rapidly.

(c) *Lower-Middle Miocene/Plio.-Pleistocene Unconformity*—This unconformity is correlative with the Coastal Range movement. The extensive volcanic activity is clearly revealed on the seismic sections. Onlap and very high amplitude of reflections associated with basaltic extrusions are easily recognized as the unconformity surface. The growth of normal faults in the Miocene sequence might be responsible for trapping hydrocarbons.

(d) *Pliocene/Pleistocene Unconformity*—Taiwan island was uplifted by the Pliocene crustal movement. Compressional stress exerted from SE to NW caused high angle thrust faults as noticed onshore and offshore as well. This tectonic movement strongly deformed the structures formed previously. Distal onlap, indicating sediments of Pleistocene age were derived from Taiwan island, and truncation can be clearly seen on the seismic sections.

All of those reflection terminations associated with the individual unconformity are indicated by arrows on the Seismic Section A-A of Figure 2. Table 1 summarizes the seismic characters for the major unconformities, structural implications, and the related crustal movements as known from geological knowledge.

The Miocene sequence, as confined in between the L.-M. Miocene/Pliocene and the Eocene/L. Oligocene unconformities (Fig. 2), can further be subdivided into six minor seismic sequence units of genetically related strata, M1 through M6 (Figs. 3 and 4), with their boundaries in accordance with the correlative reflecting horizons closely related to the formation of boundary levels as determined by the available well data. The reason we focus our attention on the Miocene formations is that they were proved to be the most prolific hydrocarbon producers in northwestern Taiwan. The reflections in these Miocene sequences appear parallel and concordant, being affected greatly by faulting. Through detailed correlation and loop-tied interpretation, we reached a concrete conclusion that the reflecting horizon of good continuity or where the strong reflections are separated from the immediately weaker ones can be considered a

TABLE 1

SUMMARY OF SEISMIC CHARACTERS OF THE MAJOR UNCONFORMITIES, STRUCTURAL IMPLICATIONS AND CRUSTAL MOVEMENTS.

SERIES	EPOCH	MAJOR SEQUENCE BOUNDARIES AND THEIR SEISMIC CHARACTERS	STRUCTURAL IMPLICATIONS	CRUSTAL MOVEMENTS (YEN'S)
PLEISTOCENE				
				Taiwan
PLIOCENE	L			
	E	high continuity, medium amplitude, medium to high frequency, distal onlap and truncation.	high angle thrust fault	
				Coastal Range
MIOCENE	L			
	M	high continuity, very high amplitude, high frequency, corresponds to basaltic extrusion, volcanoes and coastal onlap.	volcanic activity and block faulting	
	E			
				Puli
OLIGOCENE	L			
	E	high continuity, high amplitude, low frequency, coastal onlap and truncation.	truncation	
EOCENE OR PALEOCENE(?)	L			
	M			
				Taiping
	E	high continuity, high amplitude, low frequency, coastal onlap and truncation	uplift, basement fault and half graben	

SECTION BB′

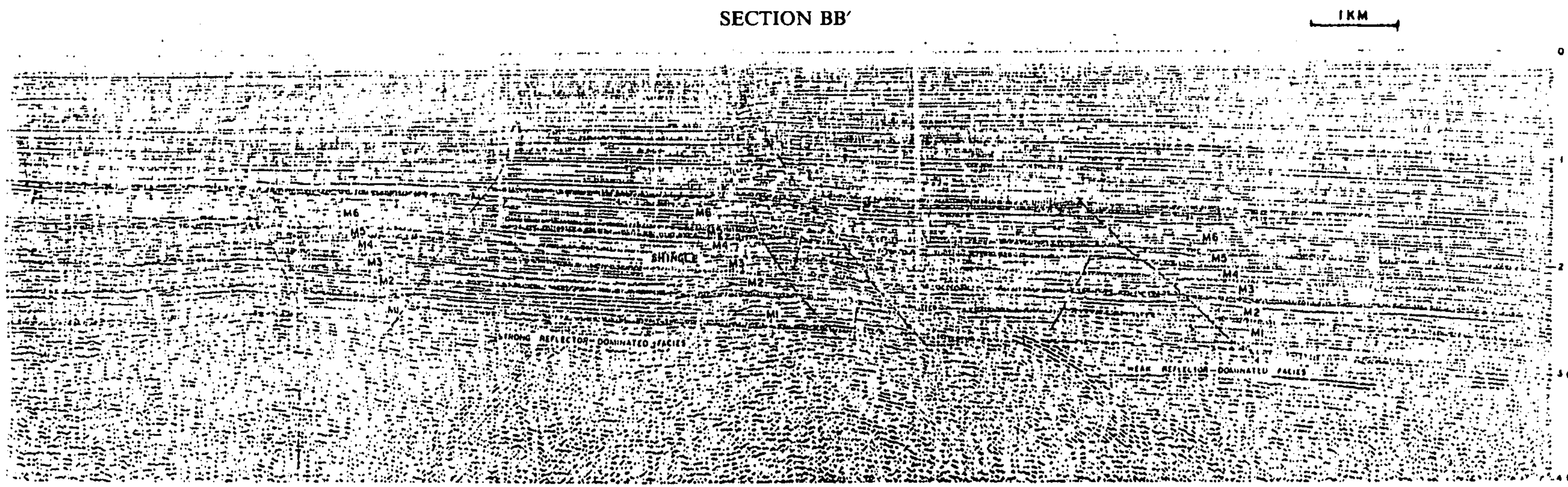

Fig. 3. Seismic section BB showing six sequence boundaries with indications of strong reflector facies, weak reflector facies and shingled progradation.

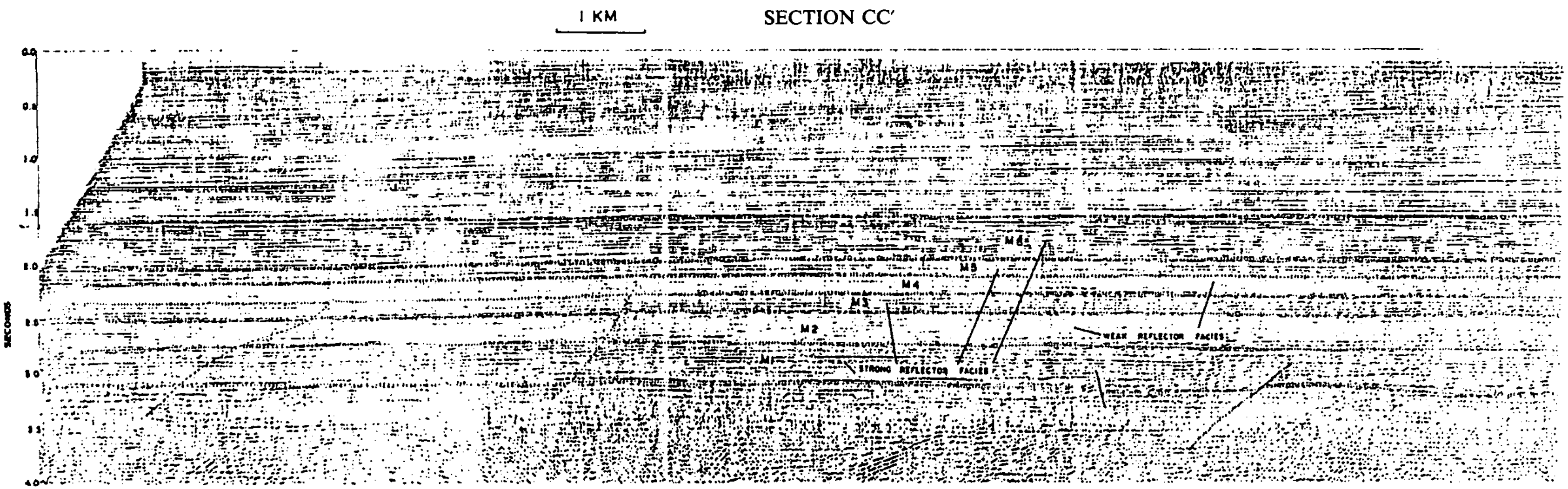

Fig. 4. Section CC, strike line, showing six seismic sequences in Miocene basin, strong reflector facies and weak reflector facies stand out alternatively.

sequence boundary in the Miocene basin. For example, the top of sequence M5 is represented by a horizon of good continuity and high amplitude recognizable throughout the study area. Some boundaries can be extended landward and correlated to basaltic extrusions. The top of M6 and base of M1 are correlated with the major L.-M. Miocene/Pliocene and Eocene/L. Oligocene unconformities respectively.

According to the borehole data such as electric logs, lithology and nannofossils, the Miocene strata in the study area can also be divided into six sequences which were deposited during different sedimentation cycles:

Cycle 1: Wuchishan and Mushan Formations; from late Oligocene to early Miocene; nannofossils NP 25 to NN1.

Cycle 2: Piling Shale and Shihti Formation of early Miocene; nannofossil NN2.

Cycle 3: Peiliao Formation of early Miocene; nannofossil NN 3.

Cycle 4: Lower Talu Shale and Talu Sandstone of early Miocene; nannofossil NN 4.

Cycle 5: Upper Talu Shale of middle Miocene; nannofossil NN 5.

Cycle 6: Nanchuang Formation of late Miocene; nannofossils NN 6 to NN 10.

Comparing the sequence boundaries defined by seismic characters to the sedimenation cycles derived from lithology and nannofossil zonation (Huang, 1981), we reached a comprehensive relationship between the two different types of data. Table 2 diagrammatically summarizes the seismic sequences in connection with the geological data.

Seismic Facies Analysis

The seismic facies in the Hsinchu Miocene basin are characterized broadly by concordant strong reflector units and weak reflector intervals; parallel and sheet-like in external form. Reflector strength is qualitatively interpreted by its visual impact. Strong reflectors form heavy lines or bands on the seismic profiles, indicating high acoustic impedance contrasts existing between layers. Weak reflectors do not standout, indicating low acoustic impedance contrasts. The facies classification is basically descriptive in that it utilizes reflection variation, and partly genetic in that it groups facies as sedimentation units on the basis of their inferred origin from regional geology and borehole data.

Primary reflection configurations may be classified as:

(a) *Strong reflector facies/Parallel bedded/Continuous*—This facies occurs throughout the western part of the study area, trending NE-SW. It implies swamp, delta plain, strand plain or neritic (shelf-platform) environments. In the case of swamp, delta plain or strand plain the strong reflections might have

TABLE 2

COMBINATION OF GEOLOGICAL DATA WITH SEISMIC SEQUENCES.

SERIES	EPOCH	REGIONAL SEA LEVEL CHANGE (RISING ← → FALLING)	NN ZONES	FORMATION	LITHOLOGY DESCRIPTION	ENVIRONMENTS	SEISMIC SEQUENCES
MIOCENE	L / M		NN10 – NN6	NANCHUANG	Basalt; Cly/Clyst; Ss.; Sh. with Coal Seams; Ss.	Fluvial	M6
MIOCENE	M		NN5	TALU SH.	Clyst; Ss.; Lms.	Neritic	M5
MIOCENE	E		NN4	TALU SS.; TALU SH.	Ss.; Sdy Lms.; Cly/Clyst.	Deltaic To Neritic	M4
MIOCENE	E		NN3	PEILIAO	Ss.; Clyst/Sh.; Lms.; S.S.; Sh.	Deltaic To Neritic	M3
MIOCENE	E		NN2	SHIHTI	Sh. With Coal Seams; Ss.; Sh. With Coal Seams	Deltaic or Swamp	M2
MIOCENE	E		NN2	PILING	Sh.; Ss.	Marine Sh.; Transgressive Ss.	M2
MIOCENE	E		NN1	MUSHAN	Sh. With Coal Seams.; Sh. Interc. With Ss.	Swamp relate To Coastal Aggradation	M1
OLIGOCENE	L		NP25	WUCHIHSAN	Ss.	Neritic Ss/Sh Sequences; Transgressive Ss.	M1

come from the sharp velocity contrasts between shale section and coal seams. On shelf-platform the strong reflections are possibly due to sharp velocity caused by calcareous sandstone or limestone. Mostly this seismic facies unit is considered to be under an environment of high depositional energy sufficient to transport and deposit significant quantities of sand, so that it is a sand-prone facies (Figs. 3 and 4).

(b) *Strong reflector facies/Parallel/Discontinous*—This facies unit is interpeted as fluvial facies, remarkably noticeable in the sequence M6. Strong but discontinuous reflections result from irregularly distributed thick sand with clay or coal seam intercalations. A widespread basaltic extrusion appears on the top of sequence M6 (Figs. 3 and 4).

(c) *Weak reflector facies/Sheet*—This sequence reflects sediments of fine particles deposited through suspension under the prodelta or neritic environment. The depositional energy is too low to develop significant sand accumulation. So it is considered a shale-prone facies. On the seismic section B-B in Fig. 3, it is not difficult to observe that the strong reflector-dominated facies on the left half degrades gradually to the weak reflector-dominated facies on the right half. Possibly this reveals that the environment varied from delta plain to prodelta.

(d) *Shingled Progradation*—We can find the shingled reflection patterns on some seismic sections (Fig. 5) obtained in a limited part of the study area. They are

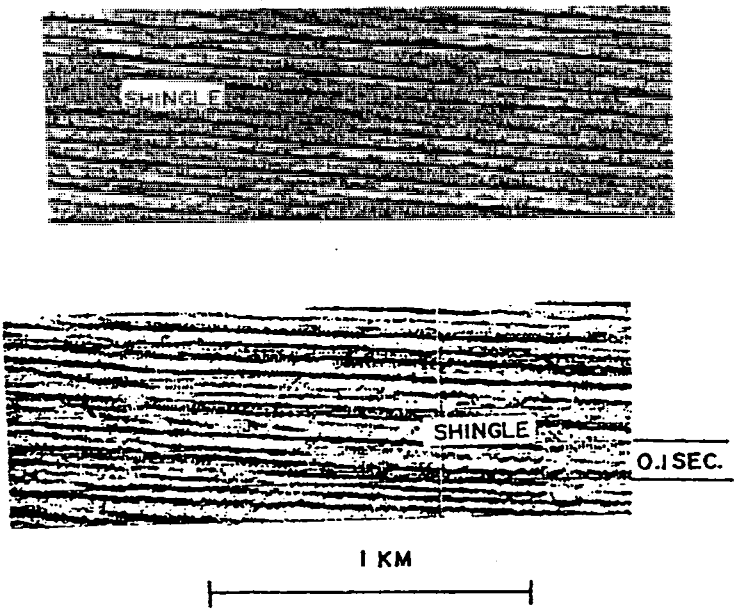

Fig. 5. Two segments of seismic profiles showing shingled progradation.

TABLE 3

SEISMIC CHARACTERISTICS AND ENVIRONMENTAL FACIES INTERPRETATION OF MIOCENE FORMATIONS, OFFSHORE HSINCHU.

FORMATION	DEPOSITIONAL FRAMEWORK	SEISMIC FACIES UNIT	ENVIRONMENTAL INTERPRETATION	EXTERNAL FORM	LATERAL RELATION
M 6	Shelf	Strong reflectors and discontinuous	non-marine fluvial clastics	Parallel	fluvial facies
M 5	Shelf	Strong reflectors and high continuity	neritic	Parallel	neritic
M 4	Shelf	Shingle Strong reflectors high continuity to weak reflectors	wave-dominated delta to prodelta	Parallel to Sheet	basinward grade to weak reflector i.e. prodelta or neritic
M 3	Shelf	Shingle Strong reflectors high continuity	wave-dominated delta	Parallel	as above
M2	Shelf	Strong reflectors high continuity to Low frequency reflector	Swamp, or delta plain ,interbedded with widespread coal bed to transgressive S.S.	Parallel	as above
MI	Shelf	Strong reflectors high continuity	Swamp or delta plain with lots of coal bed. (Coastal aggradation)	Parallel	as above

interpreted as due to progressive relative sea level rise in connection with rapid terrigenous influx along that part of the shelf, indicating the existence of wave-dominated delta. Table 3 summarizes the seismic characteristics and the environmental facies interpretation of the Miocene formations in the offshore area of Hsinchu.

Seismic Facies Map and Paleoenvironment Estimation

Figure 6 is the resultant seismic facies map, showing the distribution of various seismic characters such as onlap, volcanic disturbance, strong reflector facies, weak reflector facies, reflector facies of intermediate strength, and progradation. Referring to the seismic facies analysis described previously, we can interpret the seismic facies in terms of geological settings. Figure 7 shows the schematic environments of the Miocene formations of the study area as derived from the seismic facies distribution. The general trend of the various depositional systems agree with those deduced from other disciplines.

CONCLUSIONS

(1) Because of the good quality seismic data, seismic stratigraphic principles can be applied to the study area to derive its palaeoenvironments.

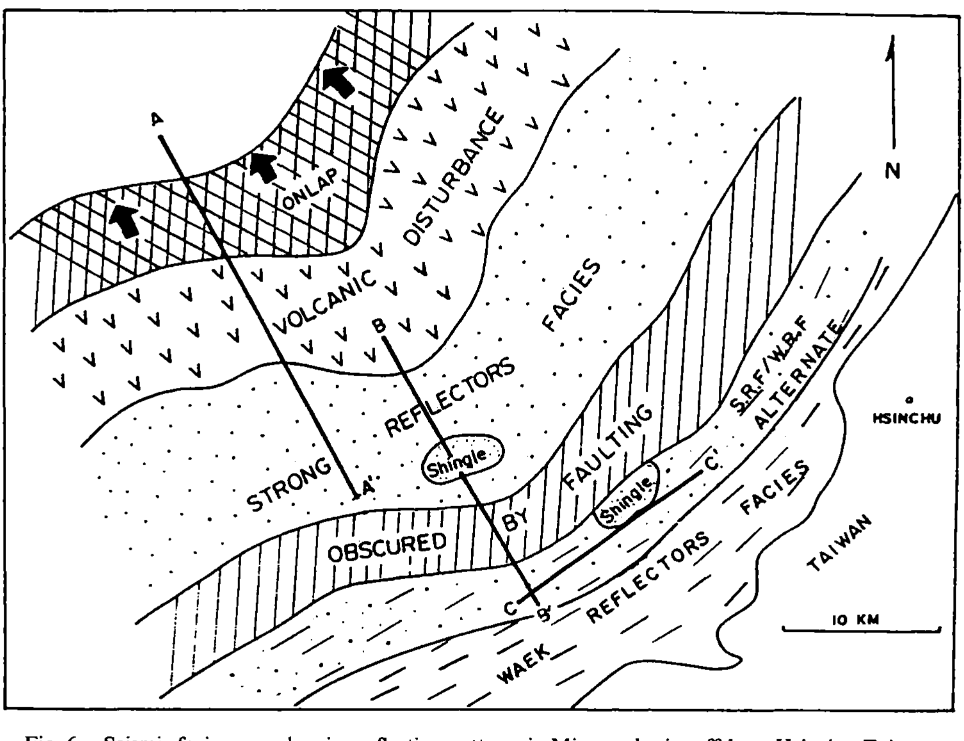

Fig. 6. Seismic facies map showing reflection patterns in Miocene basin, offshore Hsinchu, Taiwan.

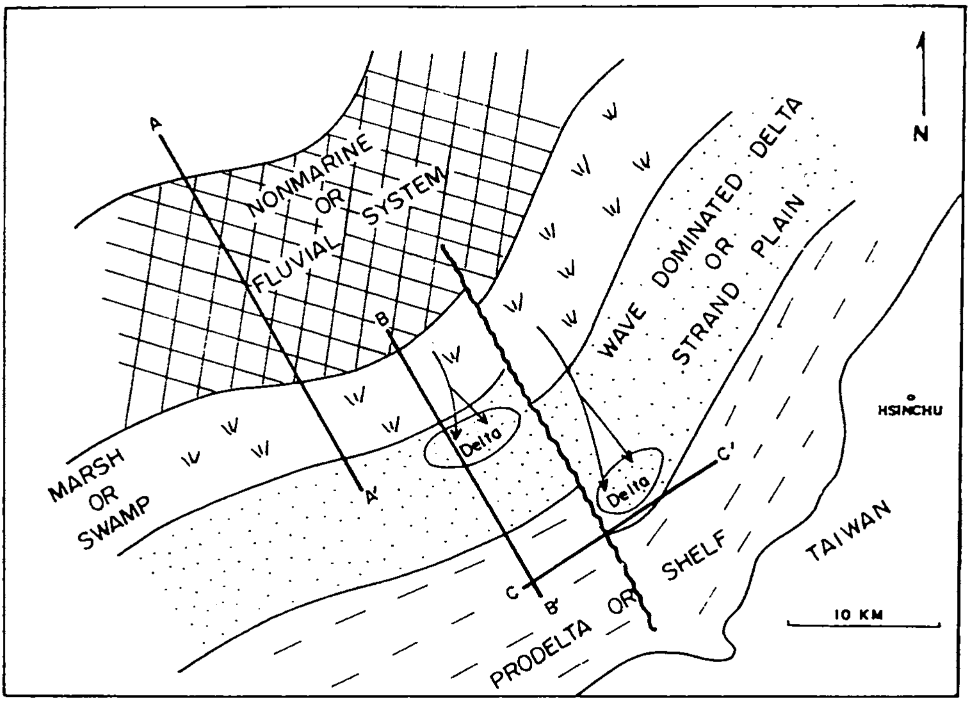

Fig. 7. Palaeoenvironmental estimation of Miocene basin roughly defined from seismic facies map.

(2) Through the seismic stratigraphic study, we are imbued with the petroleum possibilities of the foreland basin because the facts and the hypothesis indicated that oil may have formed in the sediments within the basin or accumulated in structural and stratigraphic traps. It seemed to us that all of the factors required of an oil-producing area were present.

(3) The general trend of the various depositional systems agrees with those deduced from other disciplines. However, the seismic stratigraphic study provided more knowledge about the palaeoenvironments of the Miocene formations in terms of areal extent. This interpretation can be of vital importance for the future appraisal of the prospect.

(4) The seismic stratigraphic study motivated a 3D seismic survey conducted over a limited portion of promising area in the Hsinchu basin. The newly interpreted fault patterns may account for the oil accumulation in the unique discovery well.

ACKNOWLEDGEMENTS

We are grateful to Mr. S. Yang, Vice President of the Chinese Petroleum Corporation, for the encouragement and permission for publishing this paper. We are also indebted to Mr. S. C. Sun, Chief Geologist Chinese Petroleum Corporation and

Dr. C. H. Tang and Mr. T. C. Huang of the same corporation for their valuable discussions.

REFERENCES

HO, C. S., 1982. *Tectonic Evolution of Taiwan*. The Ministry of Economic Affairs, R. O. C.

HUANG, T. C., 1981. Tertiary Calcareous Nannofossil Stratigraphy and Sedimentation Cycles in Taiwan. Reprinted from *The Proceedings of the Second ASCOPE Conference and Exhibition*, 1981, Manila, Philippines, P. 873–886.

MITCHUM, R. M. Jr., and SANGREE J. B., 1977. *Seismic Stratigraphy and Global Changes of Sea Level, Part 6: Stratigraphic Interpretation of Reflection Patterns in Depositional Sequences.* AAPG., Memoir 26, P. 117–133.

SUN, S. C., 1981. The Tertiary Basin of Offshore Taiwan. Reprinted from *The Proceedings of The Second ASCOPE Conference and Exhibition*, 1981, Manila, Philippines, P. 126–135.

YEN, T. P., 1976. Geohistory of Taiwan. *Proc. Geol. Soc. China*, No. 19, P. 52–58.

Manuscript received 6 December 1983.