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Stratigraphy and Palaeofacies Development of Carigali's Operating Areas in the Malay Basin, South China Sea

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Abstract: CARIGALI had recently undertaken a regional stratigraphic review with the aim of establishing a coherent stratigraphic scheme for correlation within and across Blocks PM 6 and PM 12 which are situated 120 km apart in the Malay Basin. Results of this study had led to the formulation of a time-stratigraphic framework for regional geological studies and seismic mapping over these two areas. This has significantly contributed to a better understanding of these parts of the Malay Basin.

The oldest sediments in these areas were deposited during Oligocene times in upper coastal plain environment and later in lower coastal plain environment. The Early Miocene section is basically composed of coastal fluviomarine sediments in PM 12 and lower coastal plain sediments in PM 6. Middle to Late Miocene sediments were predominantly laid down in coastal fluviomarine environment while those of Pliocene to Recent in holomarine environment.

INTRODUCTION

The Malay Basin is situated offshore east coast Peninsular Malaysia and is closely associated with the Thai Basin in the north and Penyu Basin and West Natuna Basin in the south (Figure 1). It is bounded at the north-eastern flanks by the Khorat Swell and Tenggol Arch respectively. PETRONAS Carigali's main operating areas in this basin are Blocks PM 6 and PM 12 (Figure 2). These blocks are parts of larger areas previously held by Esso Production Malaysia Incorporated (EPMI) and Continental Oil Company (CONOCO).

This paper is an attempt to introduce CARIGALI's present stratigraphic scheme (Samad & Nazri, 1985) which has provided the means of establishing a time-stratigraphic framework for regional evaluations within and across Block PM 6 and PM 12. It will also discuss the stratigraphy and palaeofacies development of these two areas which should provide some insight of the sedimentation history of these areas of the Malay Basin.

STRATIGRAPHIC SCHEME

When CARIGALI acquired Blocks PM 6 and PM 12, it adopted, out of operational convenience, EPMI's seismostratigraphic scheme for PM 6 and CONOCO's lithostrsatigraphic scheme for PM 12 (Figures 3 and 4). Due to their obvious differences in nomenclature and application, CARIGALI had experienced difficulties in conducting regional correlation between PM 6 and PM 12 areas which are located 120 km apart. This had hampered the understanding of the sedimentary history of these two areas due to the inavailability of a coherent stratigraphic scheme. To resolve this problem, CARIGALI undertook a regional stratigraphic review of these two areas in two phases. The first phase was to carry out a bi-

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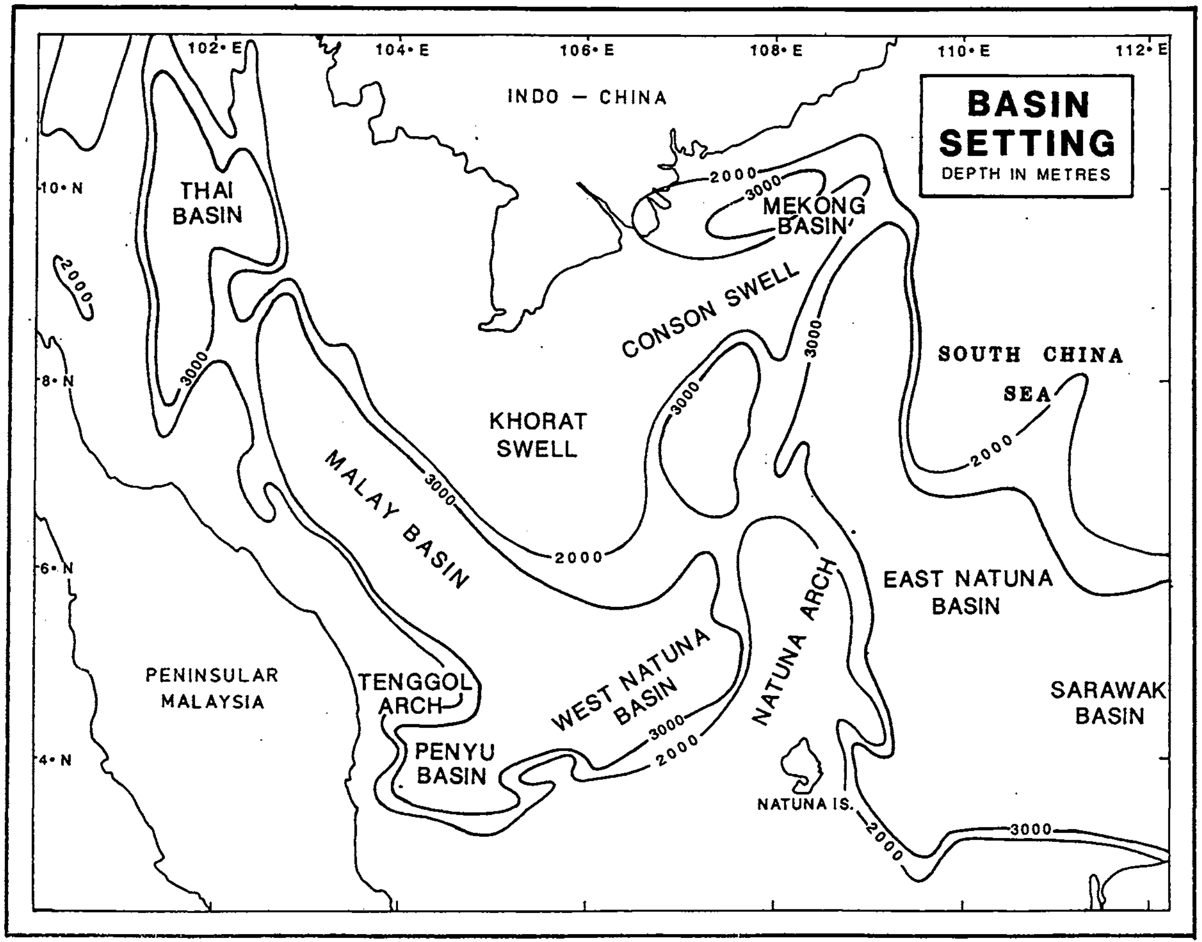


Figure 1: Sedimentary basin setting map of South China Sea. The Malay Basin can be seen to be closely associated with the Thai Basin in the north and Penyu Basin and West Natuna Basin to the south.

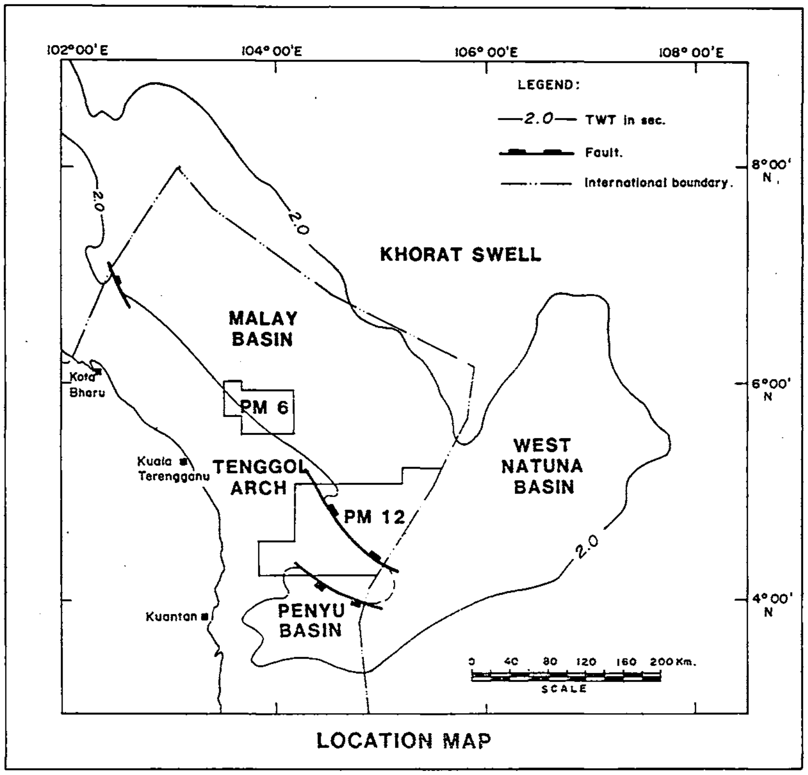
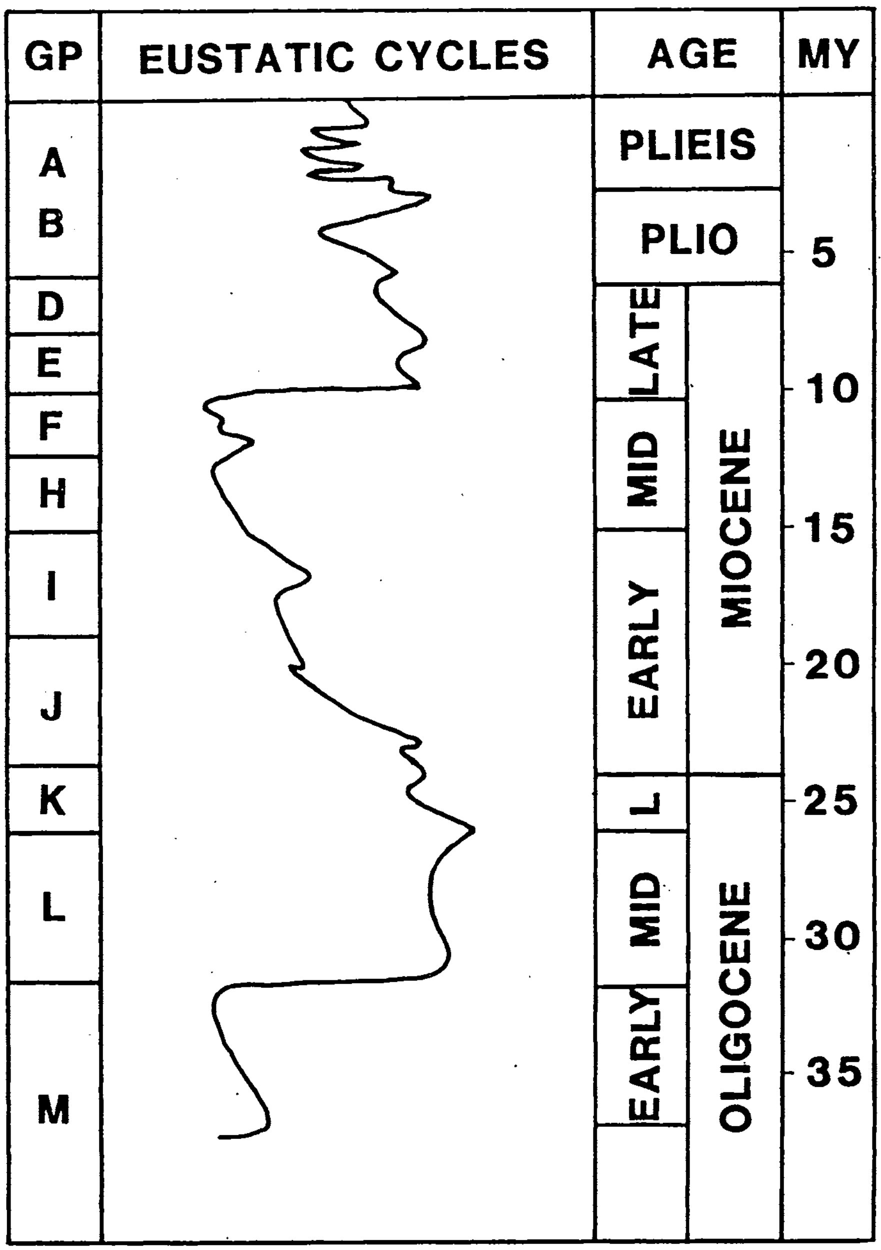


Figure 2: Location map of CARIGALI's main operating areas i.e. Blocks PM 6 and PM 12 in the Malay Basin. It can be observed that Block PM 12 covers 3 major geological provinces, namely; Malay Basin, Tenggol Arch and Penyu Basin.

ostratigraphic re-evaluation of thirteen key wells from these areas (Figure 5) in order to provide good age controls and better definition of depositional environments. The second was to integrate these data with wireline log data and seismic in an attempt to formulate a time-stratigraphic framework for regional correlation within and across the two areas.

The first phase of the study has resulted in more consistent biostratigraphic zonations (Figure 6); the most notable being the *Cicatricosisporites palynomorph* zonation and *Spenolithus heteromorphus* (NN5) and *Helicosphaera ampliaperta* (NN4) nannofossil zonation. The former has provided the means of distinguishing the Oligocene-Miocene boundary and the latter the Early and Middle Miocene boundary. Another important result of this study is in the recognition of well defined depositional environment subdivisions (eg. Figure 7) which were based on floral and faunal assemblages and wireline log shapes and patterns. The terminology used for describing the various depositional environments is shown in the environment of deposition scheme (Figure 8).

The second phase of the study has given rise to the recognition of two sets of stratigraphic markers, ie. marine transgressive pulses and regional shales (eg. Figure 9). These markers



SEISMO STRATIGRAPHIC SCHEME
(AFTER EPMI)

Figure 3: EPMI's seismostratigraphic scheme used previously in Block PM 6. The Tertiary sequence, in this scheme, is subdivided into 11 seismic groups.

LITHOSTRATIGRAPHIC SCHEME
(MODIFIED AFTER CONOCO)

EPOCH	FORMATION	MEMBER
QUATERNARY	PILONG	
PLIOCENE		
EARLY TO MIDDLE MIOCENE	SAND COAL	UPPER
EARLY MIOCENE		LOWER
	TERENGGANU SHALE	
	TAPIS	UPPER
		MIDDLE
		LOWER
EARLY MIOCENE TO OLIGOCENE	SOTONG	UPPER
		LOWER
MESOZOIC		

Figure 4: CONOCO's lithostratigraphic scheme adopted for Block PM 12 previously. In this scheme, The Tertiary sequence is subdivided into 5 lithological formations.

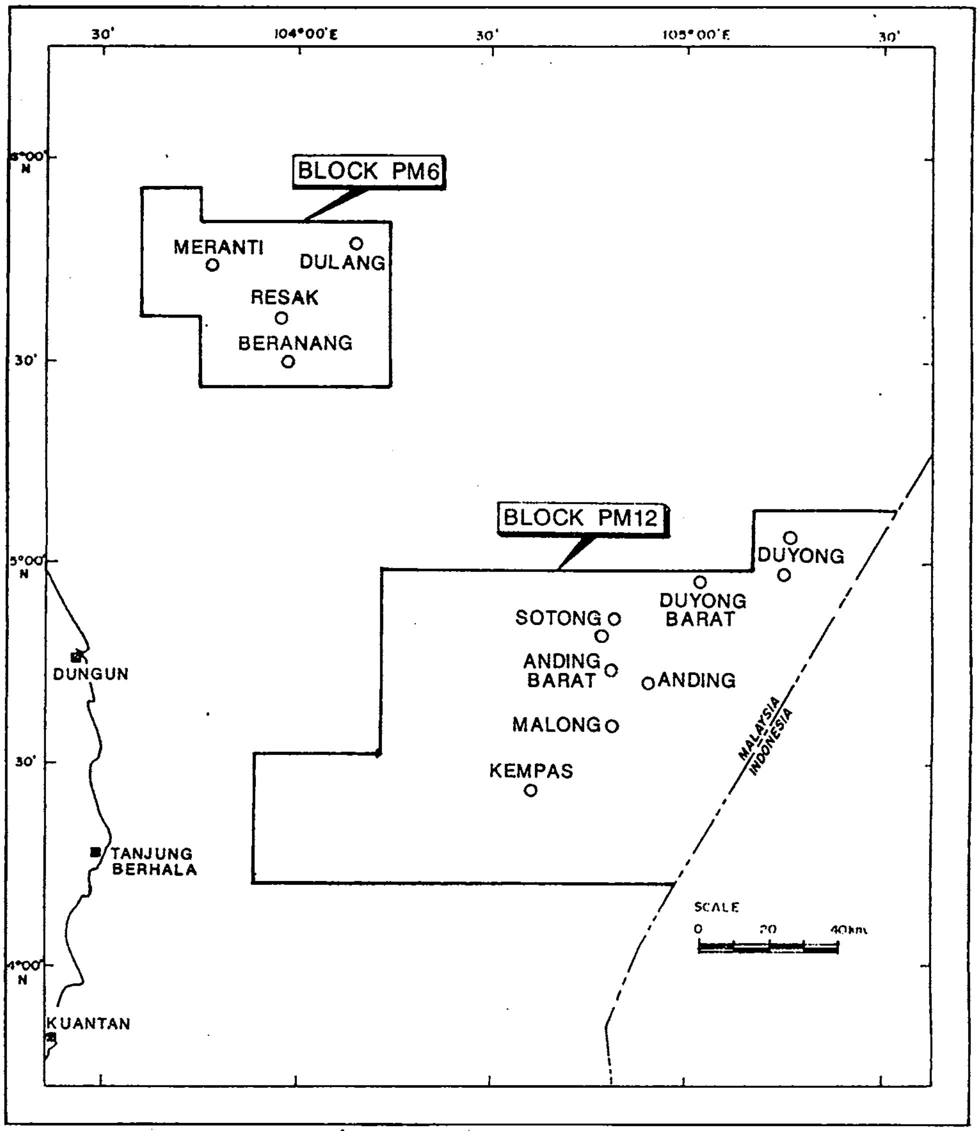
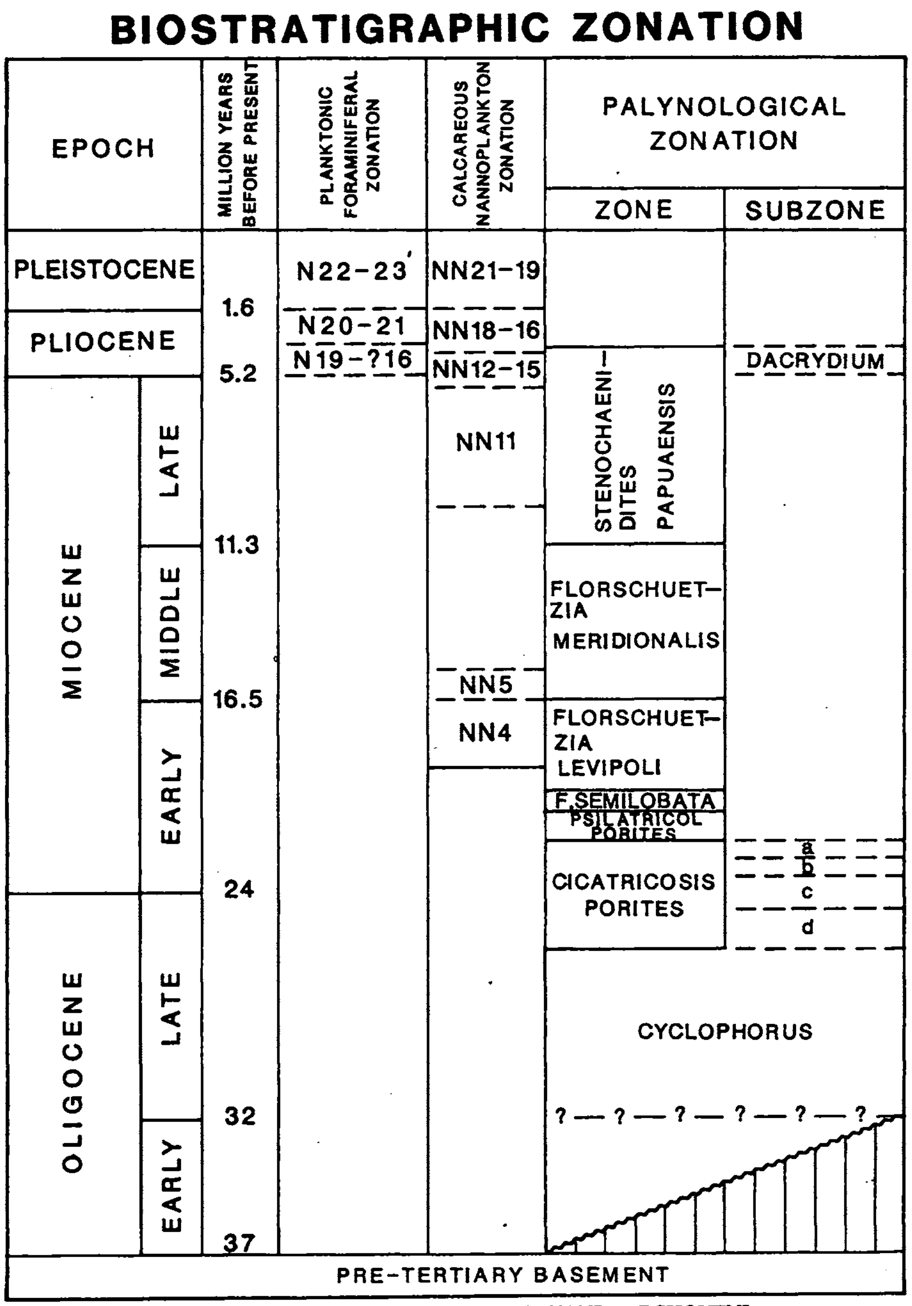


Figure 5: Location map of key wells identified for the biostratigraphic re-evalution exercise.



NOTE: a - CICATRICOSIS PORITES b - C. VANRAADSHOVENI
c - CELPHALOMAPPA c - SCOLOCYAMUS

Figure 6: Biostratigraphic zonations recognised from the biostratigraphic re-evalution exercise.

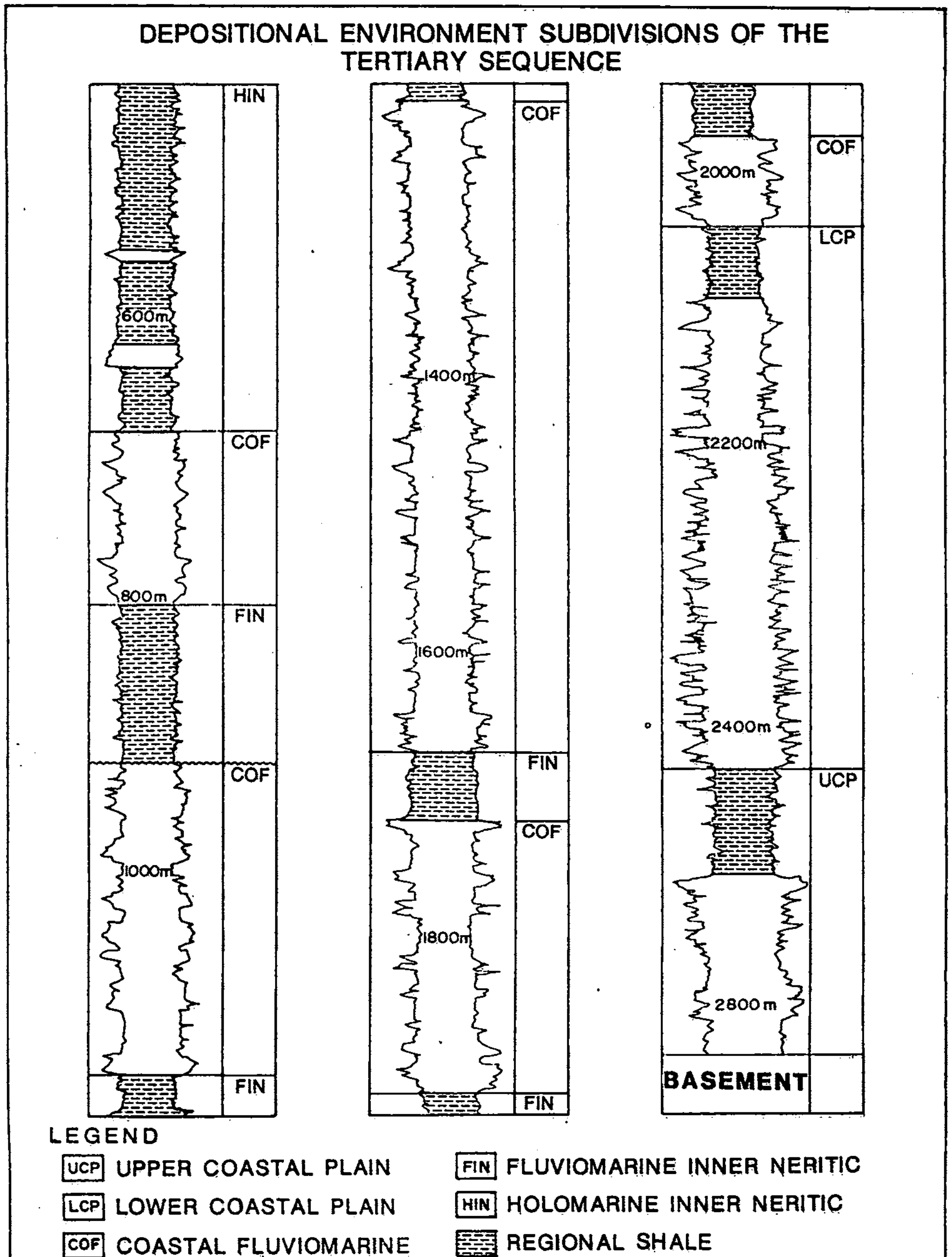


Figure 7: Depositional environments recognised within the Tertiary sequence of a typical well section in Block PM 12. It can be seen that the sedimentary sequence in this area is overall transgressive in nature.

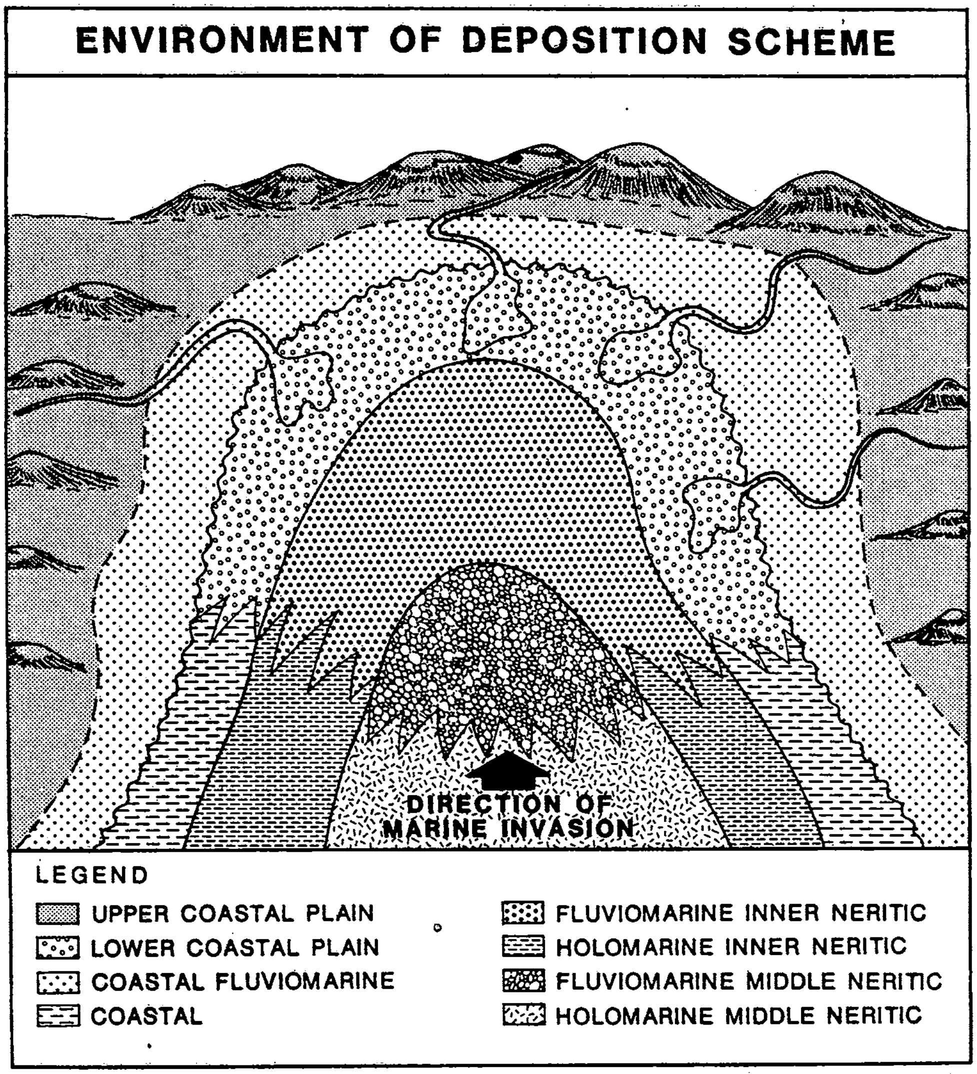


Figure 8: Environment of deposition scheme as used for an open marine setting. The direction of marine invasion is indicated by the solid arrow while the transition zone between holomarine and fluviomarine environments is shown by the jagged line.

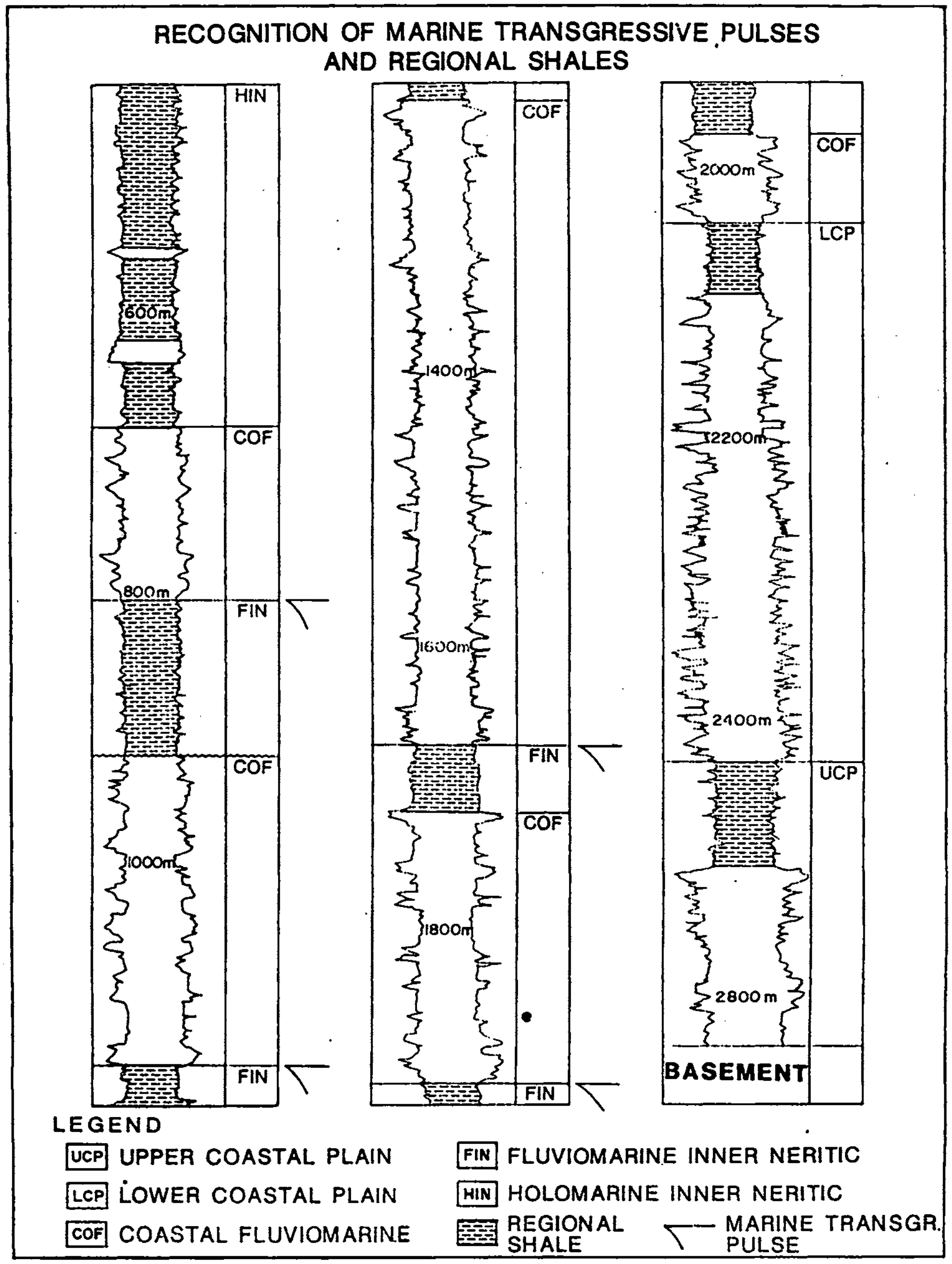


Figure 9: Marine transgressive pulses and regional shales identified from the integration of biostratigraphic, wireline log and sedimentological data.

have been found to be useful in defining time-stratigraphic boundaries since they are dated by biostratigraphic means and supported by seismic correlation. Henceforth, based on the occurrence of these stratigraphic markers, eight stratigraphic units have been recognised in the Tertiary sedimentary sequence of Block PM 6 and PM 12 (Figure 10). Examples of how these markers are being used to define stratigraphic unit boundaries are shown in figures 11 and 12.

In summary, tops of Tertiary I and II are defined by tops of regional shales, ie. Shale 'A' and Shale 'B' respectively while those of Tertiary III to IV by both regional shales and marine transgressive pulses (eg. Figure 13). The top of Tertiary VII though not identified by a transgressive pulse or shale marker is however distinguished by the onset of holomarine sedimentation occuring around the closing phase of Late Miocene times in these areas.

STRATIGRAPHY AND PALAEOFACIES DEVELOPMENT

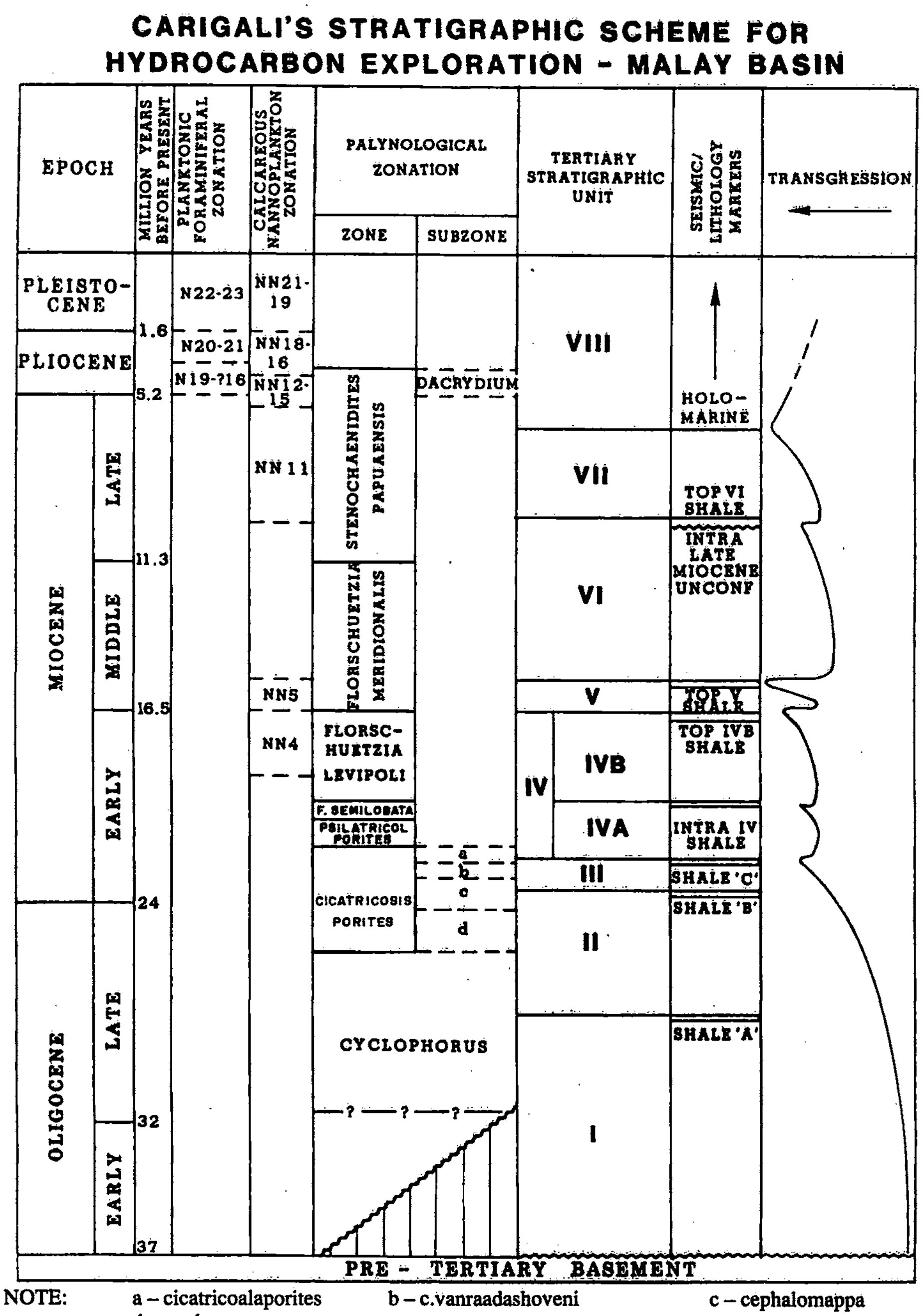
The establishment of this coherent stratigraphic scheme and the resultant time-stratigraphic framework (Figure 14) created the avenue for regional correlation and seismic mapping within and across Blocks PM 6 and PM 12 (Figures 15a, 15b, 16a & 16b). The most significant contribution made by this stratigraphic scheme is the provision of a framework for the integration of geological, geophysical and geochemical data for regional evaluations.

Among the most important conclusion derived from these regional evaluation is that a relationship exists between environment of deposition and the distribution of reservoir and source rocks. The best reservoirs are observed to occur in the coastal environments and to a lesser degree in lower coastal plain environment (refer Figure 8). However, good quality source rocks are found to be concentrated in lower coastal plain environment and to a certain extent in coastal fluviomarine environment. Palaeofacies maps constructed can therefore now be used for the prediction of source rock and reservoir rock distribution in these areas.

TERTIARY I AND II (OLIGOCENE AND OLDER?)

The progressive collision of the Indian subcontinent with the Eurasian Plate (Figure 17) during early Tertiary times (Eocene or older?) had resulted in the interior fracturing of the Sunda landmass where Thai, Malay, Penyu and West Natuna basins now lie (Hamilton, 1979 and Tapponier *et al,* 1982). This was later followed by block faulting and subsequent subsidence of the Malay Basin during Early Oligocene times (Figure 18). This early period of extensional tectonics in the basin had given rise to the formation of a series of grabens/half-garbens and horst blocks where in certain areas formed large scale depressions providing the physiographic lows for lake development.

Based on detailed palynofacies and sedimentological data, three major depositional environment subdivisions ie. lake, lakeshore and lacustrine plain are envisaged for the lacustrine sediments of Tertiary Unit I and II (Figure 19). During Tertiary I and II times the Dulang and south of Duyong areas were part of a lake while the rest of PM 6 and PM 12 areas were dominantly in lakeshore or shallower part of these lakes (Figures 20 and 21). During these times, Tenggol Arch Province was an area of erosion and/or non-deposition until Late Tertiary II times (Late Oligocene - Early Moicene) when a major portion of it was overstepped by lakeshore and lacustrine plain sediments.



NOTE: a – cicatricoalaporites b – c.vanraadashoveni c – cephalomappa d – acolocyamus

Figure 10: CARIGALI's stratigraphic scheme now used for hydrocarbon exploration in Blocks PM 6 and PM 12. The subdivisions of each stratigraphic unit are based on the recognition of regional shales and/or marine transgressive pulses and supported by seismic correlation.

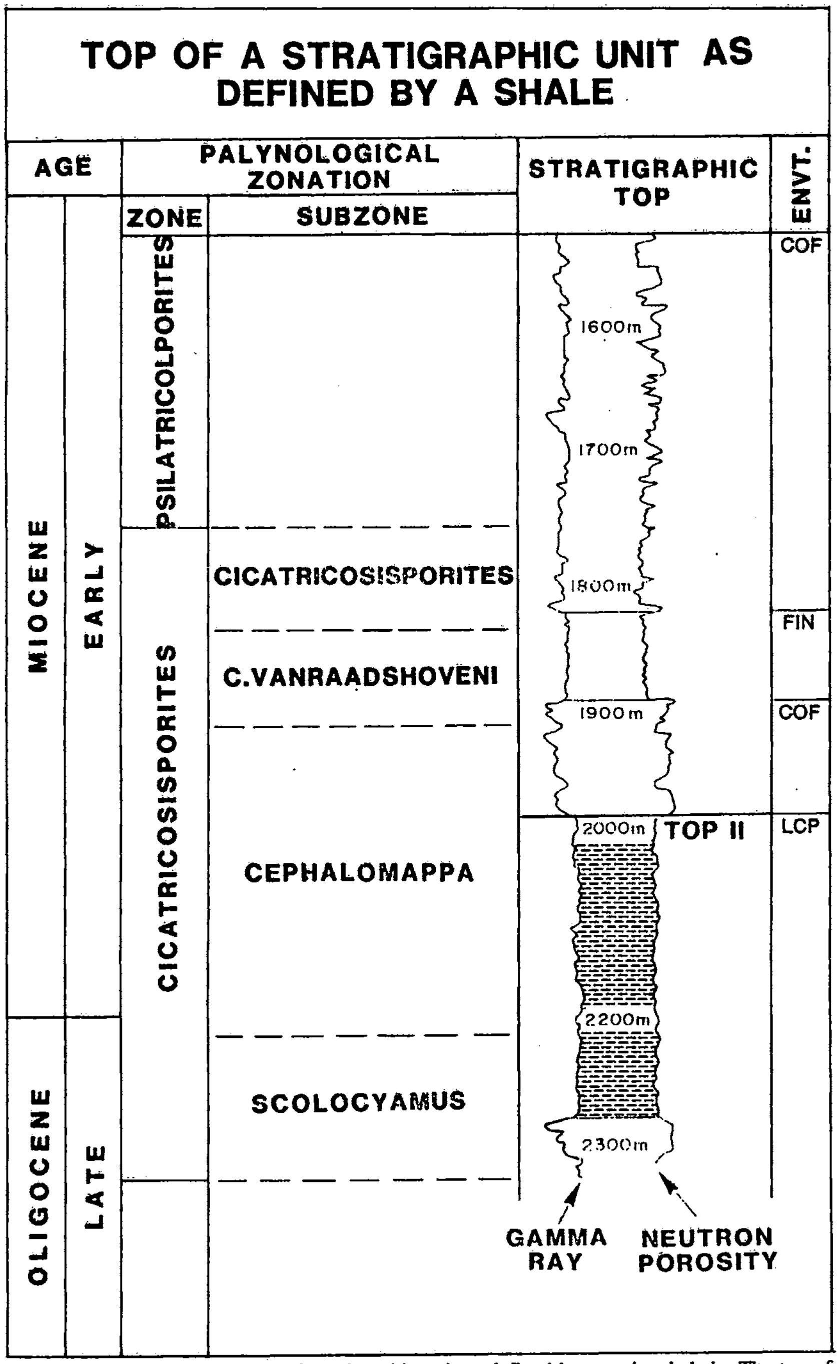


Figure 11: Example of a top of stratigraphic unit as defined by a regional shale. The top of Tertiary Unit II is defined by the top of regional shales which falls within the *Cephalomappa* subzone.

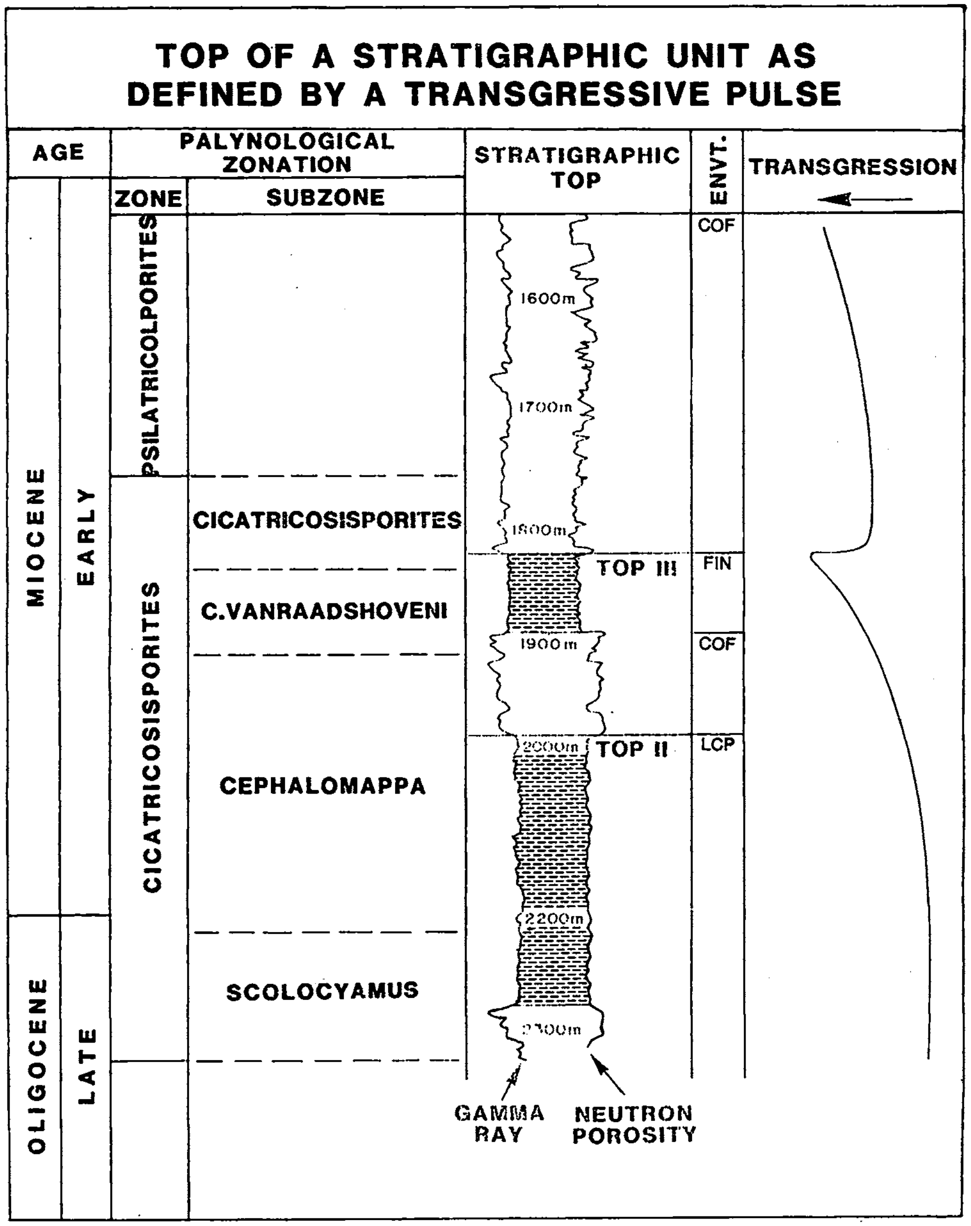


Figure 12: Example of a top of stratigraphic unit as defined by marine transgressive pulse. The top of Tertiary Unit III is defined by a transgressive pulse and also by the top of a regional shale.

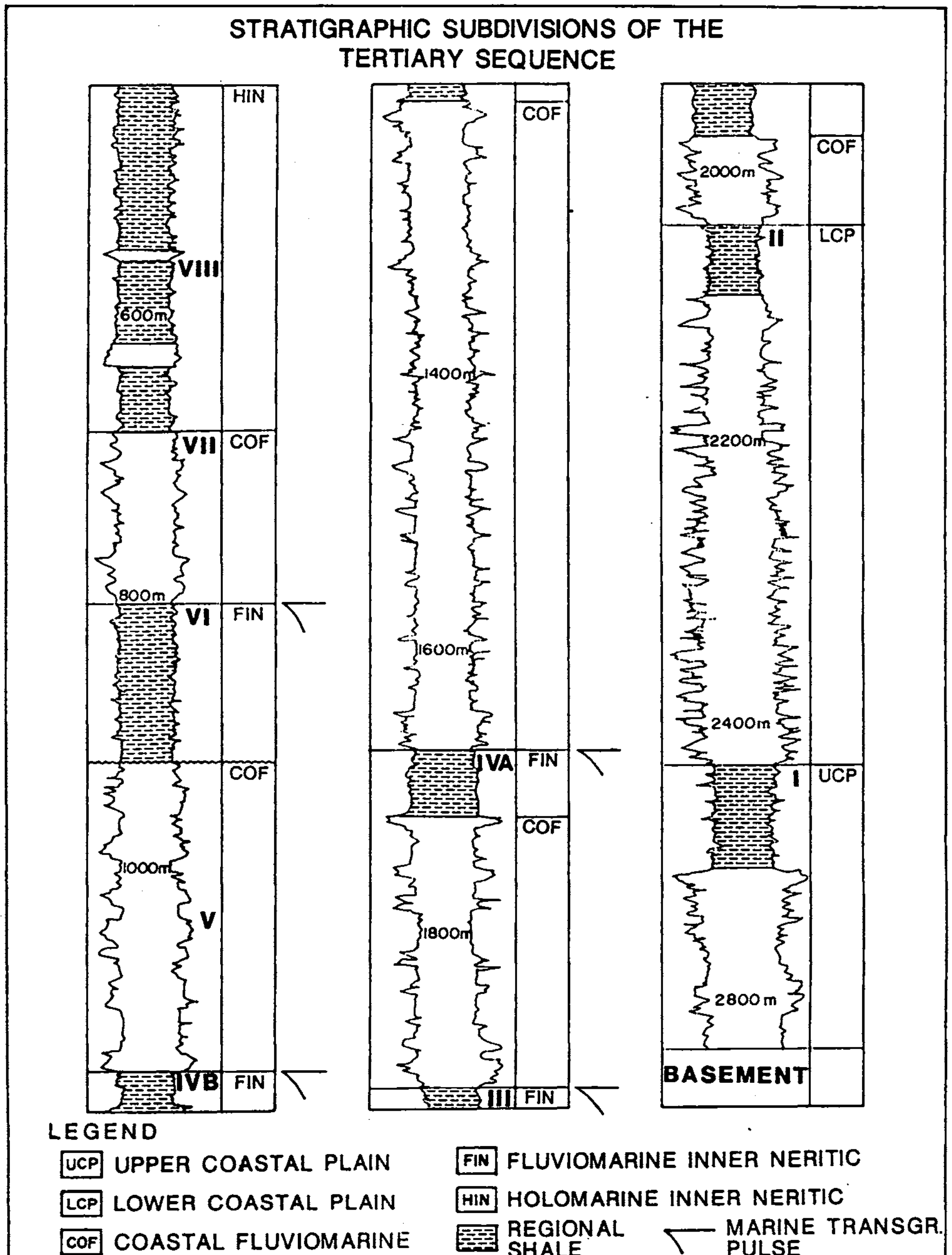


Figure 13: Stratigraphic subdivisions of the Tertiary sedimentary sequence of a typical well section in Block PM 12. Observe the top of Tertiary Unit VII, in the absence of a marine transgressive pulse and regional shale, is distinguished by the on set of holomarine sedimentation in this area.

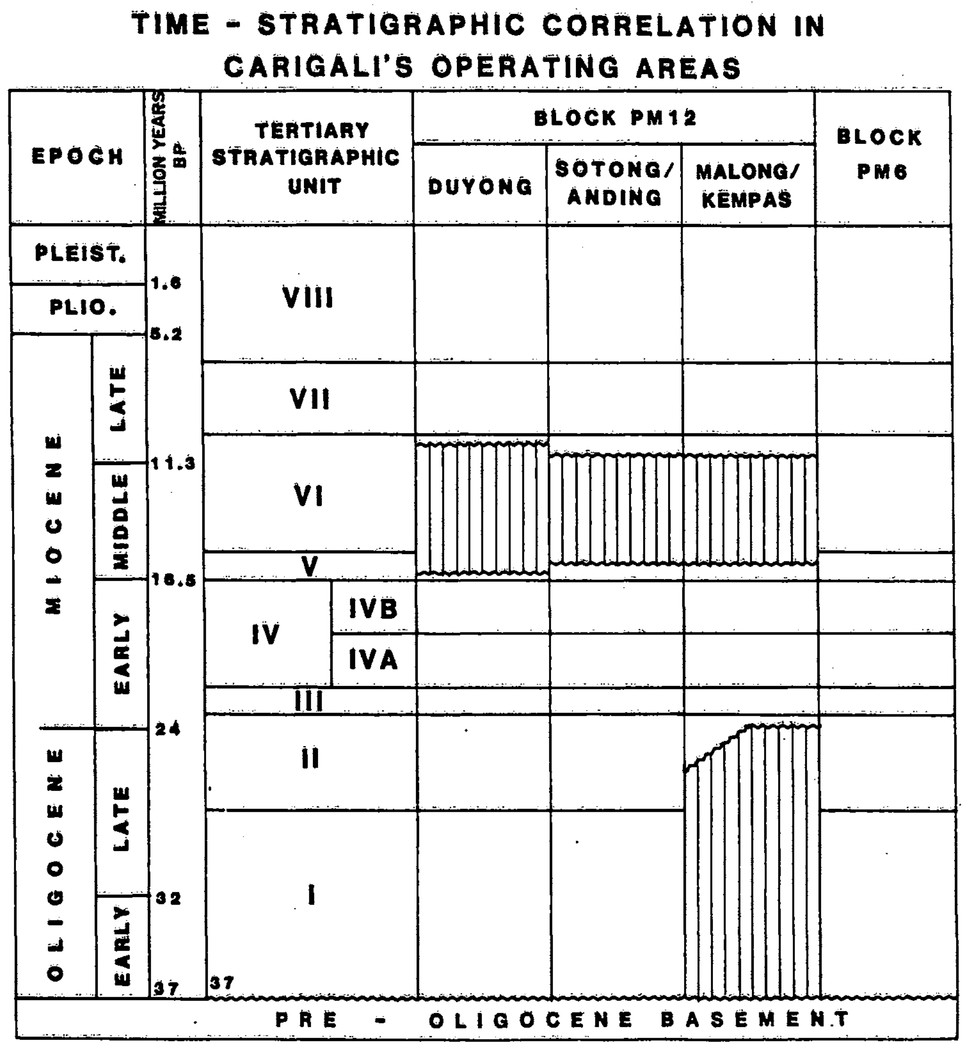


Figure 14: Time stratigraphic correlation between southern Malay Basin and Tenggol Arch areas of Block PM 12 and Block PM 6. The hatched section at Middle Miocene times in Block PM 12 represents the non-deposition and/or erosion period due to Late Miocene tectonics.

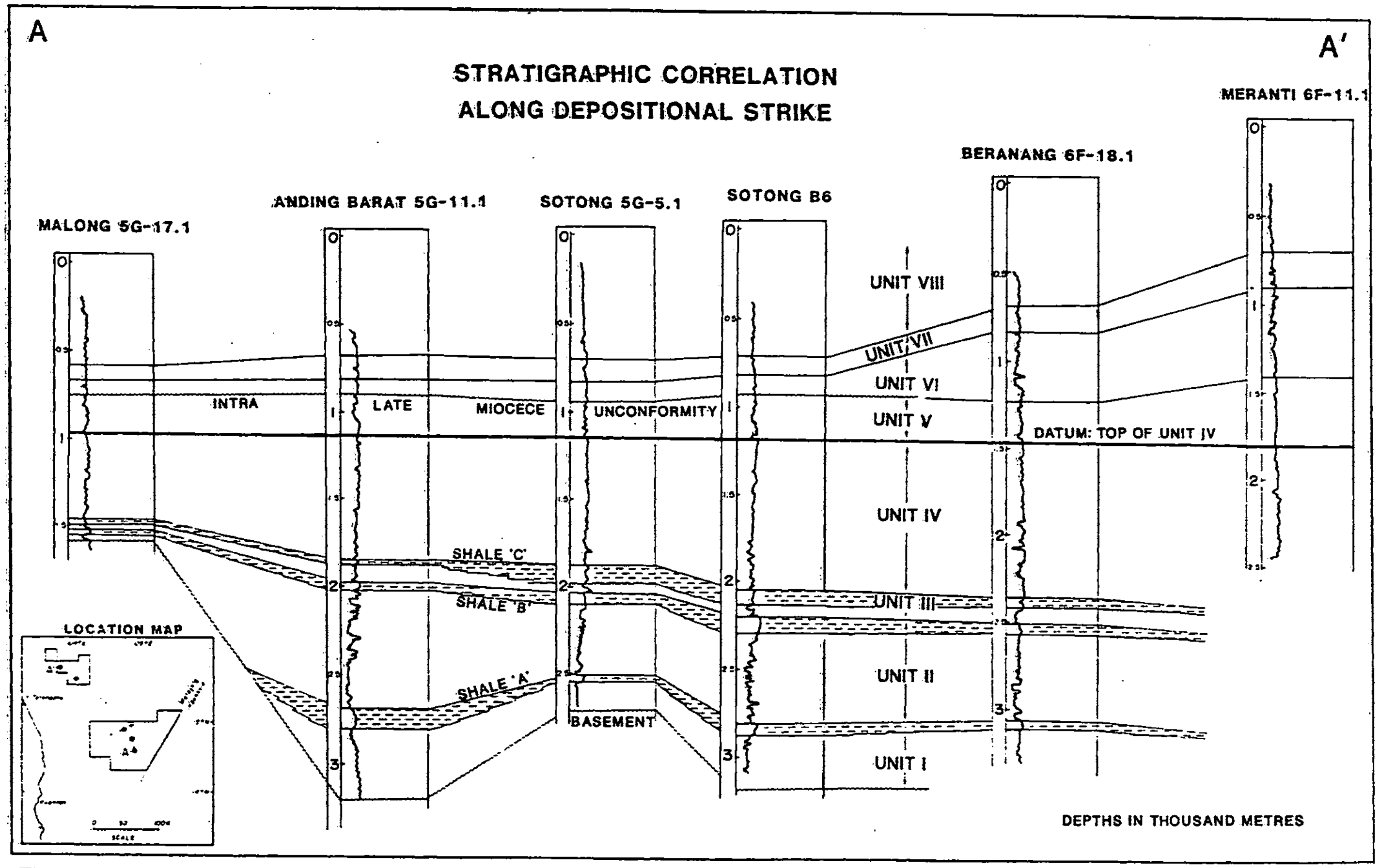


Figure 15a: Stratigraphic correlation along depositional strike from Block PM 12 to Block PM 6. Note the thickness variation of Tertiary I and II sediments being conformable to the basement topography.

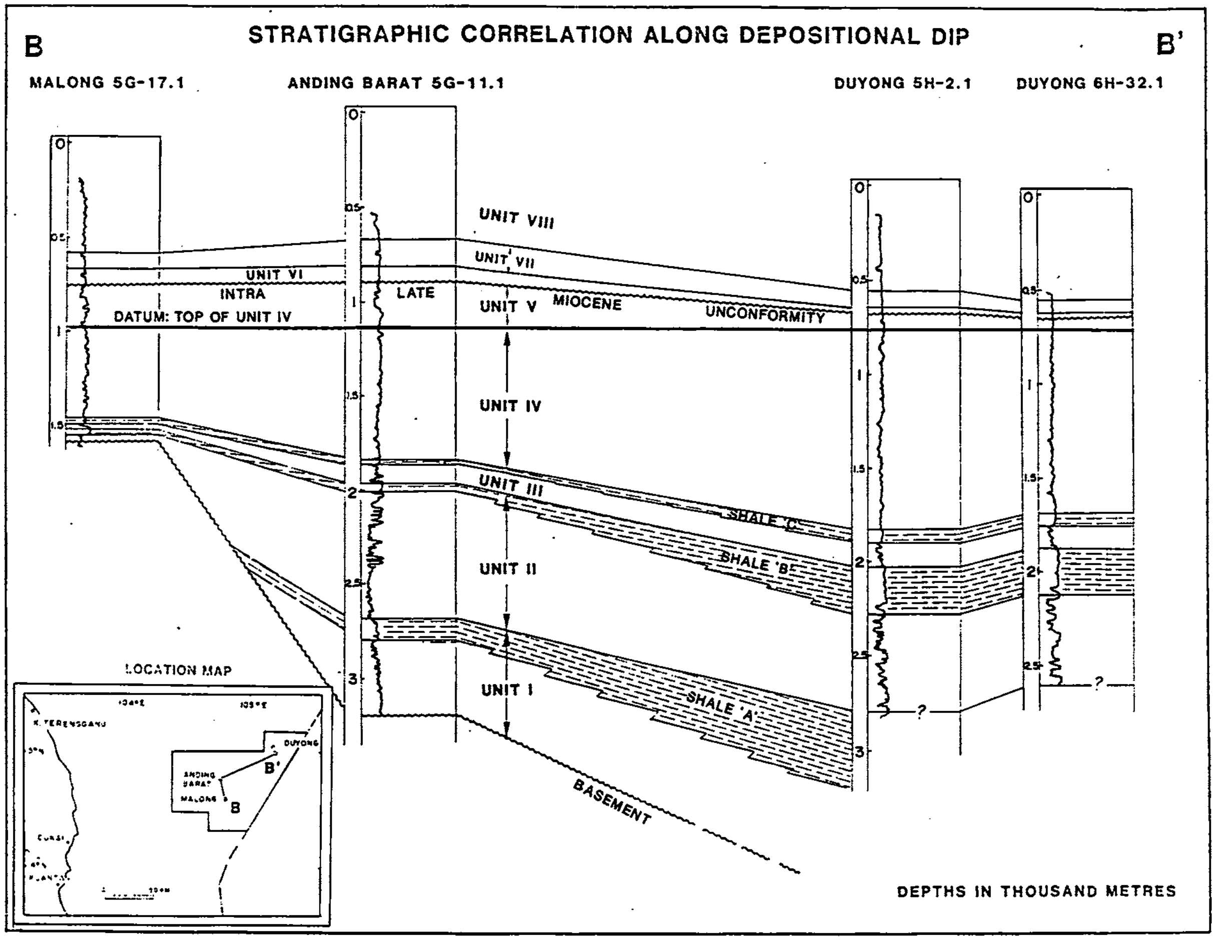


Figure 15b: Stratigraphic correlation along depositional dip within Block PM 12. Note the thickening of regional shales 'A' and 'B' and also the thinning of units V and VI in Duyong area.

SEISMIC CORRELATION OF TERTIARY STRATIGRAPHIC UNITS ANDING - FERI AREA

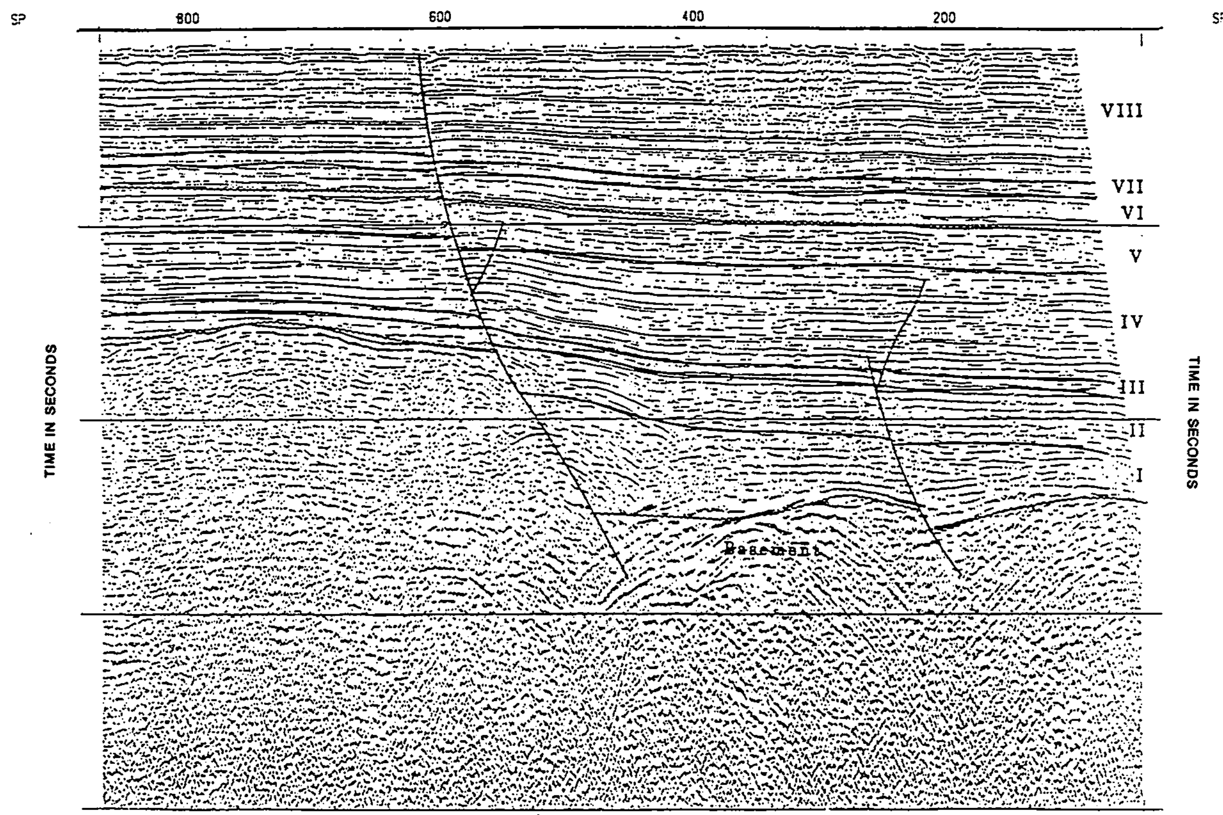


Figure 16a: Seismic correlation of Tertiary stratigraphic units in Anding-Feri area of Block PM 12. The shallow basement area to the west is the Tenggol Arch Province .

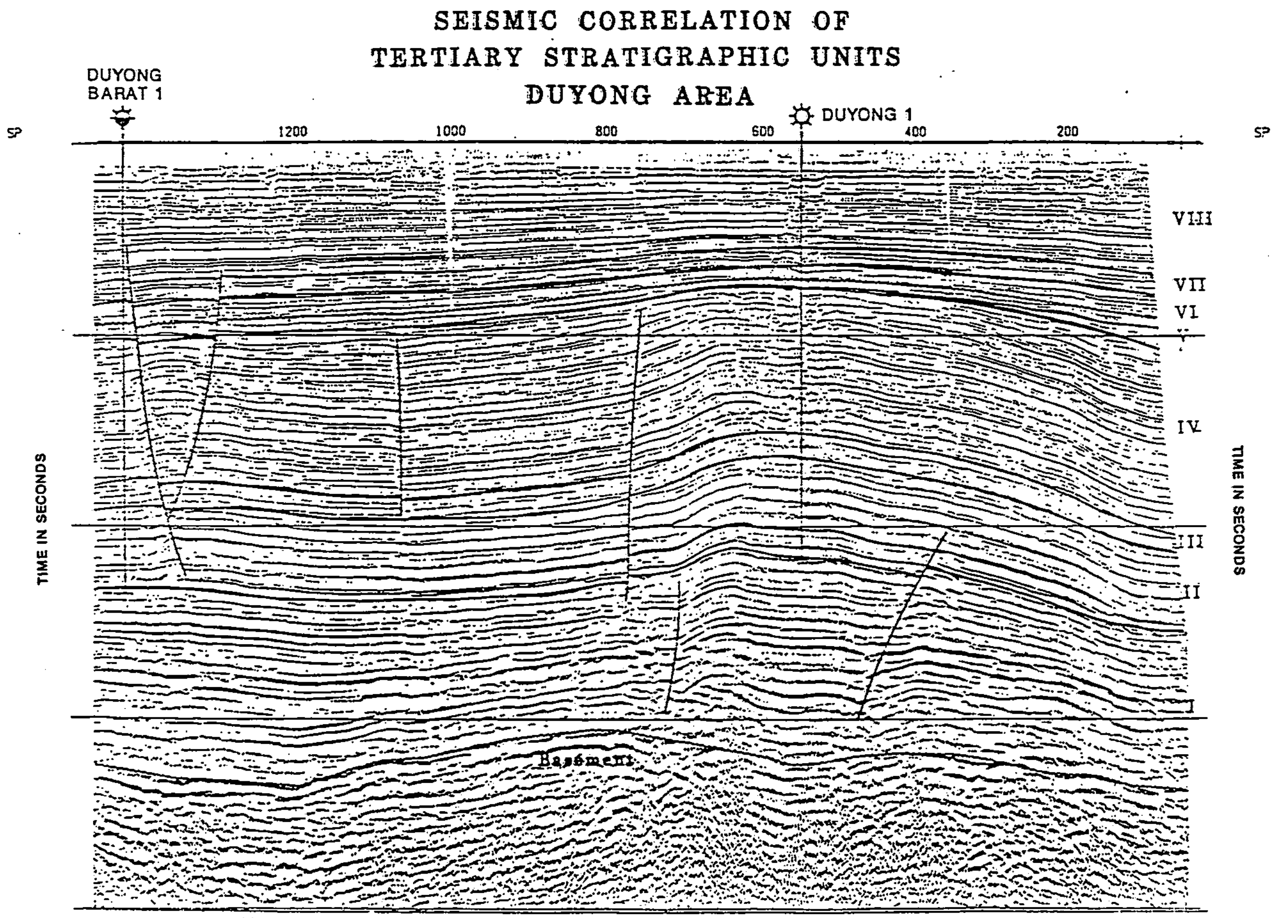


Figure 16b: Seismic correlation of Tertiary stratigraphic units in Duyong area of Block PM 12.

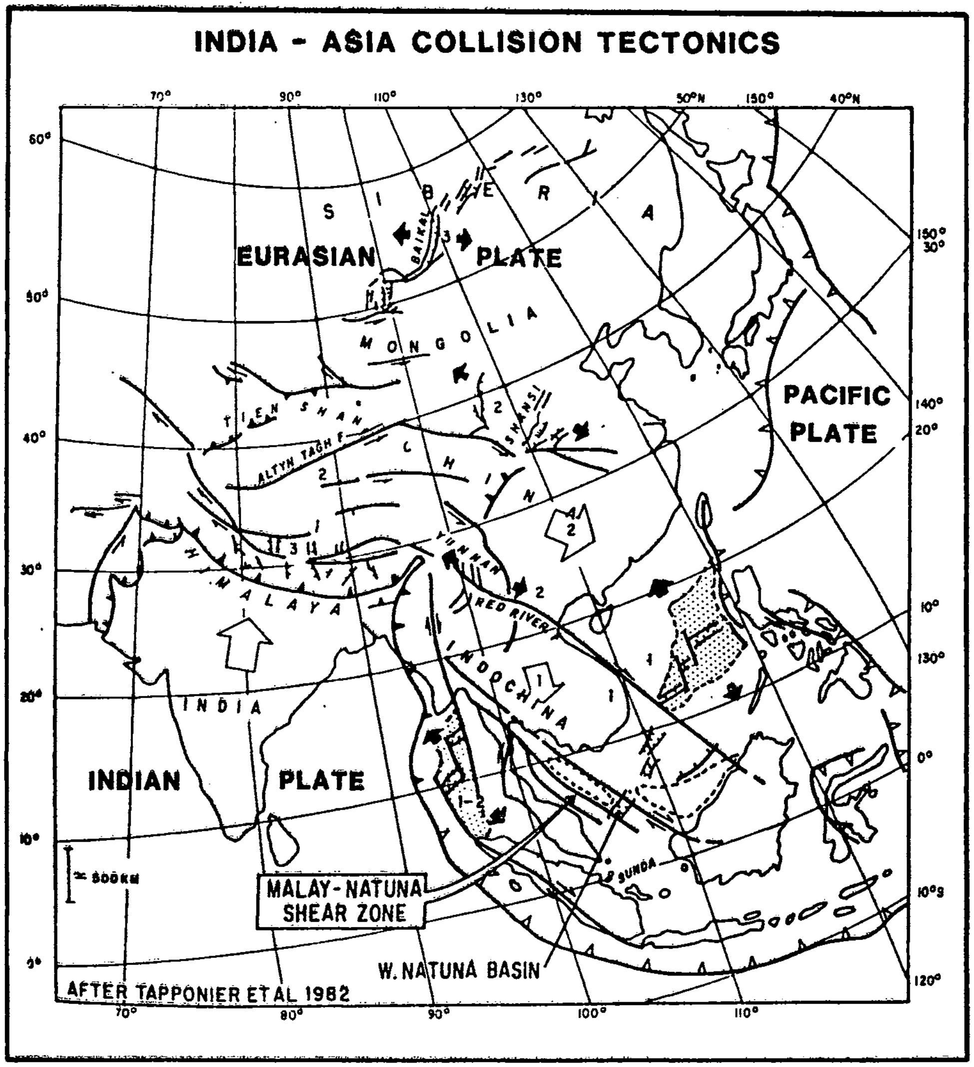


Figure 17: Schematic map of India-Asia collision tectonics which triggered the formation of the Malay Basin. The white arrows indicate major block motions with respect to Siberia while the black arrows shows the direction of extrusion-related extension.

Tertiary I sediments which represent the basal part of the Tertiary sedimentary sequence lie unconformably on the pre-Tertiary basement and their thickness variation most probably reflects to a certain degree the pre-Tertiary basement topography (Figure 15a). Tertiary II sequence together with Tertiary I formed the initial basin fill which by the end of Tertiary II times had completely infilled the topography of the basin in PM 6 and PM 12 areas.

Tertiary I sequence as well as Tertiary II is composed of a lower sand-prone unit and an

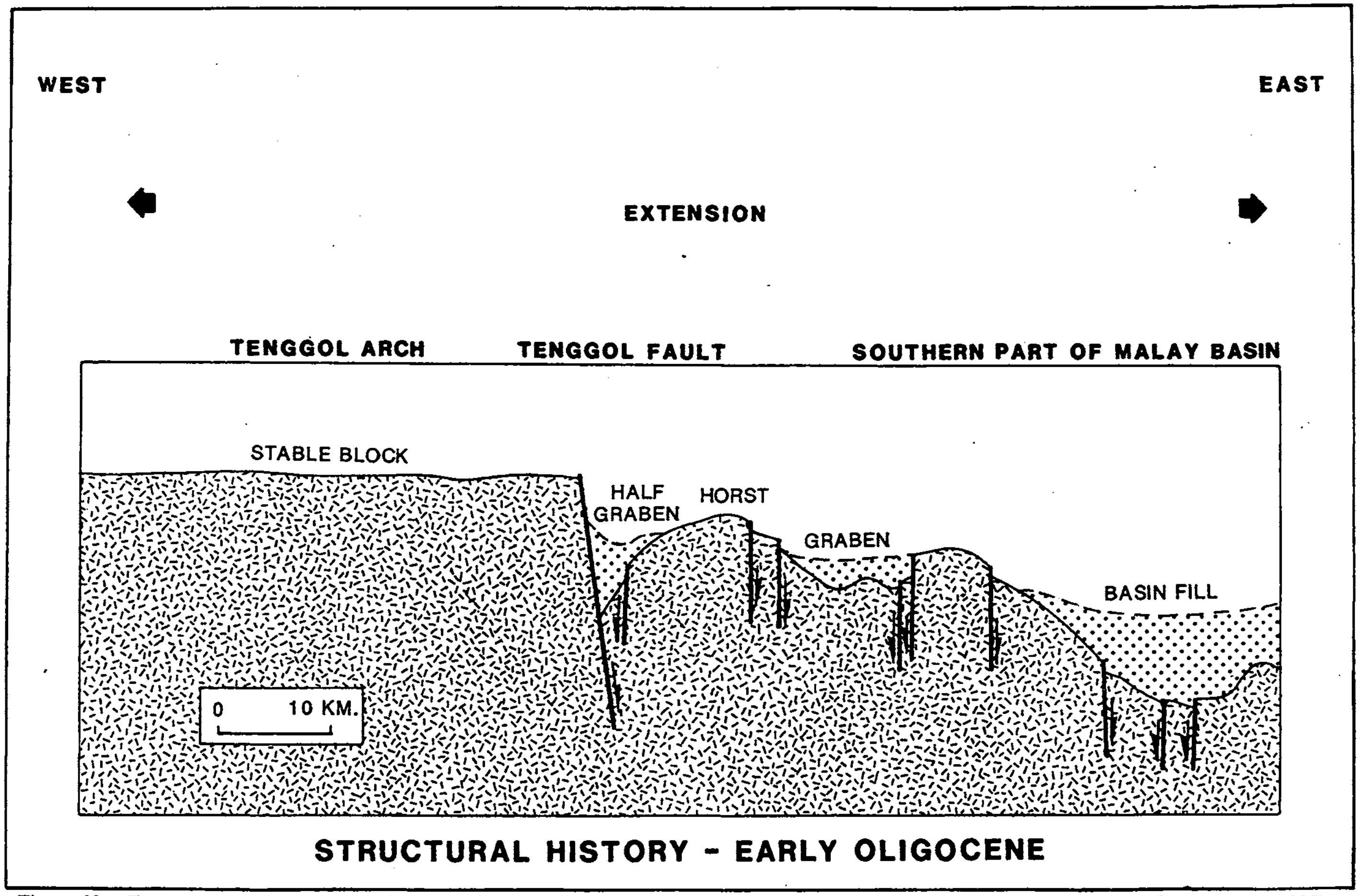
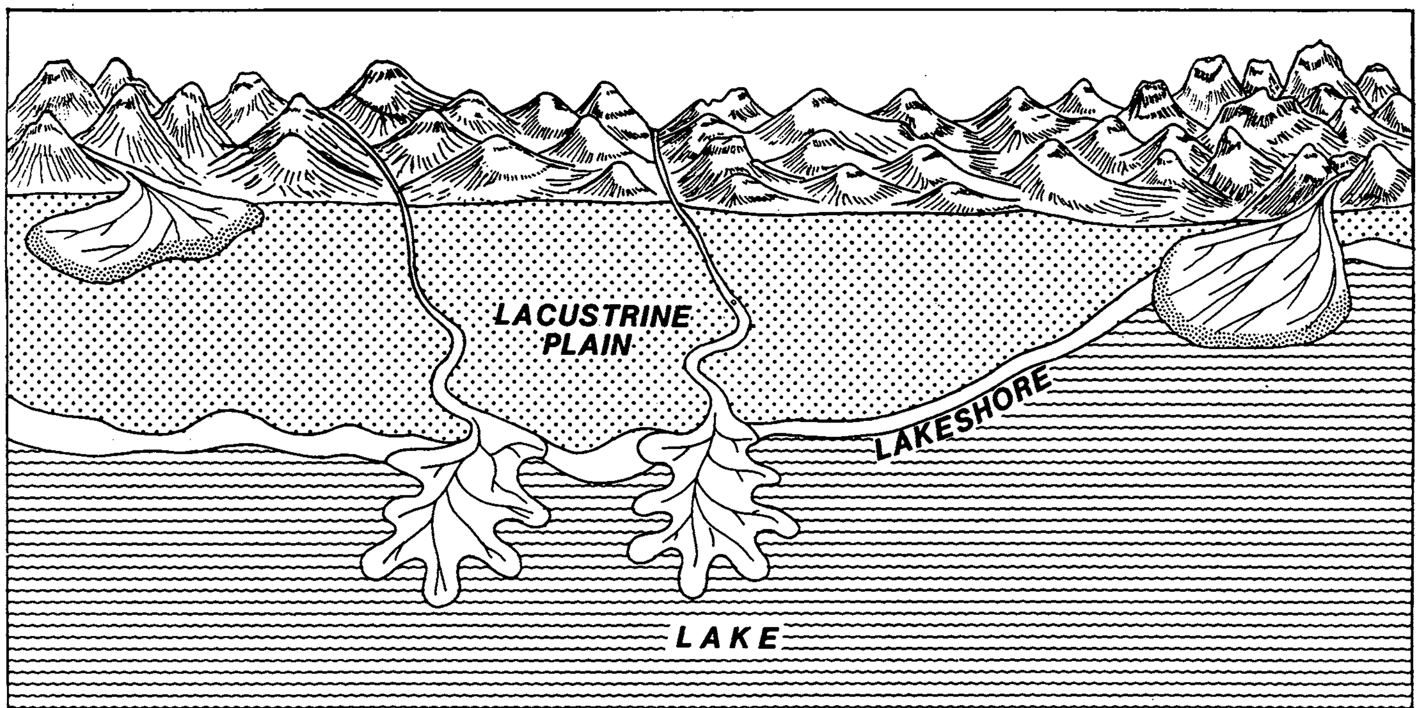


Figure 18: East-west structural reconstruction during Early Oligocene times showing the formation of half-grabens and horst blocks (after Ng. T. S., 1985)



DEPOSITIONAL SCHEME
FOR UNITS I AND II (LACUSTRINE SETTING)

Figure 19: Environment of deposition scheme used for a lacustrine setting. The best reservoir rocks are found to occur in lakeshore environment. Good quality source rocks are observed to be dominant in lake environment and to a lesser degree in lacustrine plain environment.

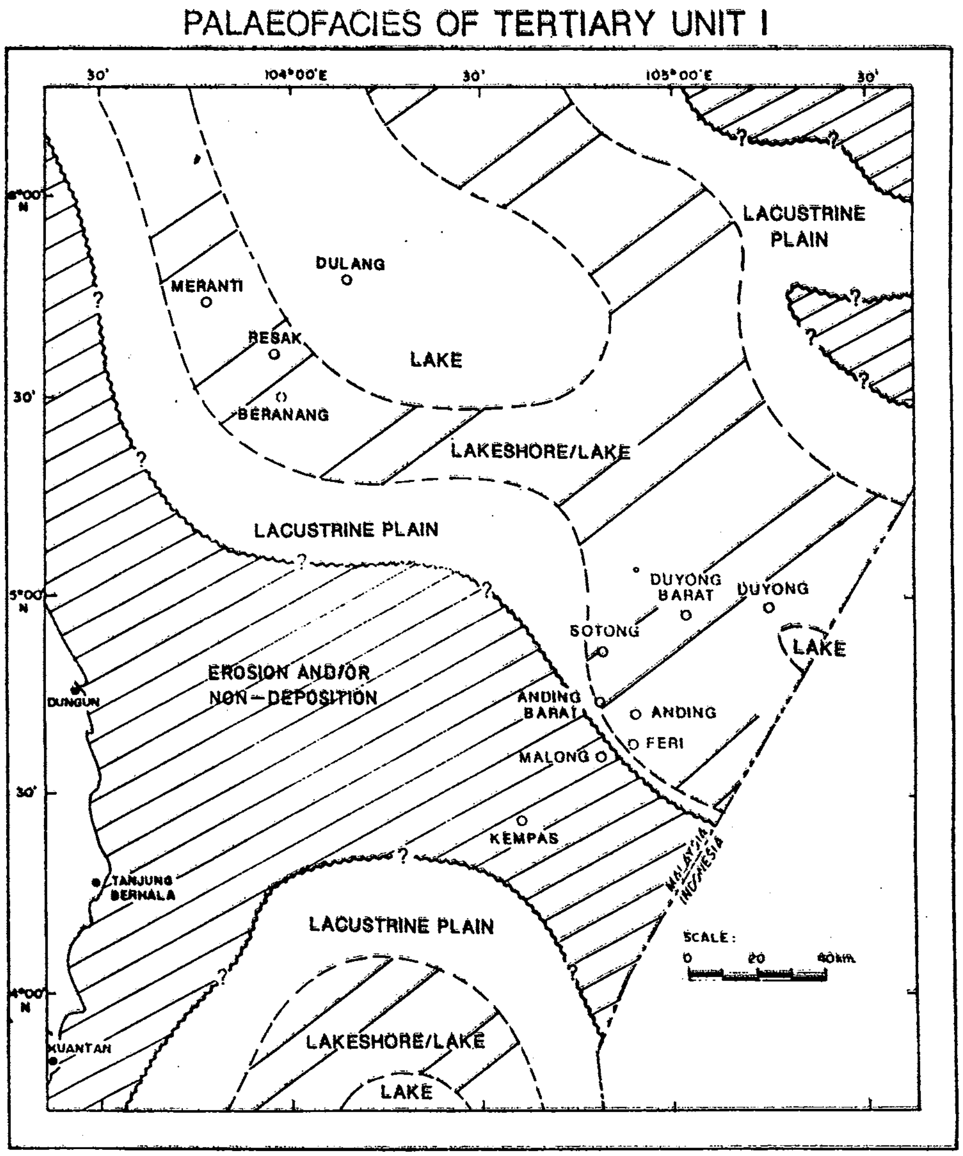


Figure 20: Paleofacies map of Tertiary Units I (early to middle Late Oligocene). 2 major lakes were developed in the major depocentre areas around Dulang and south of Duyong. Note the absence of Tertiary I sediments in Tenggol Arch area.

PALAEOFACIES OF TERTIARY UNIT II

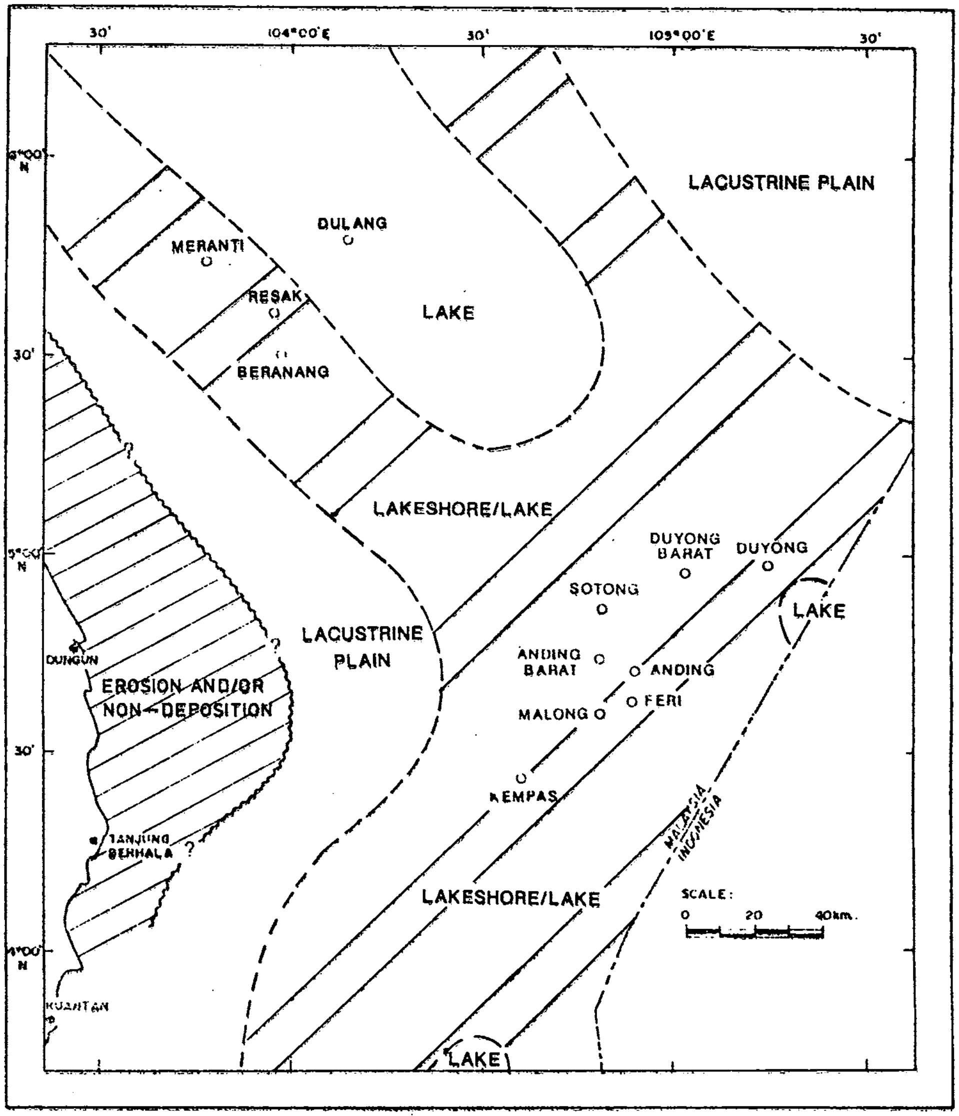


Figure 21: Palaeofacies map of Tertiary Unit II (Late Oligocene to early Early Miocene). Observe the 2 major lakes still prevailing during this time while lakeshore and lacustrine plain sediments have now covered the Tenggol Arch area.

upper shale unit (Figure 13). This cyclic pattern of sand and shale sedimentation signifies the interplay between sediment supply, basin subsidence and rise or fall in lake-water level. At this point of time there is very little evidence to suggest which of these processes dominated during the various phases of sedimentation. It is however believed that basin subsidence due to the sediment loading coupled by the continued encroachment of the South China sea due to sea floor spreading during these times could well be the major factors behind the cyclic sedimentation pattern observed in these Units.

TERTIARY III AND IV (EARLY MIOCENE)

The continued opening of the South China Sea had caused a more pronounced marine influence in the PM 6 and PM 12 area during Tertiary III times. Because of this, a different set of depositional environment scheme is being used to cater for depositional environments of a marine setting during Tertiary III times and younger (refer Figure 8). Coastal fluviomarine conditions were established in PM 12 area while in PM 6 area located more distal to the marine incursion, sediments were still being laid down in lower coastal plain environment (Figure 22). This sequence is also characterised by a lower sand-prone unit and an upper shale unit (Figure 13).

No significant change in depositional environments could be detected during Tertiary IV times when compared to Tertiary III (Figures 23 and 24). However due to an obvious depletion of coarse clastic inputs and combined with the continued encroachment of the ancestral South China Sea, a substantial decrease in sand percentages can be observed throughout the entire sequence of Tertiary IV in both PM 6 and PM 12 areas (Figure 13).

TERTIARY V AND VI (MIDDLE MIOCENE TO EARLY LATE MIOCENE)

Towards the end of Tertiary VI times, massive regional uplift, compressive folding and faulting occurred in the PM 12 area. Former depocentre areas began to show positive growth and the initiation of this pervasive structuring seemed to have progressed northwesterly from one anticlinal trend to another (Ng, 1985) (Figure 25). This tectonic activity could have started as early as Tertiary III times in Block PM 12 area which could have therefore undergone maximum uplift when compared to areas north of it.

The uplift and subsequent erosion produced a striking regional unconformity in PM 12 which has been dated as an intra Late Miocene event (Late Tertiary VI times). In this area, a major section of Tertiary V and VI was truncated due to this event. In the Duyong area, truncation of Tertiary V and VI sediments was followed by a period of non-deposition. This unconformity becomes less pronounced towards the northwest of PM 12 and finally disappears in PM 6 (Figure 15b).

By Tertiary V times, coastal fluviomarine conditions were established in Block PM 6 while fluviomarine inner neritic influence had progressed further north of Block PM 12 due to the continued advancement of the ancestral South China sea (Figure 26). However during Tertiary VI times, the coastal fluviomarine and fluviomarine inner neritic influences were reduced. This can be attributed to prograding coastline into a transgressive sea occurring during these times (Figure 27).

PALAEOFACIES OF TERTIARY UNIT III

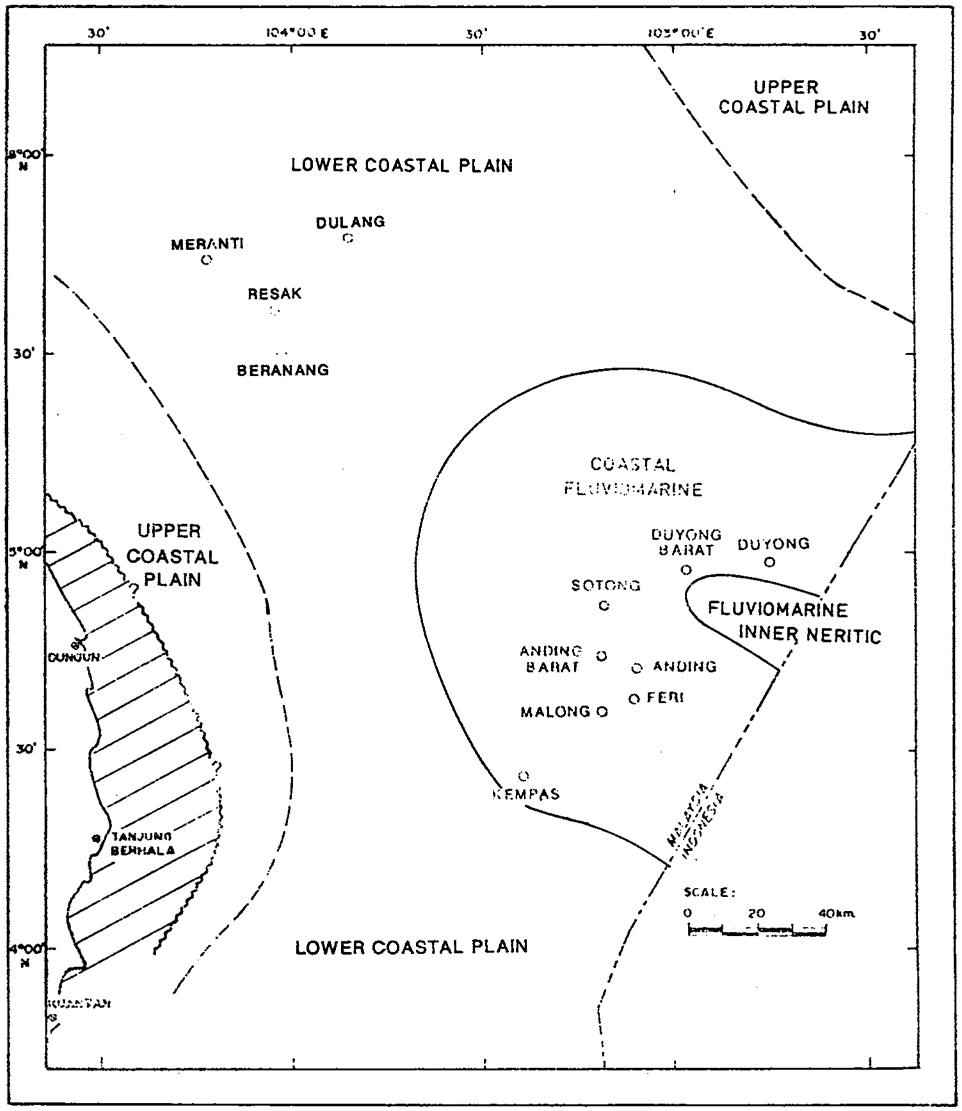


Figure 22: Palaeofacies map of Tertiary Unit III (early Early Miocene). During this time, the first major marine influence was felt in Block PM 12 while Block PM 6 was marginally affected.

PALAEOFACIES OF TERTIARY UNIT IV A

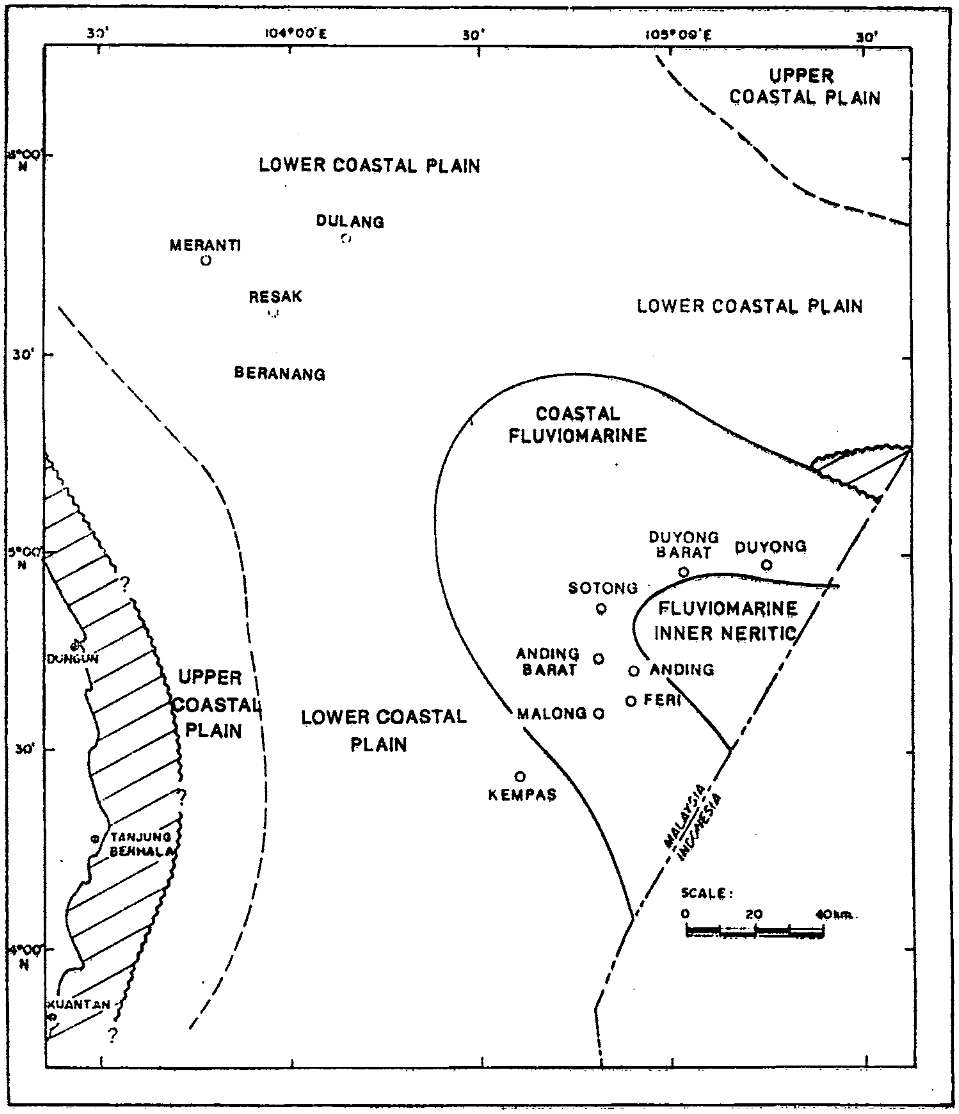


Figure 23: Palaeofacies map of Tertiary Unit IVA (middle Early Miocene). Depositional environments during this time remained similar to those in Tertiary III.

PALAEOFACIES OF TERTIARY UNIT IVB

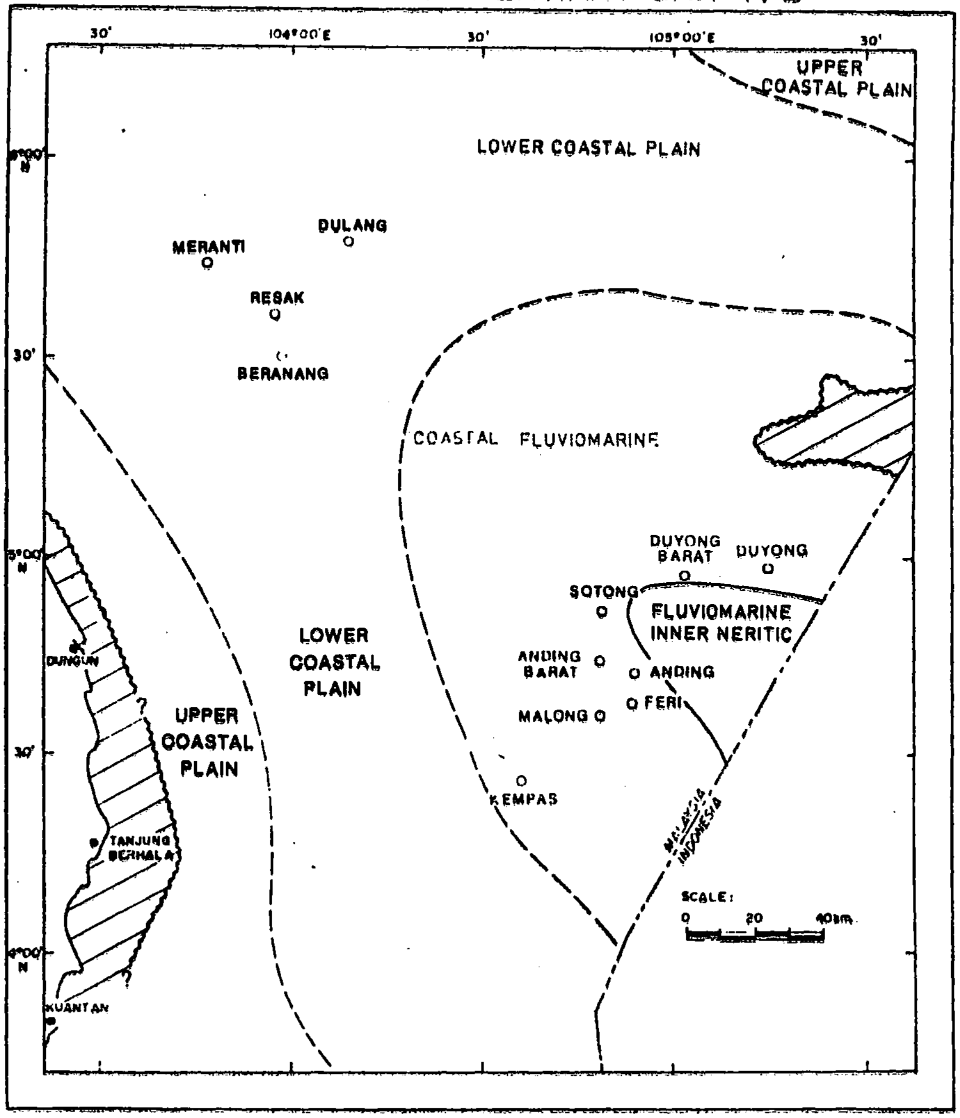


Figure 24: Palaeofacies map of Tertiary Unit IVB (middle to late Early Miocene). Note the encroachment of the coastal fluviomarine belt towards PM 6 area.

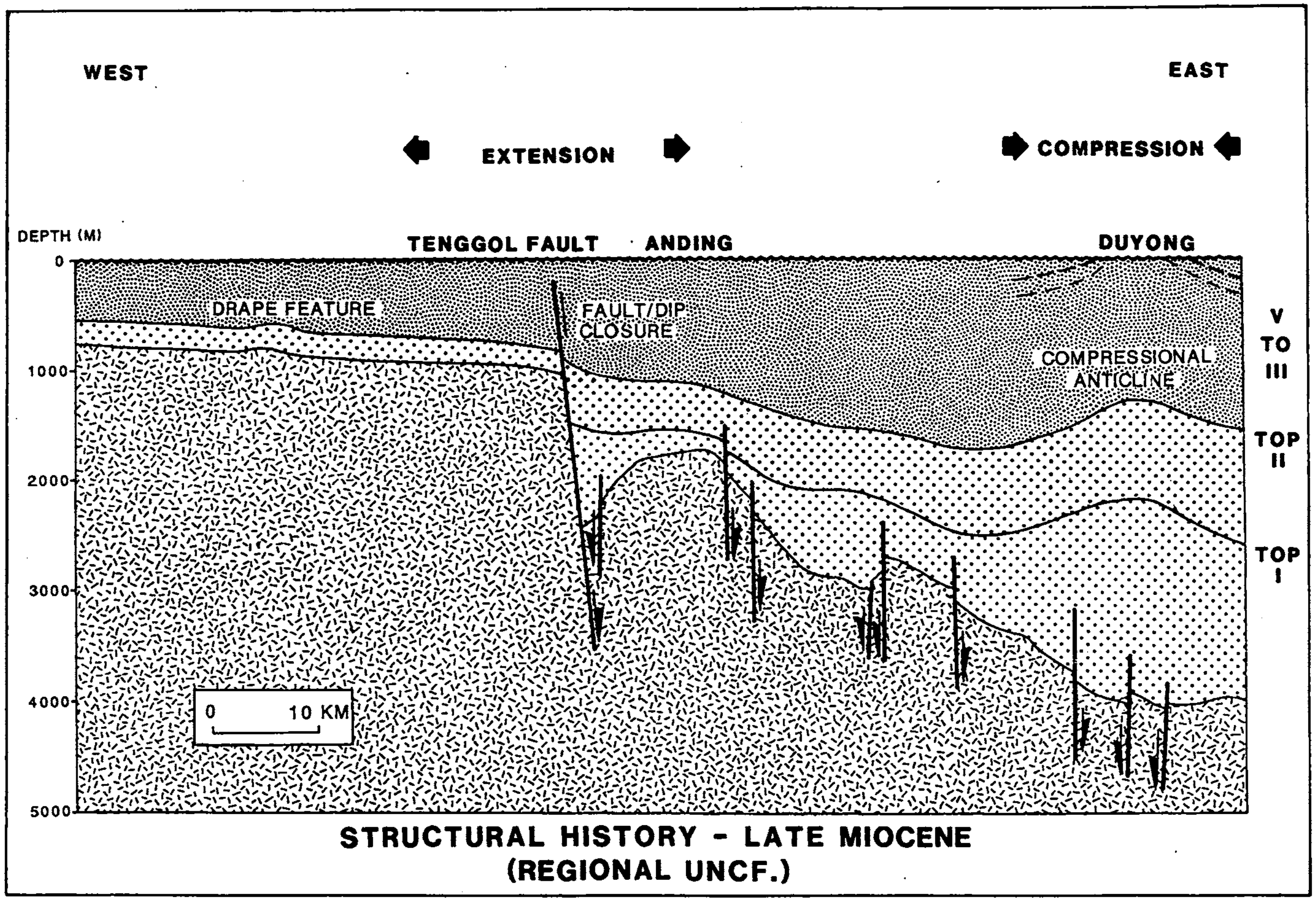


Figure 25: East-west structural reconstruction during Late Miocene times indicating pervasive structuring in Duyong area (after Ng. T. S., 1985).

PALAEOFACIES OF TERTIARY UNIT V

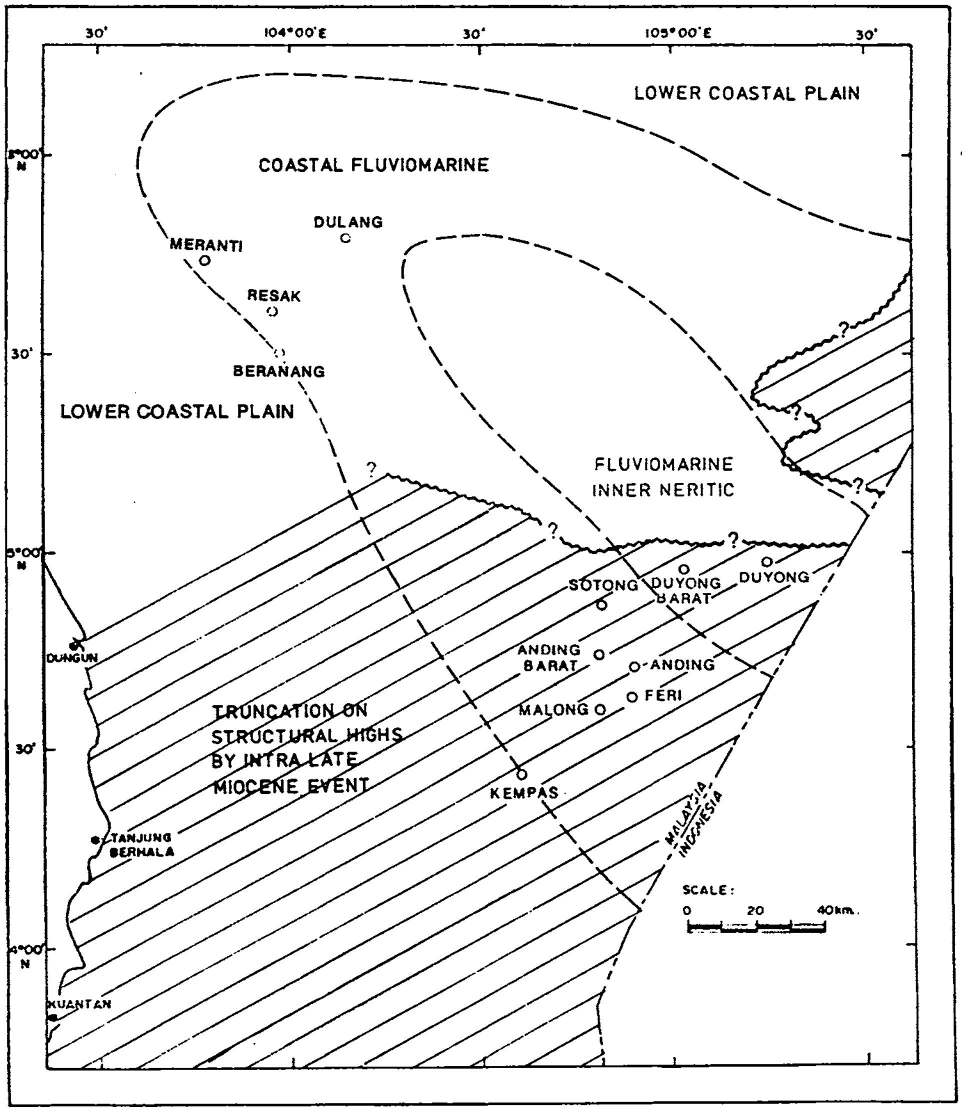


Figure 26: Palaeofacies map of Tertiary Unit V (early middle Miocene).Observe the fluviomarine influence stretching over PM 6 area.

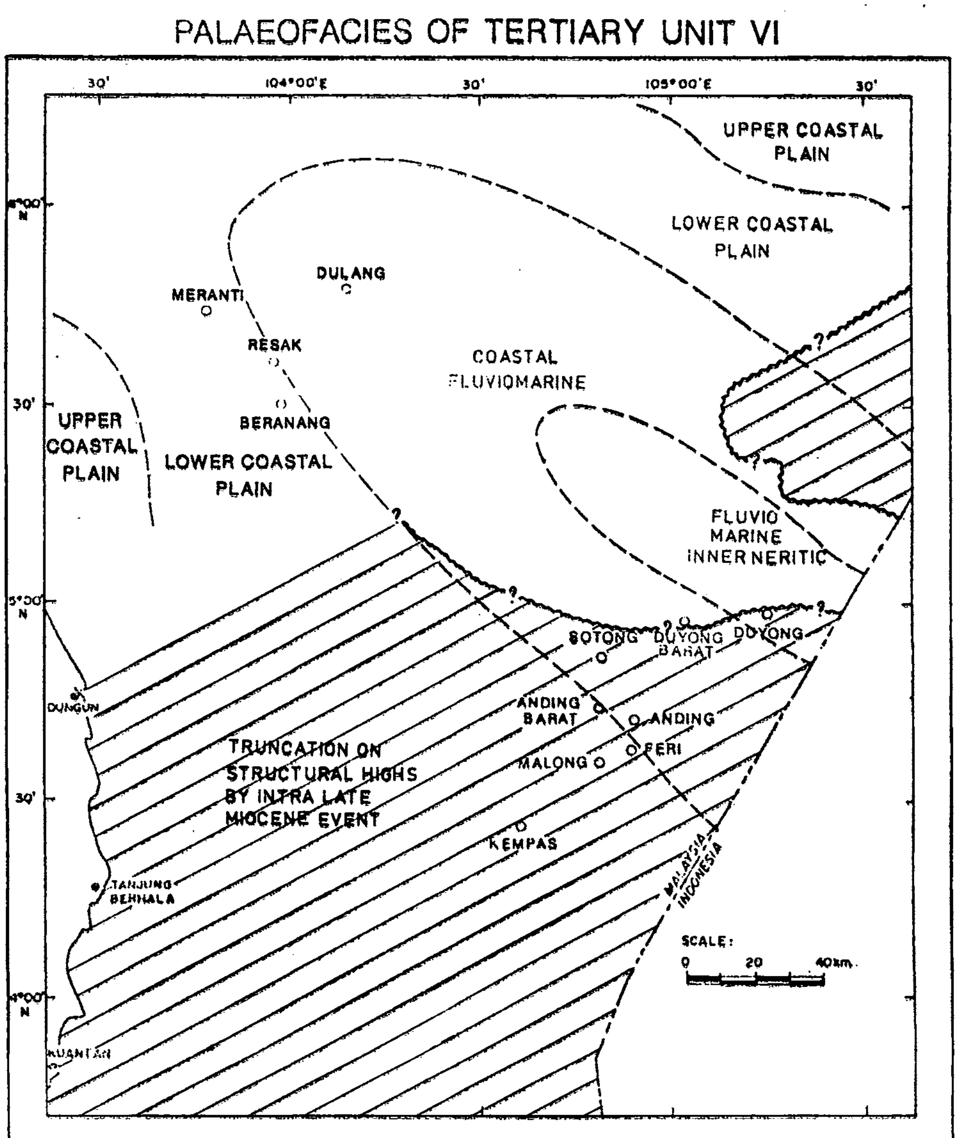


Figure 27: Palaeofacies map of Tertiary Unit VI (middle to early Late Miocene). Note the slight retreat of the fluviomarine belt south-eastwards.

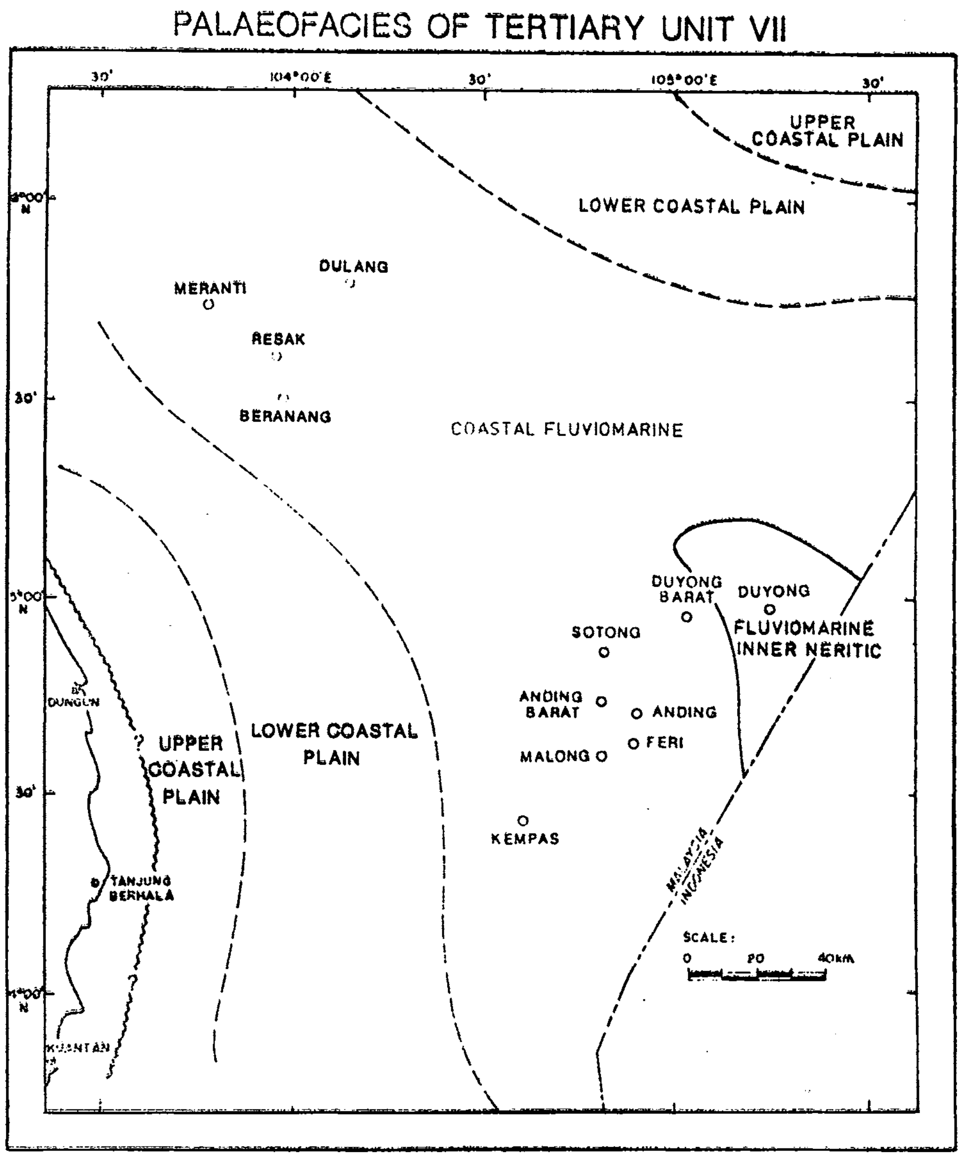


Figure 28: Palaeofacies map of Tertiary Unit VII (middle Late Miocene). The coastal fluviomarine belt has now transcended over the entire basin.

PALAEOFACIES OF TERTIARY UNIT VIII

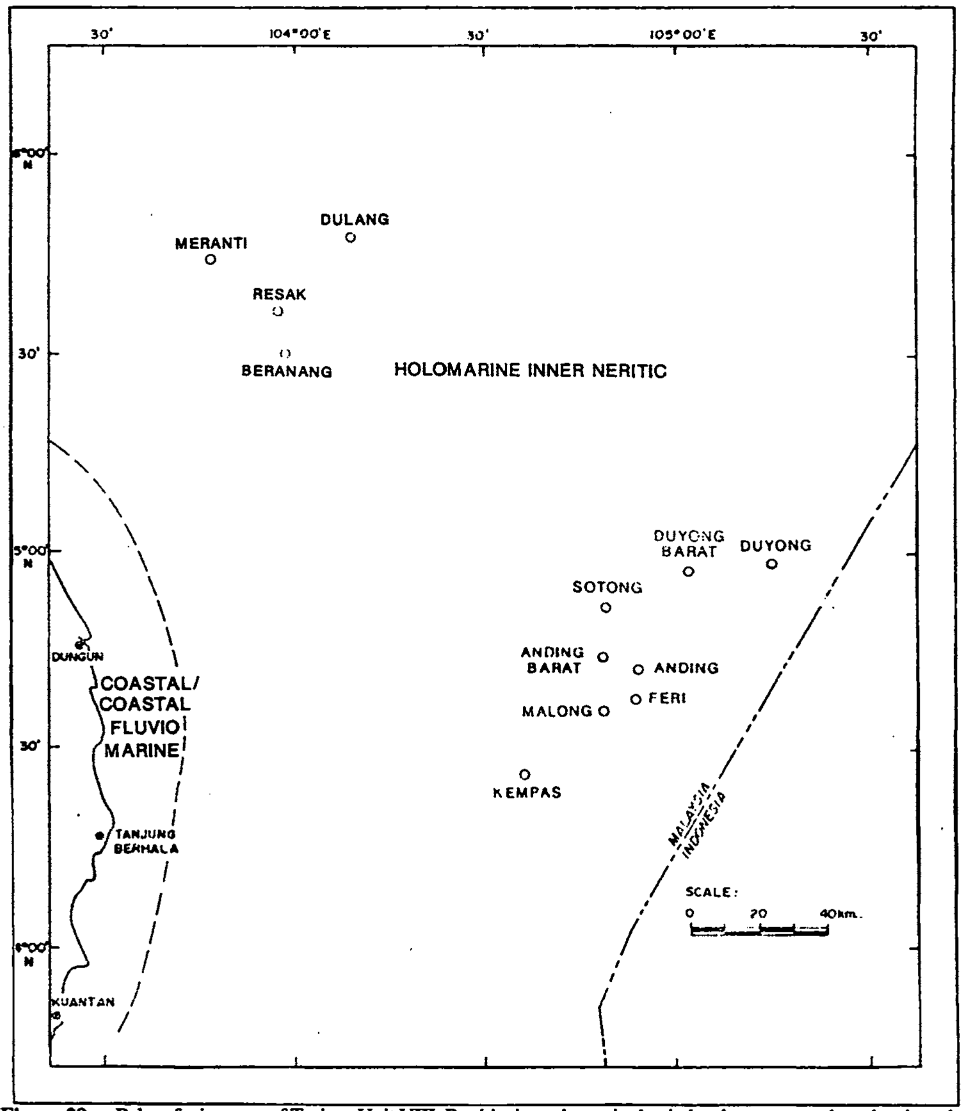


Figure 29: Palaeofacies map of Teriary Unit VIII. By this time, the entire basin has been covered predominantly by holomarine inner neritic sediments.

TERTIARY VII AND VIII (MIDDLE LATE MIOCENE TO RECENT)

Sedimentation within coastal fluviomarine environment continued to dominate during Tertiary VII times in both PM 6 and PM 12 areas with the exception of the Duyong area where fluviomarine inner neritic sediments prevailed (Figure 28). Finally in Tertiary VIII times the entire Malay Basin was predominantly covered by holomarine inner neritic sediments until the present time (Figure 29).

CONCLUSION

The establishment of the eight stratigraphic units in the Oligocene to Recent sedimentary sequence has provided a practical stratigraphic scheme for regional geological correlation and seismic mapping. The present stratigraphic framework has also facilitated the integration of geological, geophysical and geochemical data for regional evaluations and has significantly contributed to a better understanding of the sedimentary history of PM 6 and PM 12 areas in the Malay Basin.

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