Miocene-Pliocene paleogeographic evolution of a tract of Sarawak offshore between Bintulu and Miri

Eros Agostinelli, Mohamad Raisuddin bin Ahmad Tajuddin,
Eugenio Antonielli and Mohamad bin Mohd Aris

Agip (Malaysia) Ltd., Malaysian Branch

Abstract: A data base consisting of 5,200 km of seismic lines and data from six wells has been utilized to recontruct the evolution of the main environments of sedimentation in a tract of the Sarawak Offshore between Bintulu and Miri.

A sequence of six maps shows the progressive shifting through time of the position of the paleo-coastline in the area as well as that of the major deltaic systems.

The presence of a morphological paleoescarpment along the so-called West Baram line is evident since at least the Middle Miocene. The data suggest its presence also in older ages but it cannot definitely be demonstrated with our data set.

The basin to the northeast of this paleoescarpment has been filled mainly during the Late Miocene-Pliocene by the deposits associated with the progradation of the paleo-Baram delta system.

The spatial distribution of the different environments of sedimentation is at any time controlled by the position of the coastline (input of sediments) and by the presence of the paleoescarpment. This situation is still reflected by the present geography of the area.

INTRODUCTION

The area studied in this paper is covered by the Block SK-9 (Fig 1) currently explored for oil and gas by a joint-venture composed of Agip (Malaysia), Operator (60%), OMV (25%) and Petronas Carigali (15%).

The block is located in the Sarawak basin and spans over the transition between the Balingian, Luconia and Baram delta Provinces, so being in an optimal location to understand, through its study, the relationship between these geological provinces.

The sedimentary sequence of this area is composed of a thick clastic prism, ranging in age from Late Cretaceous (?)-Eocene to Recent deposited on a relatively shallow water continental shelf facing, at least from the Paleocene (Ru and Pigott 1986) a deep water basin toward the north-northeast.

Interbedded in this clastic sequence are two main episodes of carbonatic sedimentation. The first one in the Late Oligocene-Early Miocene, the second one in the Middle to Upper Miocene.

This sedimentary sequence is part of a foredeep basin northward of a collision zone between microplates. Part of this basin was finally deformed and uplifted during the collision.
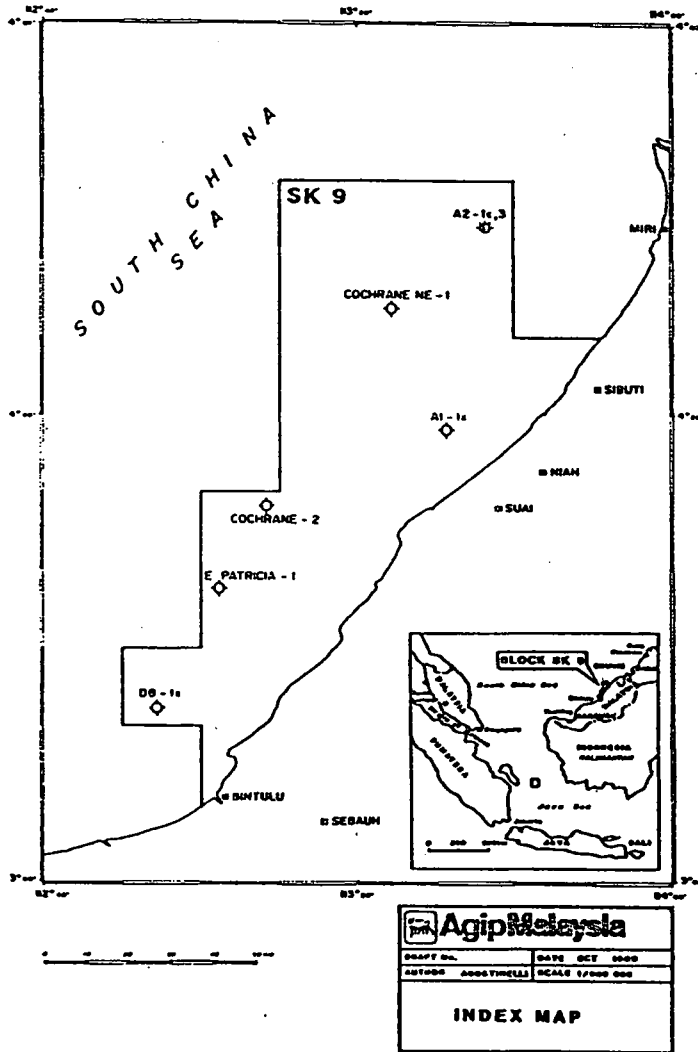
Figure 1: Index map

A good and easily applicable stratigraphy to this thick monotonous sequence has proven quite difficult to realize, because of the mostly coastal to very shallow water environments of sedimentation with subsequent lack of widespread biomarkers.

Also the sequence stratigraphy concepts developed by the Exxon school (Vail, 1987; Van Wagoner *et al.* , 1987) are not easily applicable, at least in the studied area, due to the lack of evident Type 1 depositional sequence boundaries.

In fact, decreases of relative sea level in the area seem to have never been large enough to reach the shelf depositional break, so never exposing large tracts

of platform to erosion. Hence, only tectonically controlled erosional surfaces of limited areal extent are present.

To overcome this problem, Shell devised a stratigraphy based on the cyclicity of the basin fill record. The entire sequence has been so divided into major Cycles (Ho, 1978). Each Cycle is described as a main regressive sequence interrupted by a basinwide transgression.

The same concepts have been now developed as the so called "genetic stratigraphic sequences in basin analysis" by Galloway (Galloway, 1989).

In our effort to reconstruct the paleogeographical evolution of this tract of the Sarawak Offshore we have applied the tools of the seismic stratigraphy to the analysis of seismic lines and wells, but utilizing the recognition of flooding surfaces to subdivide the sedimentary column.

METHODOLOGY

A data base consisting of some 5,200 km of new migrated seismic lines and six wells has been utilized in the study. Data from the wells consist of original logs, computer interpretation of lithologies, interpreted stratigraphies and paleoenvironments of deposition from microfossil content.

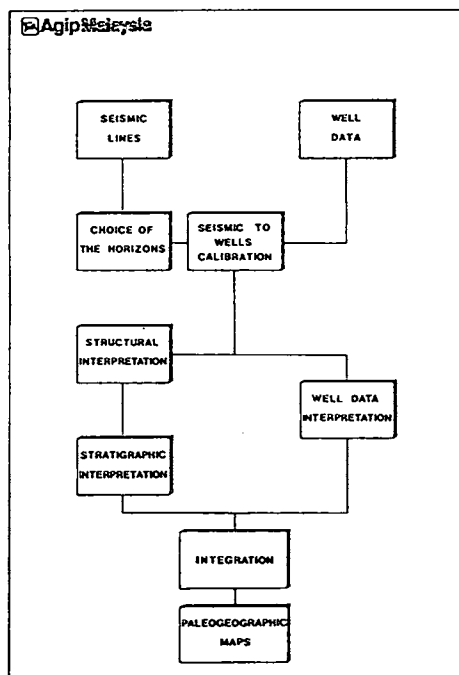The methodology followed is illustrated in Fig 2.

Figure 2 : Methodology followed in the study

The seismic reflectors were chosen as to follow major transgressive events recognisable also in the wells and interpreted as top of relevant Cycles or sub-cycles as for Ho Kiam Fui's classification (Ho, 1978).

Then seismic lines and well data were independently interpreted for paleoenvironment reconstruction and the two interpretations were finally integrated.

The final paleogeographic maps show the situation at the top of each Cycle.

PALEOGEOGRAPHIC MAPS

The six maps so obtained show the paleogeographic evolution through the Miocene and depict the various environments of sedimentation. No major changes are interpreted to have occurred during the Pliocene. Through the analysis of the maps it is possible to identify major changes caused by the various factors controlling the distribution of the environments of sedimentation: tectonic, subsidence, eustatic se-level variations, climate, and sediment input.

This Cycle is characterised, in the interpreted area, by two physiographic elements: a major delta to the southwest and a carbonate platform to the northeast (Fig. 3)

Lower coastal plain to coastal environments are quite widespread in the southwest, and the paleocoastline was oriented more or less orthogonally to the present one.

Going from SW to NE, the environment of deposition changes from transitional, sand rich, to more marine. shale rich, in a very gradual way.

In the central part, the clastic environments grade into an area of extensive carbonate deposition. These limestones, situated far away from clastic sources, are interpreted to be the equivalent of the outcropping Subis Limestone Formation onshore Sarawak.

The carbonatic platform can be subdivided into two sub-environments : a barrier with presence of buildups, and a backreef. The two sub-environments are divided by a sequence of carbonatic ramps.

The depositional model can be interpreted as that of a rimmed shelf (Read 1985).

In the backreef environment, the presence of patch reefs of limited thickness and extension is sometimes visible. The ramps separating the two environments were probably formed during successive pulses of relative sea-level rise that culminated in the final drowning of the carbonatic platform in the lower part of Cycle II, drowning aided by the increasing input of clastics into the basin.

This stage of carbonatic deposition has been recognised as widely distributed in South East Asia (Fulthrope et al., 1989) during the so-called Neogene Trans-
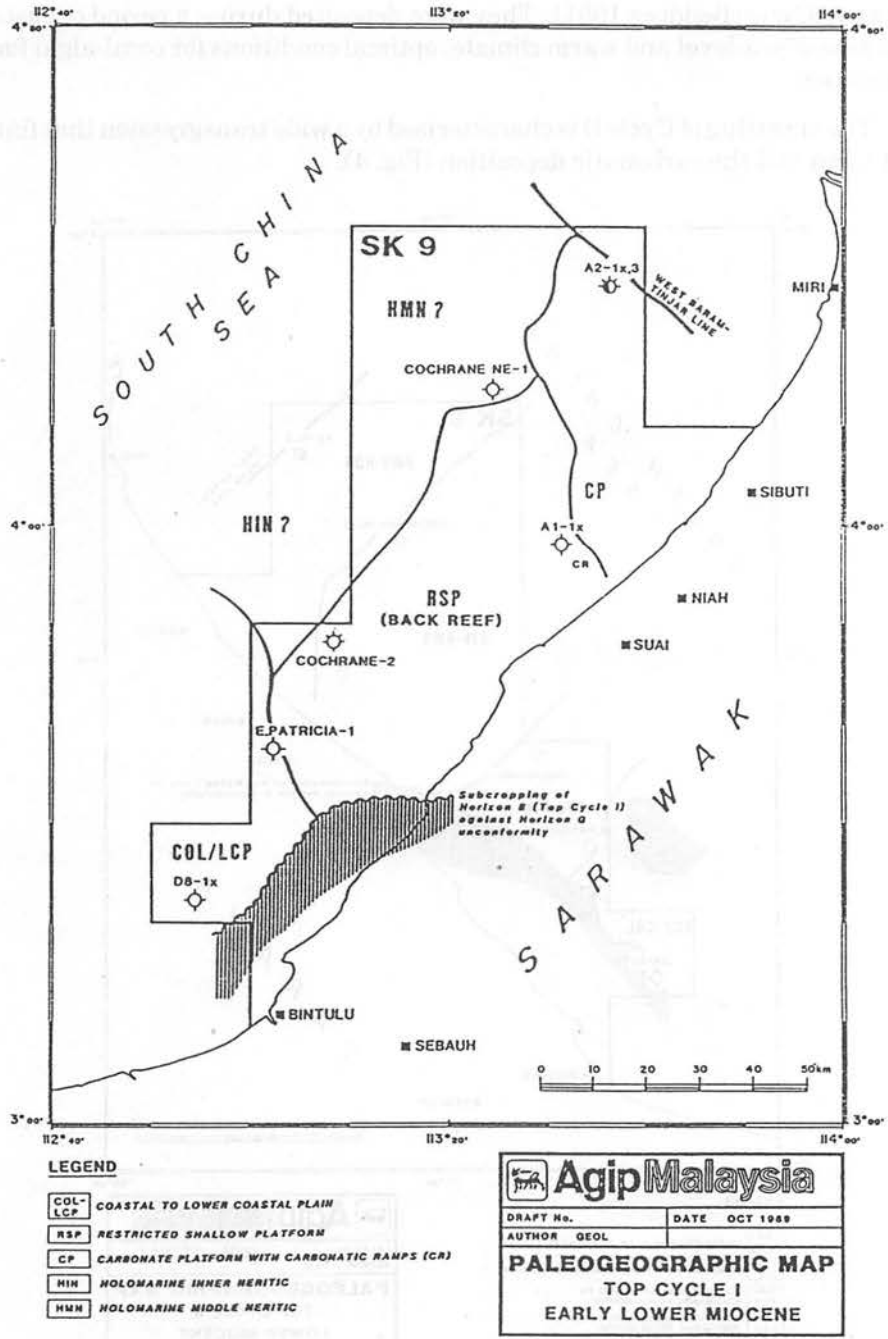
Figure 3 : Paleogeographic map at Top Cycle I. The eroded area is due, as in all the following maps, to the uplift subsequent to the tectonic phases of Upper Miocene and Pliocene.

gressive Cycle (Beddoes 1981). They were deposited during a period of eustatic increase of sea-level and warm climate, optimal conditions for coral-algal facies deposition.

The onsetting of Cycle II is characterised by a wide transgression that finally put to an end the carbonatic deposition (Fig. 4).
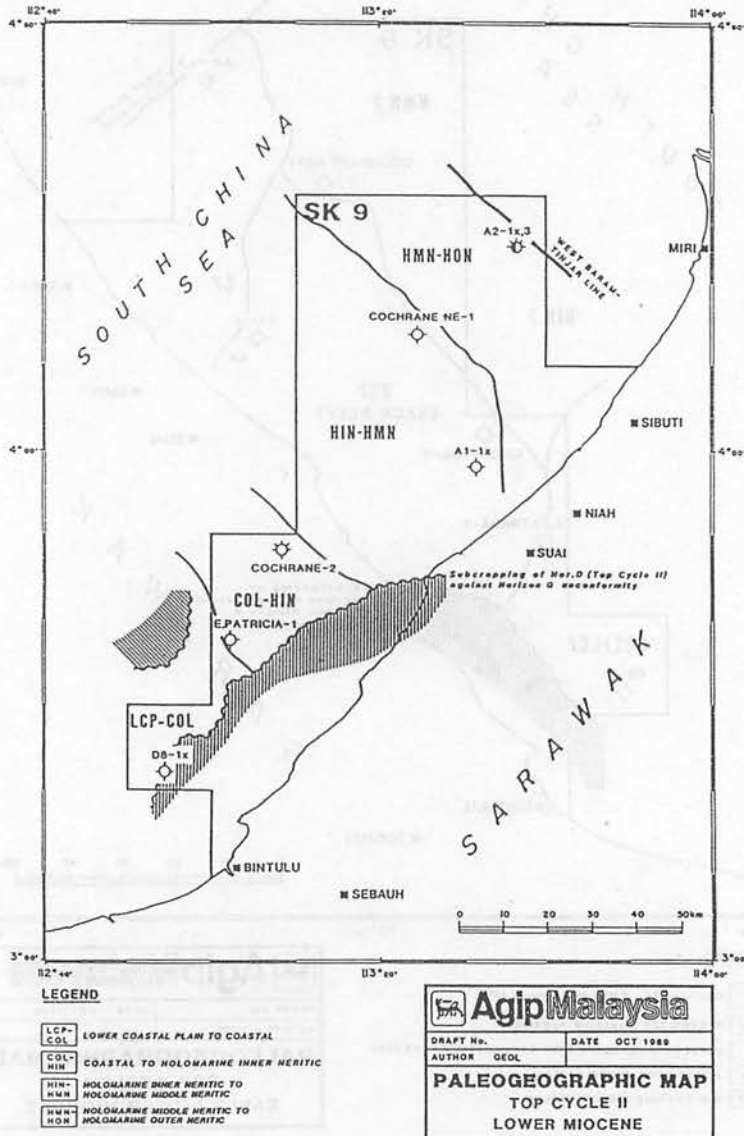

Figure 4 : Paleogeographic map at Top Cycle II. The base of Cycle II transgression has drawn the carbonate platform.

A regressive cycle started with a slow progradation of clastics sediments in a northeastern direction. The progradational pattern is characterised by a very low angle. The sediments were deposited on a broad and shallow shelf gently deepening toward the northeast.

As in Cycle I, the Cycle II paleocoastline is oriented roughly at right angle to the present coastline, with the source of sediments located outside the studied area.

The factors that mainly controlled the distribution of the environments of sedimentation seem to be eustatic sea-level changes and subsidence.

A deeper water basin is already present toward the northeast. The presence and influence of the West Baram-Tinjar Line during Cycle II could not be determined because of the lack of information in that area and at that depth in our data.

Another wide transgression pulse marks the end ot Cycle II (Fig. 5). Widespread shale deposition occurred on almost all the area of study.

The subsequent regressive cycle shows strong differences in comparison with the previous one. having a paleocoastline oriented roughly parallel to the present one. This is demonstrated by the presence of coast to coast fluviomarine environments in the southeast. A small delta was also probably present in the Suai-Sibuti area.

The reorganisation of the coastline was probably due to the effect of the migration toward the northwest of the overthrusts created by the collision between the Miri and Sunda microplates. The collision caused the emergence of new land that was eroded and whose sediments were deposited by streams in the adjacent foredeep basin.

The paleogeographic map of Cycle III shows also a strong bathymetric control in the northeast corner of the area. The environments of deposition become of deeper water and the transitions between the various environments become narrow. This strongly suggests the presence of a quite steep gradient in the water depth in that direction, in coincidence with the area were the West Baram-Tinjar Line is interpreted to be present.

The same general paleogeography established during Cycle III is present also during Cycle IV, with one major difference caused by the onsetting of carbonatic deposition in the northern part of the area of study (Fig. 6).

This second episode of carbonatic deposition follows more or less the pattern that occurred during Cycle I. The area covered by carbonates in this part of the basin was less widespread because of the more proximal location to the coastline.
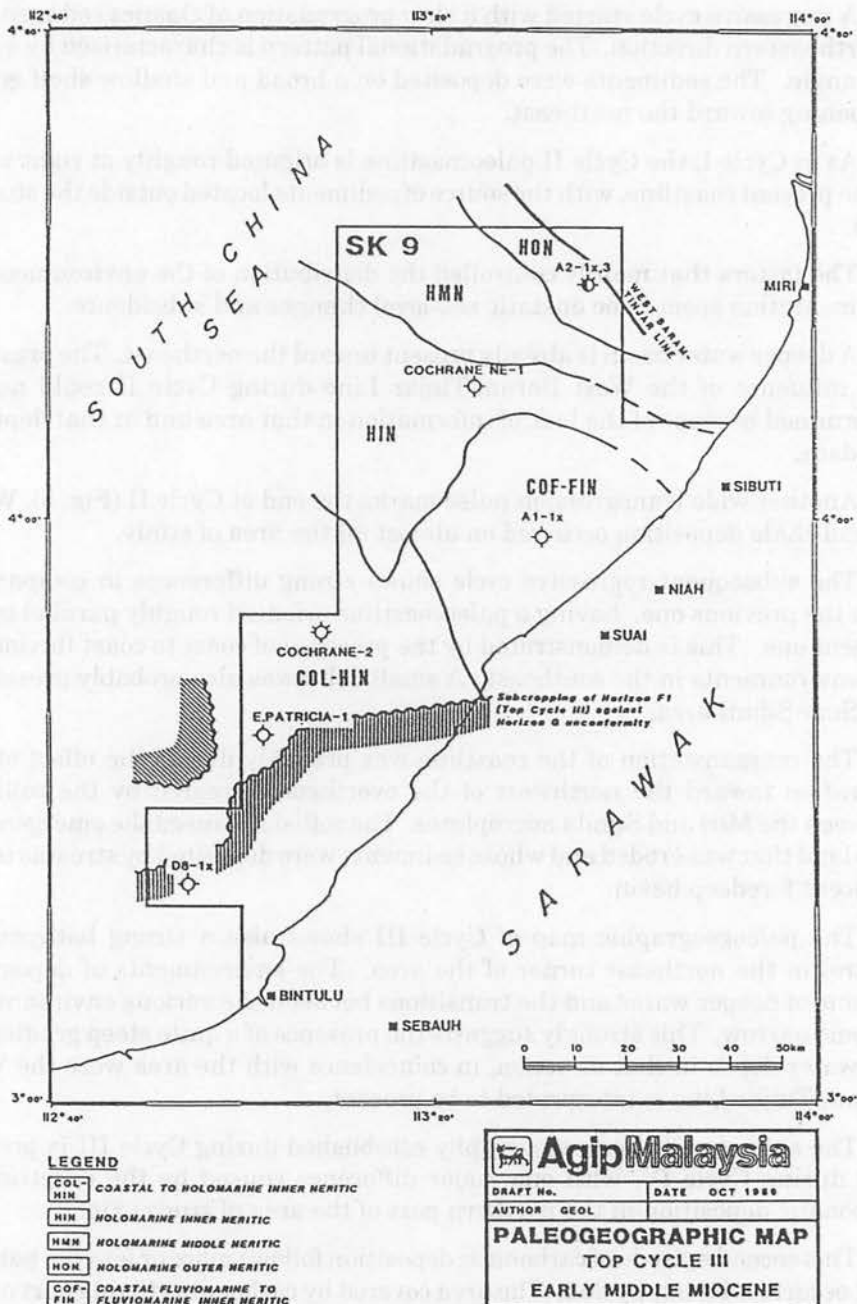
Figure 5 : Paleogeographic map at Top Cycle III. After another major transgression the paleo-coastline is reorganised parallel to the present one and there ia a shifting in the position of the main delta.
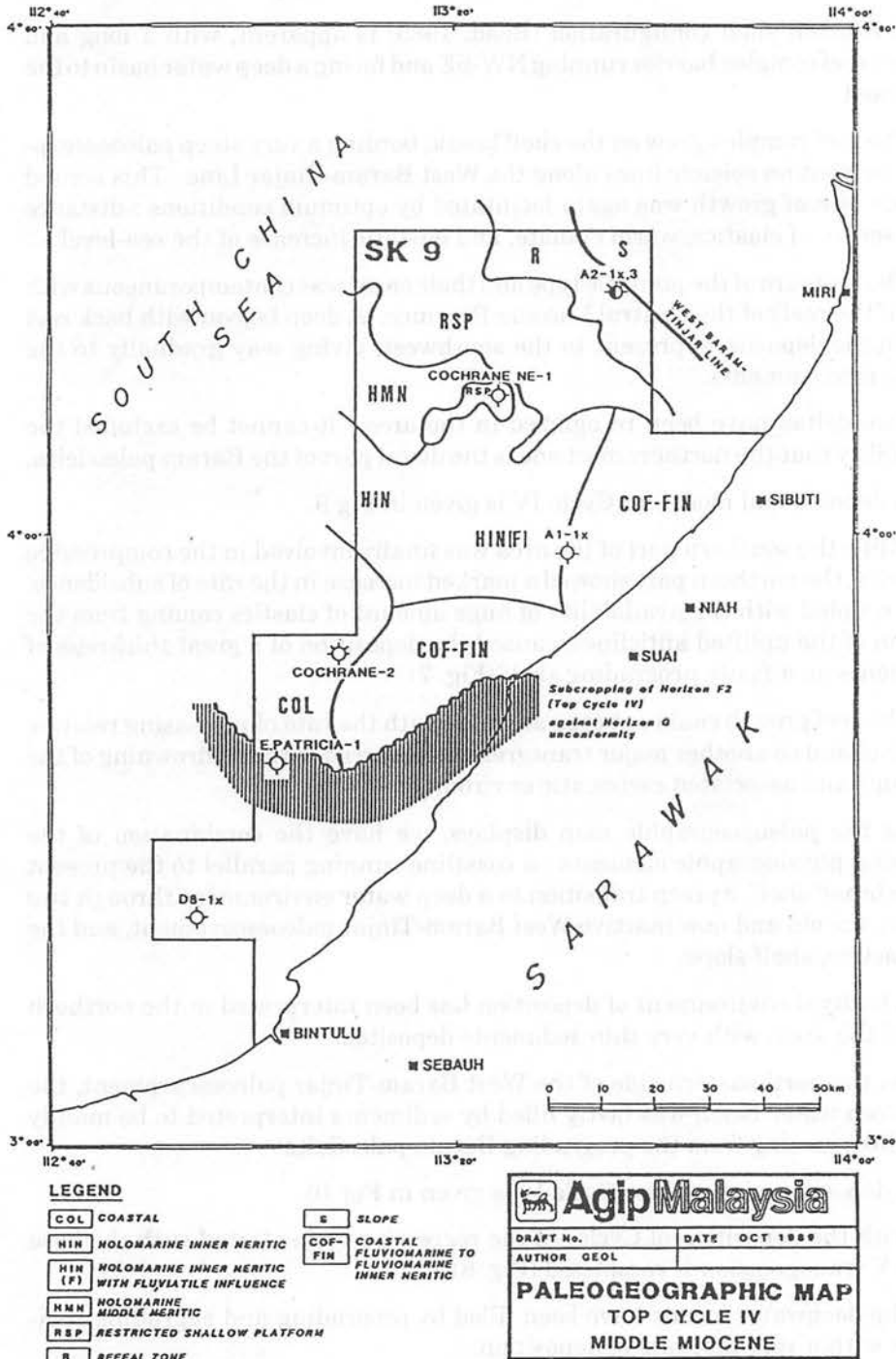
Figure 6 : Paleogeographic map at Top Cycle IV. Second period of carbonate deposition.

A rimmed shelf configuration (Read, 1985) is apparent, with a long and narrow reef complex barrier running NW-SE and facing a deep water basin to the northeast.

The reef complex grew on the shelf break, bording a very steep paleoescarpment evident on seismic lines along the West Baram-Tinjar Line. This second episode of reef growth was again facilitated by optimum conditions : distance from source of clastics, warm climate, and eustatic increase of the sea-level.

The reefs are of the pinnacle type and their onset was contemporaneous with that of the reefs of the Central Luconia Province. A deep lagoon with back reef carbonatic deposits is present to the southwest, giving way gradually to the clastic environments.

Two deltas have been recognized in the area. It cannot be excluded the possibility that the northernmost one is the distal part of the Baram paleodelta.

A depositional model for Cycle IV is given in Fig 9.

While the southern part of the area was finally involved in the compressive tectonics, the northern part showed a marked increase in the rate of subsidence. This, coupled with the availability of huge amount of clastics coming from the erosion of the uplifted anticlines, caused the deposition of a great thickness of sediments on a fastly prograding shelf (Fig. 7).

The reef growth could not cope anymore with the rate of increasing relative sea-level and so another major transgression occurred with the drowning of the buildups and associated carbonatic environments.

As the paleogeographic map displays, we have the combination of the following physiographic elements : a coastline running parallel to the present one, a broad shelf, a steep transition to a deep water environment through two slopes: the old and now inactive West Baram-Tinjar paleoescarpment, and the new, active, shelf slope.

A bathyal environment of deposition has been interpreted in the northern part of the area, with very thin sediments deposited.

On the northeastern side of the West Baram-Tinjar paleoescarpment, the very deep water basin was fastly filled by sediments interpreted to be mainly turbidites coming from the prograding Baram paleodelta.

A depositional model for Cycle V is given in Fig 10.

With the deposition of Cycle Vu the regressive cycle started with the base Cycle V transgression is completed (Fig. 8)

The deepwater basins have been filled by prograding and aggrading sediments with a very fast rate of deposition.
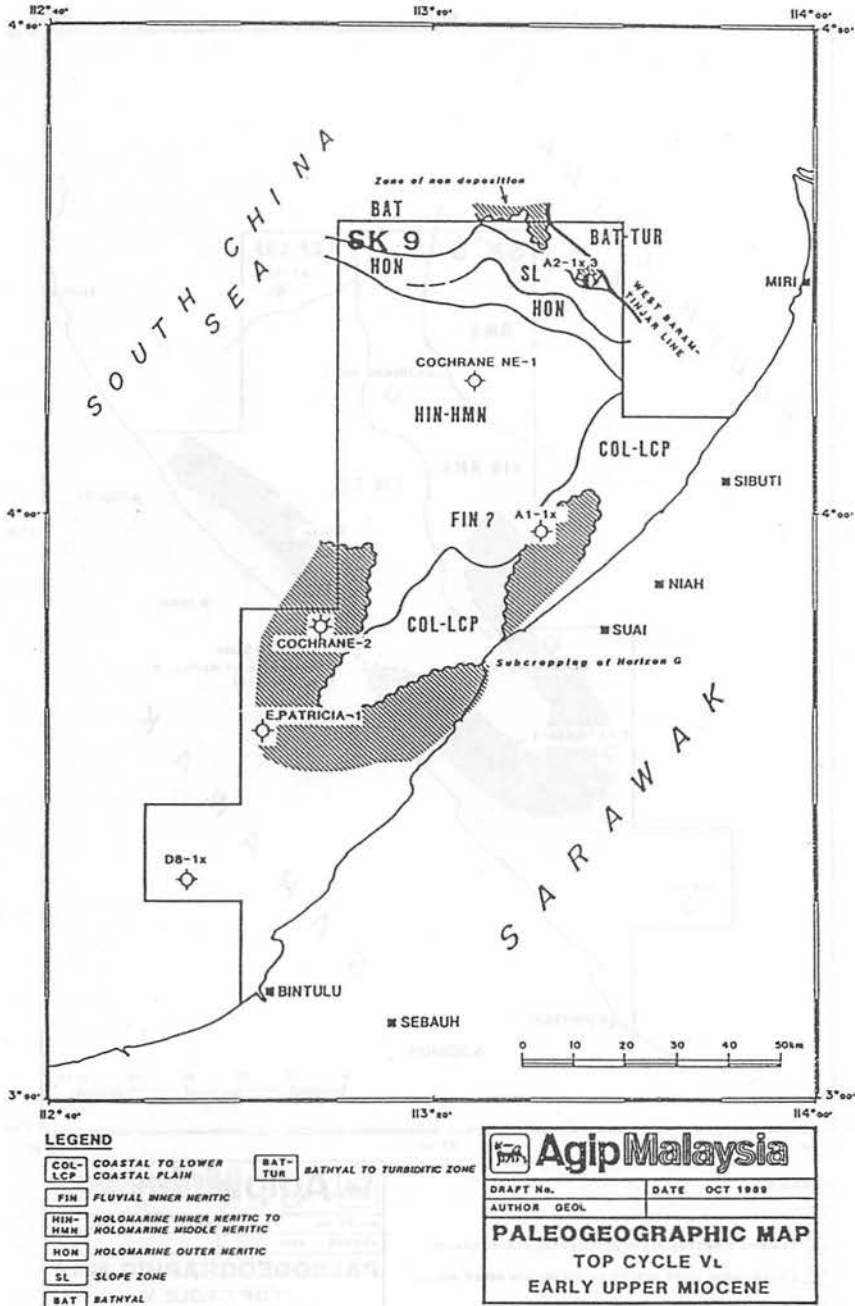
Figure 7 : Paleogeographic map at Top Cycle V. A major transgression has submerged the reefs. Clastic progradation starts again.
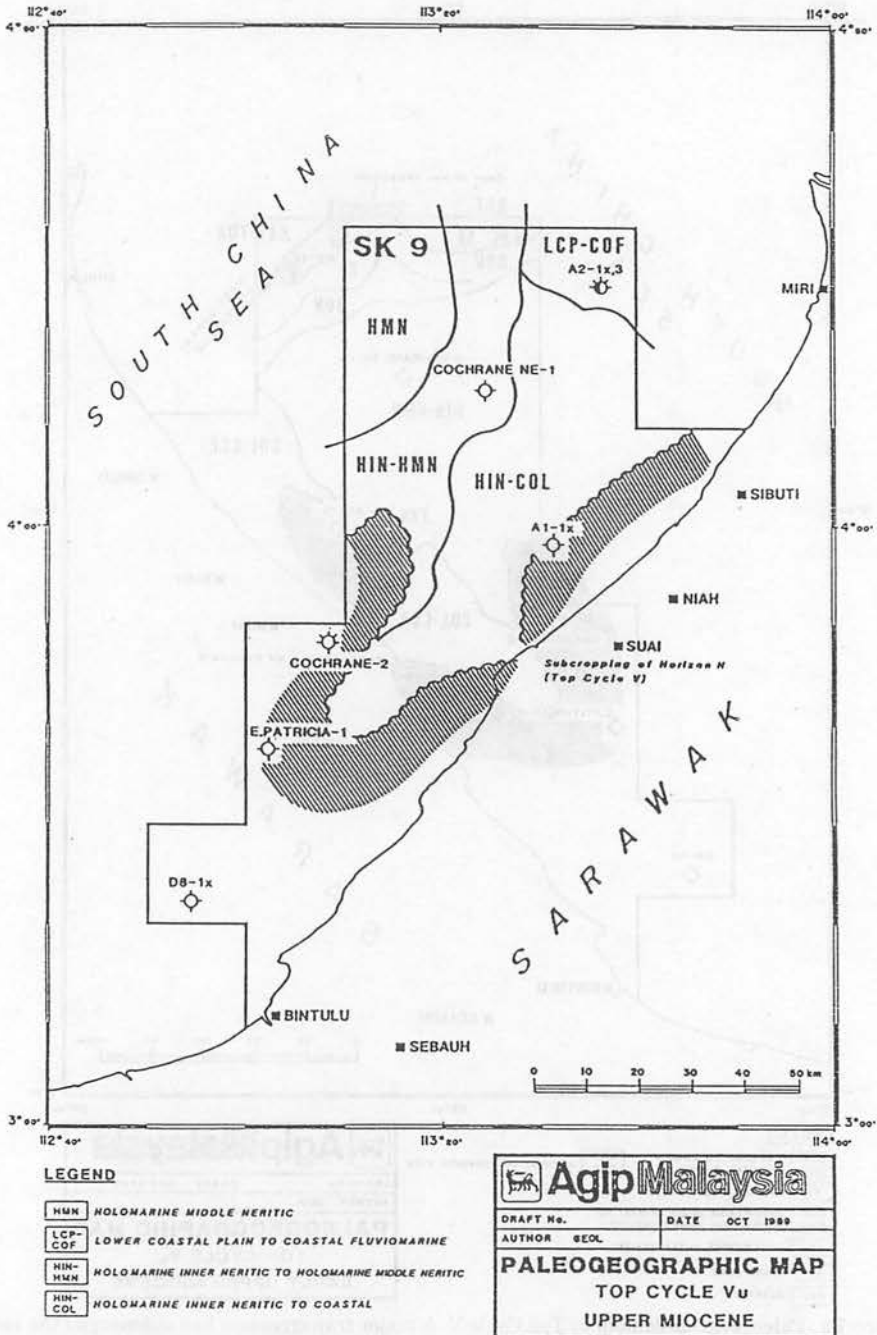
Figure 8 : Paleogeographic map at Top Cycle Vu. A major transgression has submerged the reefs.
Clastic progradation starts again.

The Baram paleodelta is prograded within the area of study filling the deep water basin and shifting it in a northwesterly direction (Fig 11).

DISCUSSION

The paleogeography of this area of the Sarawak basin shows distinctive phases of evolution during which the facies distribution was controlled by different factors.

During Cycles I and II the paleocoastline was arranged at about a right angle to the present one.

The presence and action of the West Baram-Tinjar Line cannot be identified with our data set in this interval. Anyway, the basin deepened northeastward. A carbonate platform was present during Cycle I due to optimal reef growing conditions and was drowned during the bottommost part of Cycle II in successive pulses. Ramps on drowned shelf (Read, 1985) were so formed and a carbonate platform of the backstepped rim type developed.

After the transgression Cycle II was deposited in a clastic ramp on drowned shelf, with a very gentle prograding pattern.

Starting from Cycle III the paleocoastline is oriented more or less as the present one (i.e. SW-NE), due to the advancing orogenic front from the southeast.

Two major elements control the facies distribution: position of the coastline and so direction of input of clastic material, and bathymetric control, with increasing water depth in a northeast direction. Both are at the end controlled by tectonics.

The presence of a steep paleoescarpment along the West Baram-Tinjar Line is evident on our data base from the Middle Miocene. Anyway it cannot be excluded, and on the contrary is even probable, that the line was present also in older times (Lower Miocene and older). In fact the overall facies arrangement during Cycles I, II and III points unequivocally toward a deeper water basin toward the northeast.

During Cycle IV, due to another period of optimal reef growing conditions, carbonate sedimentation resumed in the area.

The carbonate platform was intially of the rimmed shelf type (Read, 1985), changing according to the various locations from "bypass margin gullied slope" to "bypass margin escarpment" to "erosional margin".

The persistent increase of relative sea-level transformed it to a raised rim. The rim was composed of isolated pinnacles with deep water channels in between them. These deepwater channels allowed water circulation between the "ocean"

and the deeply submerged lagoon. The latter gave way landward to a clastic environment (Fig 9).

DEPOSITIONAL MODEL AT TOP CYCLE IV (MIDDLE MIOCENE)
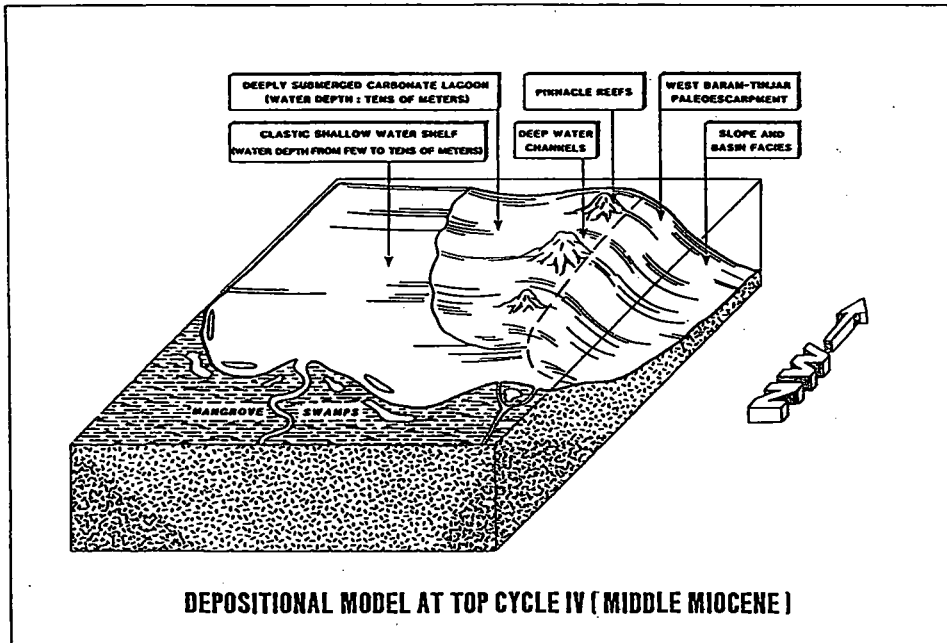
Figure 9 : Depositional model at Top Cycle IV. The model shows the interplay between coastline orientation and West Baram-Tinjar Line during a period of reef growth. The model is that of an incipient drowning-rimmed shelf (Read, 1985)
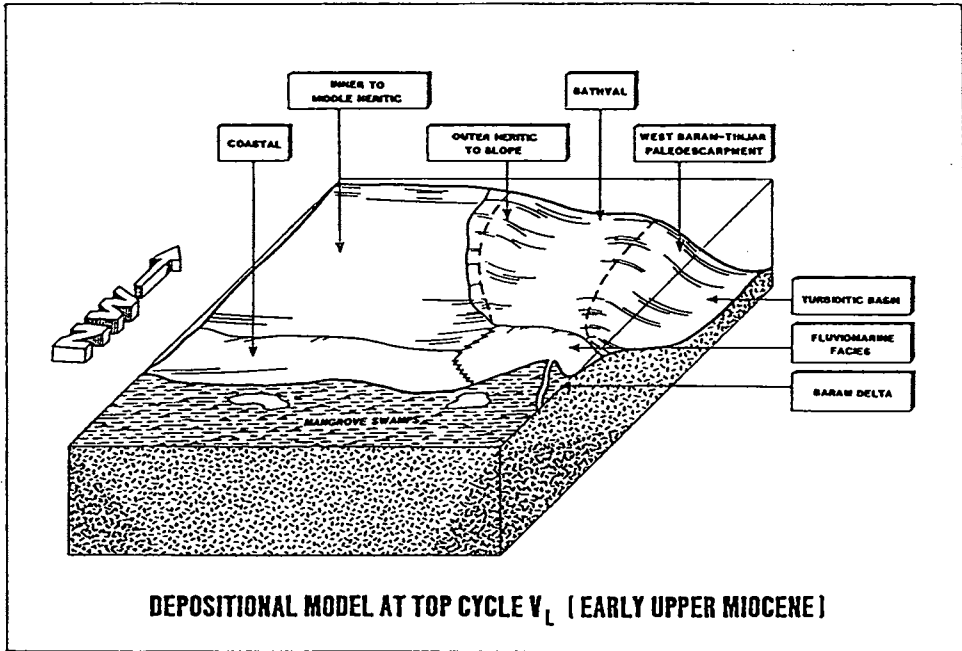
The base Cycle V transgression, that definitely drowned the reefs in the area, seems to be a combination of eustatic increase of sea-level and increased rate of subsidence. Such an increase was probably a response to the loading of the lithosphere caused by overthrusts created during an almost synchronous tectonic phase onshore.

Subsequently a clastic ramp on distally steepened drowned shelf formed (Fig 10), starting to prograde and aggrade rapidly, due to the enormous amount of clastics available through the erosion of the uplifted anticlines.

Two slope breaks were present : the active one, through which water depths reached some hundred of meters, and the inactive old one. To the northeast of the inactive slope water depth was even deeper.

The progradation of the shelf clastic facies was achieved through mixed oblique-sigmoidal patterns with a very fast rate of sedimentation.

To the northeast of the West Baram-Tinjar Line the deep water basins were completely filled during Cycle V before by turbidites coming from the advancing Baram paleodelta, then by the paleodelta deposits themselves.

DEPOSITIONAL MODEL AT TOP CYCLE V$_L$ (EARLY UPPER MIOCENE)

Figure 10 : Depositional model at Top Cycle V$_L$.. The model shows the situation after the base Cycle V tranegression has submerged the reefs. The clastic shelf progradation have not yet reached the previous shelf break, that was tectonically controlled. The model is that of a clastic ramp on distally steepened drowned shelf.

At the Miocene-Pliocene boundary all the major deep water basin were filled by the progradation of the clastic shelf and of the Baram paleodelta and marginal marine to shallow marine environments prevailed.
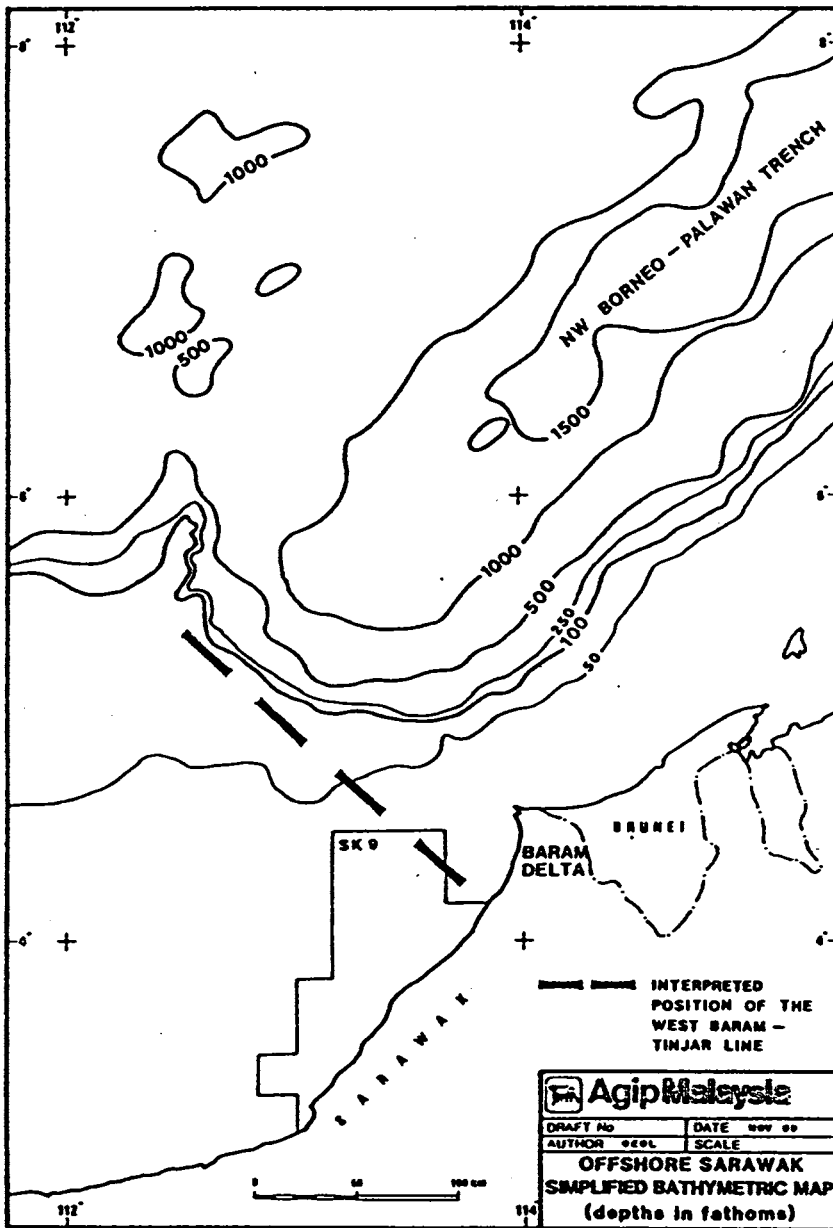
The presence of the West Baram-Tinjar paleoescarpment is still visible today to the northwest of the study area (Fig 11).

There, where the prograding Baram delta has not yet filled the basin, an abrupt escarpment directed NW-SE is clearly evident on bathymetric maps (Fig 11). This escarpment sharply marks the end of the NW Borneo-Palawan Trench.

CONCLUSIONS

Different kinds of observations can be drawn from this study.

● Along its evolution through the Miocene and Pliocene, the area of study has been always located in an interdeltaic bight in the vicinity of major deltas.

● During the Lower Miocene, the major delta was located to the west while from the Middle Miocene it is located to the northeast. This shift

Figure 11: Bathymetric map of offshore Sarawak. The presence of the West Baram-Tinjar paleoescarpment is still evident to the northwest of the area of study, where the progradation of the Baram delta has not yet buried the paleotopography.

This line marks the southwestern termination of the NW Borneo-Palawan trough.

could be tentatively attributed to a major tectonic phase occurred onshore that rearranged the stream pattern, coupled with a major transgression both occurred during the lower part of Cycle III.

- Only minor streams were discharging directly in the area of study after the Middle Miocene.

- The rearrangement of the paleocoastline direction occurred in the Middle Miocene can be interpreted as due to the same tectonic phase that rearranged the stream patterns.

- The subsidence rate during the Miocene was always great enough to overcome the eustatic sea-level variations : as a result no Type 1 unconformities (Van Wagoner *et al.*, 1988) were formed.

- The increase of subsidence and sedimentation rates occurred during the Upper Miocene can be interpreted as due to the loading of the lithosphere by the advancing overthrusts coupled with the availability of an enormous quantity of clastics coming from the erosion of the same overthrusts.

- The two episodes of carbonatic sedimentation were both controlled by optimal conditions eustatic increase of sea-level, distance from clastic sources, warm climate, deep water basin to the northeast.

- The area on which the carbonate platforms grew was probably controlled by the paleoescarpment along the West Baram-Tinjar Line.

- The presence of this paleoescarpment is proven from the Middle Miocene. but also during the Lower Miocene and older times its existence is probable.

- The paleoescarpment is still evident to the northwest of our area, where sediment input has not yet buried the paleotopography.

- The gross facies distribution in the portion of basin studied seems to be mainly controlled by the tectonics. The position of the clastic sources and variations of subsidence rate and sedimentation rate were controlled by it.

- Climate and eustacy played a role in the kind of facies that were deposited.

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