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Dent Group and its equivalent in the offshore Kinabatangan area, East Sabah

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Abstract: Field studies and seismic interpretation have recently been conducted on the Dent Peninsula and its offshore area, which is known as Exploration Block SB-6 of which Western Mining Cooperation (WMC) is the operator. The studies indicated that the deposition of the Dent group, which consists of the Sabahat, Ganduman and Togopi Formations, are similarly formed west to east in the offshore as well as on the onshore area.

On the onshore Dent Peninsula, the Togopi Formation is mainly made up of marls. The Ganduman Formation displays well-preserved outcrops of delta plain deposits grading to shallow marine deltaic and holomarine eastward. The argillaceous Sabahat Formation is interpreted to be a holomarine deposit. In the offshore, on seismic, the Ganduman Formation is represented by the well expressed topset, while the Sabahat is represented by the clinoform and downlap seismic packages. These formations are believed to be derived from an older formation which is not seen on the onshore Dent Peninsula but it is preserved in the offshore Kinabatangan area of Block SB-6. This formation is of age equivalent to the Tanjung Formation which formed the semi-circular basins in onshore Sabah.

INTRODUCTION

The study area is located in the most eastern part of Sabah, covering the Dent Peninsula and the surrounding offshore areas, known as SB 6 Exploration Block (Fig. 1). The block covers a total of 13,760 sq km and comprises 6,300 km^2 in the offshore and 7,370 km^2 in the onshore area. Western Mining Cooperation (WMC) (1991) is the current operator with PETRONAS Carigali as a partner for the block.

Nine wells were drilled in the offshore area by the previous operator including Elf Aquitaine Petroleum Company and Sabah Teiseki Oil Company from the year 1970 to 1975.

A fieldwork in the Dent Peninsula area, organised by WMC, was conducted in February and March 1992. This was aimed to carry out detailed geological fieldwork to verify the geological features interpreted based on the Synthetic Aperture Radar (SAR) and to study the petroleum geology of all the geological formations in the study area (International Stratigraphic Consultant, 1992).

This was followed by the seismo-stratigraphic studies on the regional seismic lines acquired in northern offshore area, aimed at understanding the sedimentary geology and to define the sequence boundaries for all the offshore subsurface "formations" (Walker *et al.*, 1992).

In-house regional studies, involving the above mentioned techniques have led to the establishment of the relationship between the offshore and onshore geology and helped in the understanding of the regional geology of the study area.

OBJECTIVE

This paper intends to:

i) Discuss the depositional environments, reservoir distributions for all the geological formations and the tectonic history of the study area.
ii) Illustrate the correlation between the onshore and offshore formations.
iii) Relate the geology of the area with other parts of Sabah.

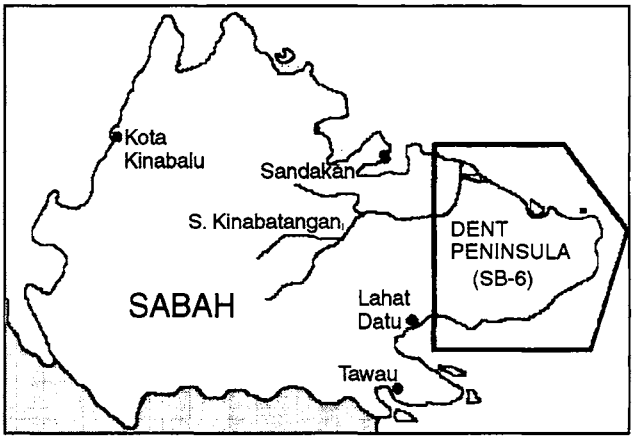

Figure 1. Location map of the study area.

GEOLOGY OF THE ONSHORE DENT PENINSULA

The onshore Dent Peninsula area was studied and mapped by several workers including the geologists from Sabah Shell Petroleum Company Limited back in the 1960's. However, the earliest published geological work for the area was by Haile and Wong in 1965 in the report entitled *"The geology and mineral resources of the Dent Peninsula"*, Memoir 16, Geological Survey Borneo Region, Malaysia.

According to the report, the rock units in the Dent Peninsula area are divided into two groups namely the Dent Group comprises Sabahat, Ganduman and Togopi Formations and the Segama Group. The descriptions of the onshore geological formations to be discussed in this chapter are mainly based on the report and the observations made during the fieldwork. The geological map of the Dent Peninsula together with the localities of the selected outcrops are shown in Figure 2.

Segama Group

The Segama Group in the Dent Peninsula is mainly represented by the Tungku and Ayer Formations which form high hills to the west of the Dent Peninsula. Good outcrops of the Segama Group were found in the upstream of the Tungku and Membatu rivers at localities 1 and 2.

The Segama Group is characterised by matrix supported conglomeratic beds with rounded clasts. The matrices are predominantly made up of tuffaceous sandstone. The clasts are heterolithic and consists of ultrabasic volcanic rock and tuffaceous sandstone boulders. The individual clasts range from 4 inches to one foot in diameter (Figs. 3 and 4).

Sabahat Formation

The Sabahat Formation is made up predominantly of shale. The shale is dark in colour and occasionally interbedded with thin siltstone and sandstone beds. The formation is slightly

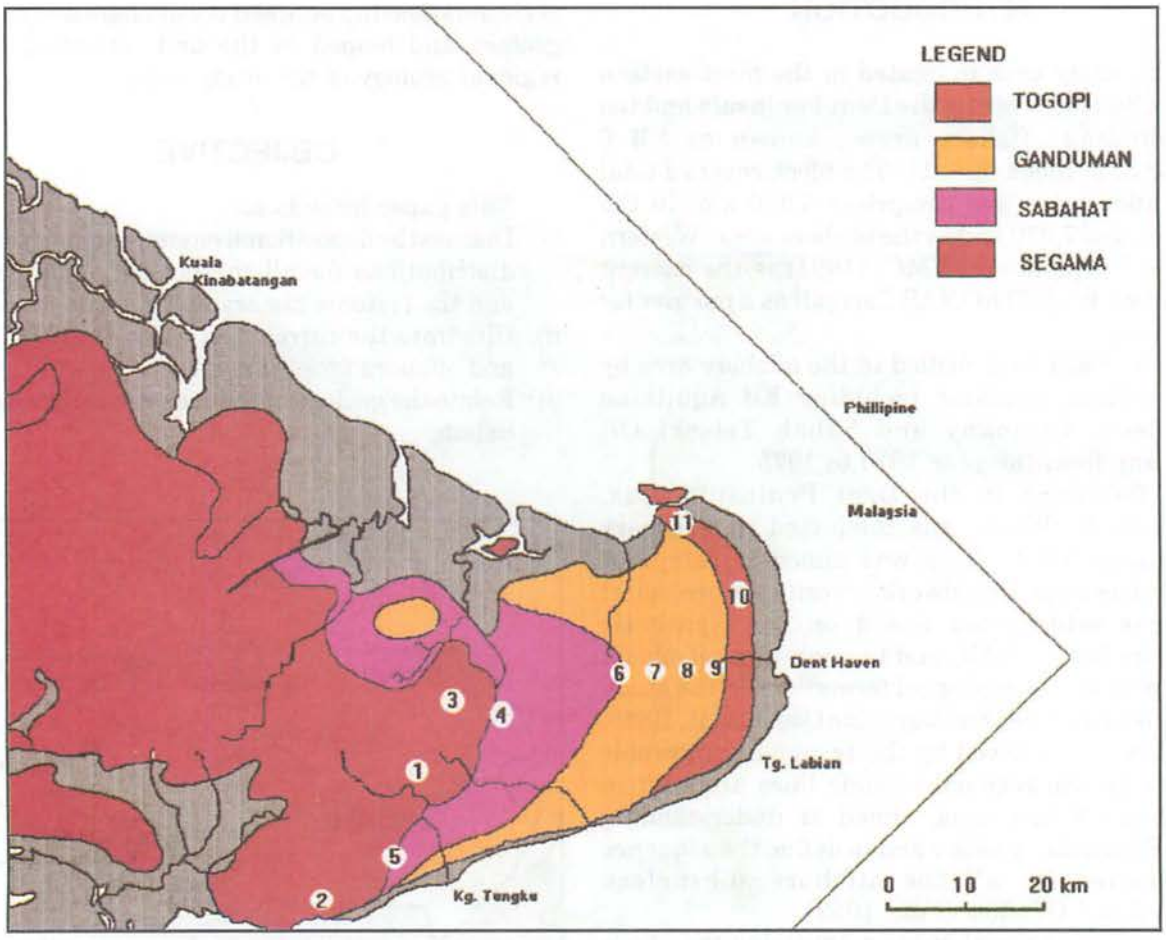

Figure 2. The geological map of the Dent Peninsula (after Haile and Wong, 1964), and the locations of the selected outcrops.

Figure 3. Outcrop of Segama Group (Tungku Formation) at a fault scarp, upstream of Sungai Tungku.

Figure 4. Another outcrop of Segama Group (Ayer Formation) at the riverbank of Sungai Membatu.

Figure 5. Angular contact between the Segama Group and the Sabahat Formation, upstream of Sungai Makua.

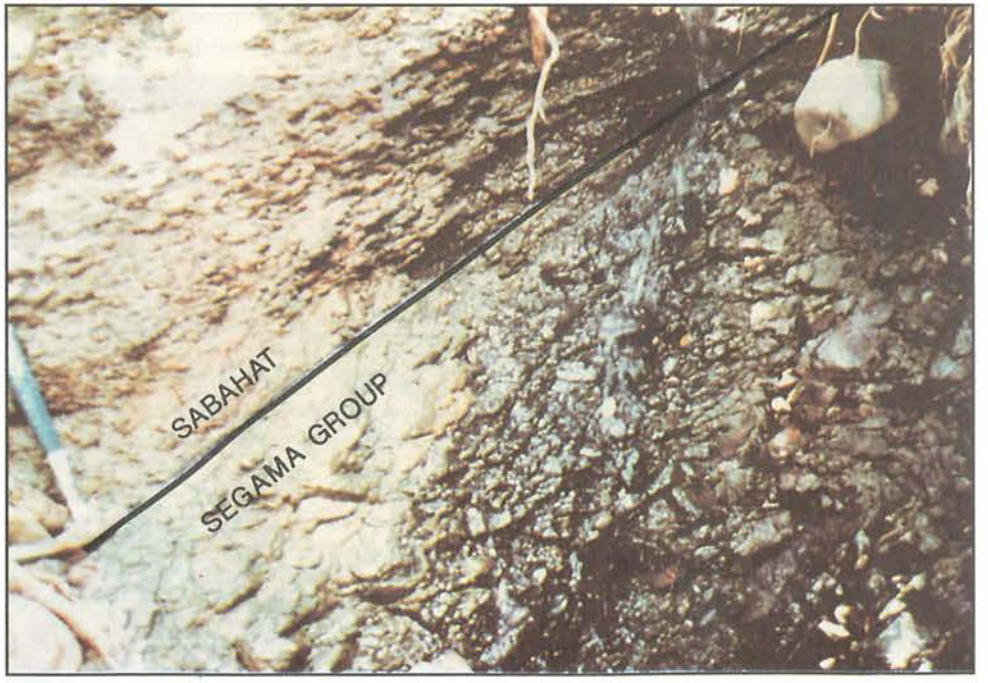

Figure 6. A close up view of the contact between the Segama Group and the Sabahat Formation, in a small stream at Bukit Marua quarry.

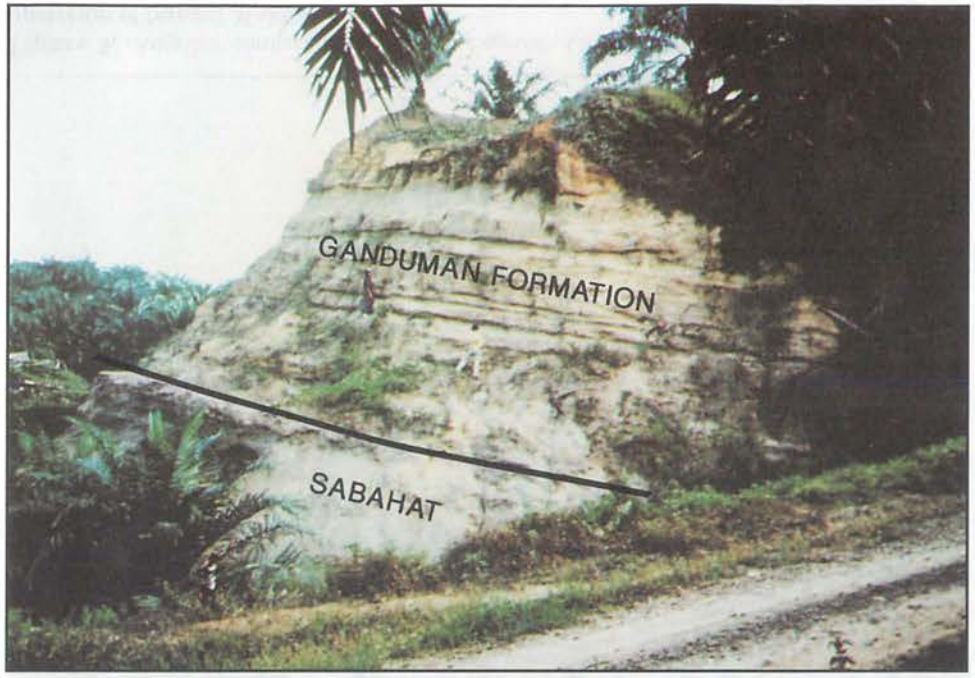

Figure 7. A transitional contact between the Sabahat and Ganduman Formation at locality 6.

Figure 8. A well-preserved outcrop of Ganduman Formation with multiple channels and overbank deposits at locality 6.

Figure 9. Ganduman Formation at locality 8, showing several unconformable layers deposited in the contemporaneous shelf-edge area.

Figure 10. Togopi outcrop at locality 10. The formation is predominantly made up of limestone, corals, claystone and calcereous sandstone.

conglomeratic in the basal unit, close to the contact with the Segama Group (Figs. 5 and 6). The formation is unconformably overlying the Segama Group and the angular nature of the contact could clearly be seen at Merau anticline and in the upstream of Makua river, at localities 4 and 5.

Ganduman Formation

The contact between the Ganduman Formation and the underlying Sabahat Formation is transitional in nature (locality 6, Fig. 7). The Ganduman Formation is characterised by a very sandy formation and interpreted to be deposited in a fluvial-deltaic system (Fig. 8). The outcrops with channel features and well-preserved trough cross-bedding, crevasse splay and interdistributary shale deposits are very well-preserved at locality 7.

Moving eastward, the outcrops become more sandy, and get into more marine environments whereby the sands are predominantly deposited as sand bars in a shallow marine environment (Locality 8, Fig. 9). Further to the east, the depositional environments are geting more marine where the sandy facies dies out into shaly facies which demarcated the contemporaneous shelf edge limit during the deposition of the Ganduman Formation (Locality 9).

Togopi Formation

The Togopi Formation in the eastern Dent Peninsula area is made up of loosely cemented rubbly limestone, calcareous sandstone, claystone and marl (Fig. 10). Fossils are abundant and well-preserved. Molluscs, corals, echinoid fragments, crabs and other marine fossils were found.

Field observation noticed that the Togopi Formation forms as layered sediments, and channel features are common. No carbonate build up unit is seen in this formation. It is interpreted that the Togopi Formation was deposited as transported carbonate and preserved together with marine clastic, forming marls.

CORRELATION BETWEEN THE ONSHORE AND OFFSHORE FORMATIONS

Field studies indicate that all the geological formations in the Dent Peninsula dip eastward. Dip readings range from 50–70° for the Segama Group and become gentler in the range of 15–20° eastward, in the Sabahat, Ganduman and Togopi Formations. The schematic east-west cross section for the Dent Peninsula showing their relative topographic height and the nature of their contact is shown in Figure 11.

Another interesting phenomenon observed during this field study is the occurrence of a transpressional fault, called Tabin fault (Fig. 12). The fault was first identified by the Synthetic Aperture Radar (SAR) and it was further verified by fieldwork. However, the throw direction of the fault is not in agreement between the SAR interpretation and field observation (the insert figure).

The thrust-uplift nature of the fault is clearly expressed in the Ganduman Valley, where it demarcated the northern boundary of the Ganduman outcrops. The southern upthrusted block forms Dent Peninsula and the north plunging block is preserved in the subsurface offshore Kinabatangan. This gives clue on the relative position between the onshore and offshore formations. However, this expression diminishes to the east and appears to be a normal fault in the offshore area.

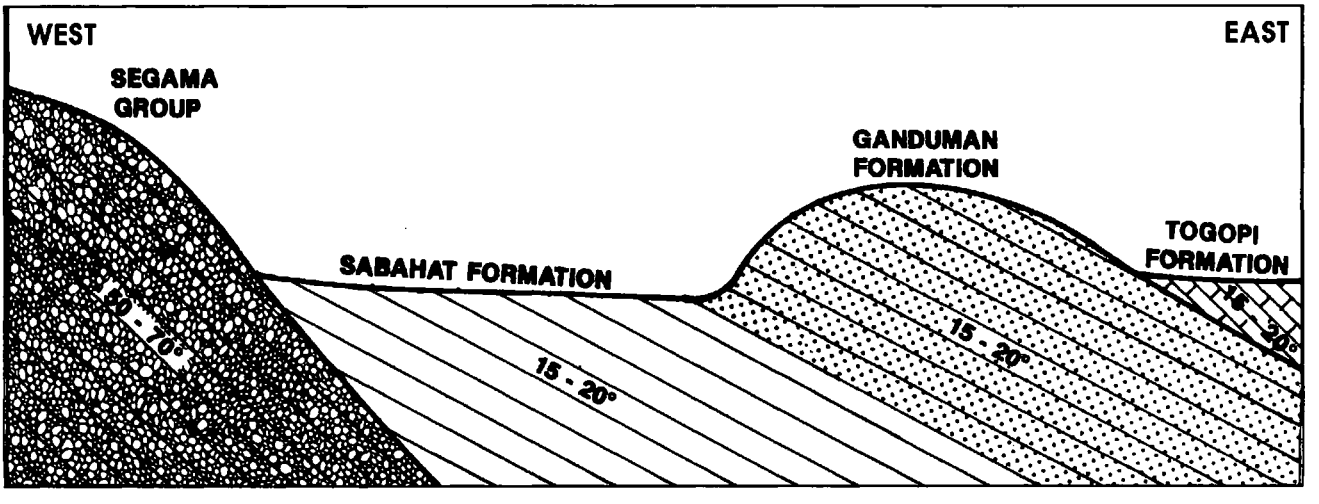

Figure 11. Schematic east-west geological cross section of Dent Peninsula. (Horizontal scale, 1:250,000, vertically not to scale)

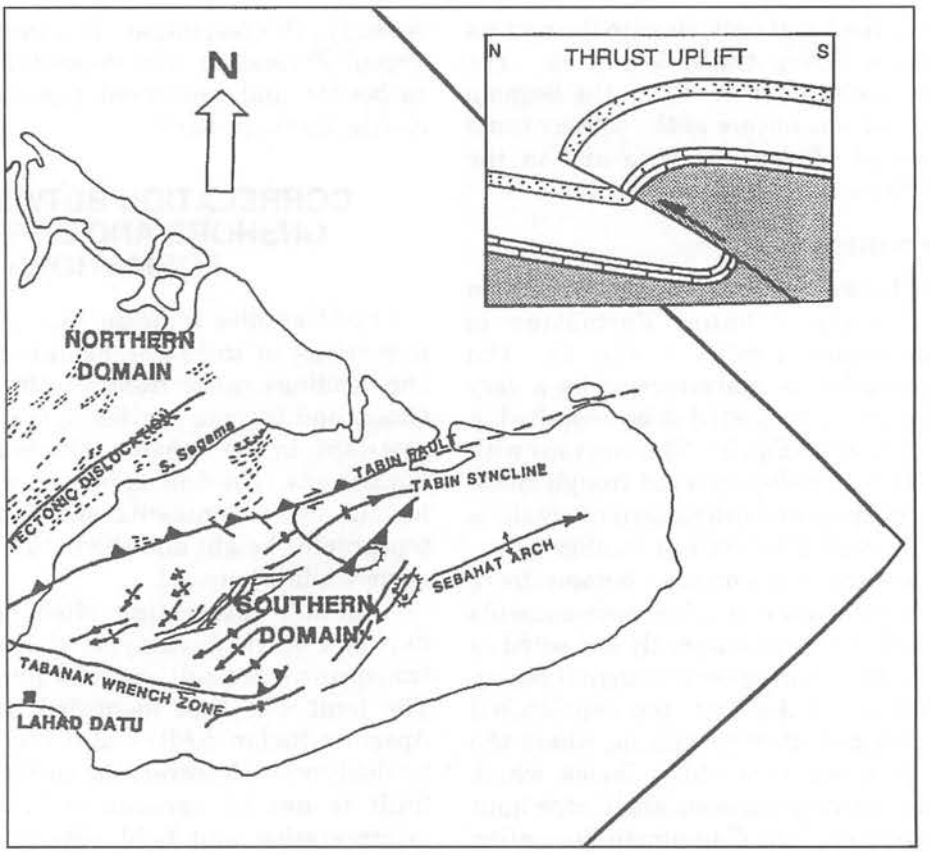

Figure 12. Showing the position and the lateral extent of Tabin Fault.

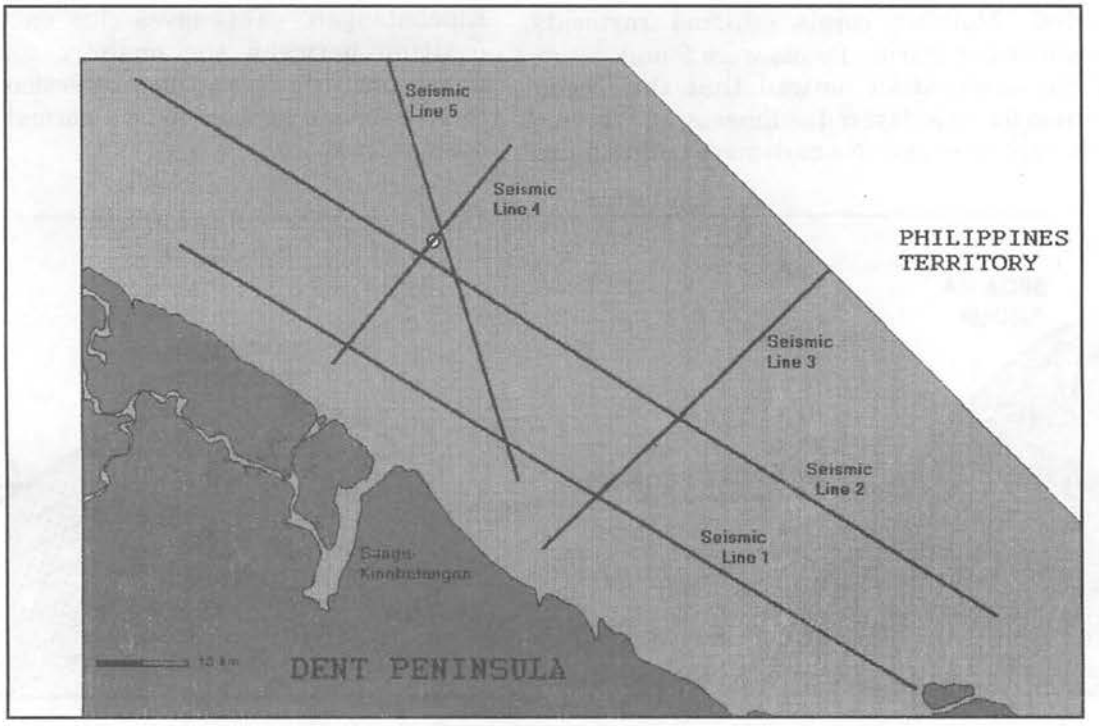

Figure 13. Orientation of the selected seismic lines.

In the offshore Kinabatangan area, the sedimentary succession unit was also called as "formation" by the previous operator. The names of the offshore rock formation followed what were believed to be the equivalents to the onshore geological formations in the Dent Peninsula. However, due to the combination of poor seismic data quality and other factors, the relationship between the onshore and offshore formations are not well understood.

The orientation of the several selected regional lines are shown in Figure 13 while Figure 14 shows the uninterpreted seismic line 1. A severe unconformity can be seen on Figure 14a and well developed topset packages grading to clinoform and bottomset can be seen on Figure 14b. Theoretically, the topset seismic package represents a progradational sedimentation which correspond to the delta-front deposits. The clinoform and bottomset represent the prodelta and offshore deposits respectively. In an attempt to correlate between the offshore and the onshore formations, the seismic line 1 (Fig. 14b) has been rotated eastward for about 20 degrees in order to put the offshore formations into the present-day position of the onshore formations. The shallow reflectors were deleted in the horizontal position, which reflects the amount of sediments that had been eroded in the onshore area (Fig. 15).

By comparing Figures 11 and 15, one could observe that the sedimentary successions both in the onshore and the offshore areas are almost identical, commencing with the Segama Group, Sabahat, Ganduman and Togopi Formations. Furthermore, the biostratigraphic data attested that these formations are of equivalent ages. The Togopi Formation both in the onshore and the offshore areas was deposited during the late Pliocene to Pleistocene time, the Ganduman Formation in the early to late Pliocene and the Sabahat Formation in the late Miocene to Pliocene times (Fig. 16). By using these data, the correlation between the offshore and the onshore formations can now be established.

OFFSHORE SUBSURFACE FORMATIONS

The previous section discussed the techniques used in correlating the onshore and the offshore subsurface formations. Both the age and the lithological composition of the Dent Group, that is Sabahat, Ganduman and Togopi Formations seem to tie very well.

However, it should be emphasised that a similar facies will be lithologically different as the depositional mechanism and environment changes. Therefore, the correlation should not be solely based on the lithological facies but also the time of deposition (from seismic correlation and biostratigraphic data). In this case, for the seismic interpretation, the time line which is used as a control for the subsurface correlation must first be established.

The subsurface "formation" in the real meaning is a time-unit, whereas the onshore formation is a lithological facies unit. However, this paper will utilise the same formation name for the subsurface formation which is of age equivalent to the onshore formation.

The nature and the lateral extent of all the offshore formations based on seismic interpretations, well data and other available information will be discussed. Several compressed seismic lines with interpreted time lines which define the formation boundaries are also incorporated.

Togopi Formation

The Togopi Formation occurs at a very shallow depth, hardly exceeding 1 second of two-way time (about 1,000 m). The formation, as it was described in all the well reports, is made up predominantly of clay with abundant shell fragments and intercalation of thin unconsolidated fine to medium grained sands as opposed to marl in the onshore area.

Ganduman and Sabahat Formations

The boundary between the two formations can easily be picked from seismic lines, whereby the Ganduman Formation is characterised by topset seismic package while the transitional boundary between the two is represented by shingles. The Sabahat Formation on the other hand is represented by the clinoform and bottomset seismic facies (Figs. 17, 18 and 19).

The Ganduman Formation is made up predominantly of sandstone with coarsening upward sequence, suggesting the sands were deposited as prograding shallow marine sand bars. Toward the shallower interval, the formation is represented by the coastal plain sediments with fining upward sequence sand packages and occasionally topped by coal beds. The Sabahat Formation is predominantly made up of shale.

The biostratigraphic study attested that the Ganduman Formation was deposited within a proximal environment, ranging from coastal fluvial to fluvial inner neritic. The Sabahat Formation on the other hand, is interpreted to have been deposited within the depositional environments ranging from holomarine middle neritic to holomarine outer neritic and it is represented by a shaly sequence.

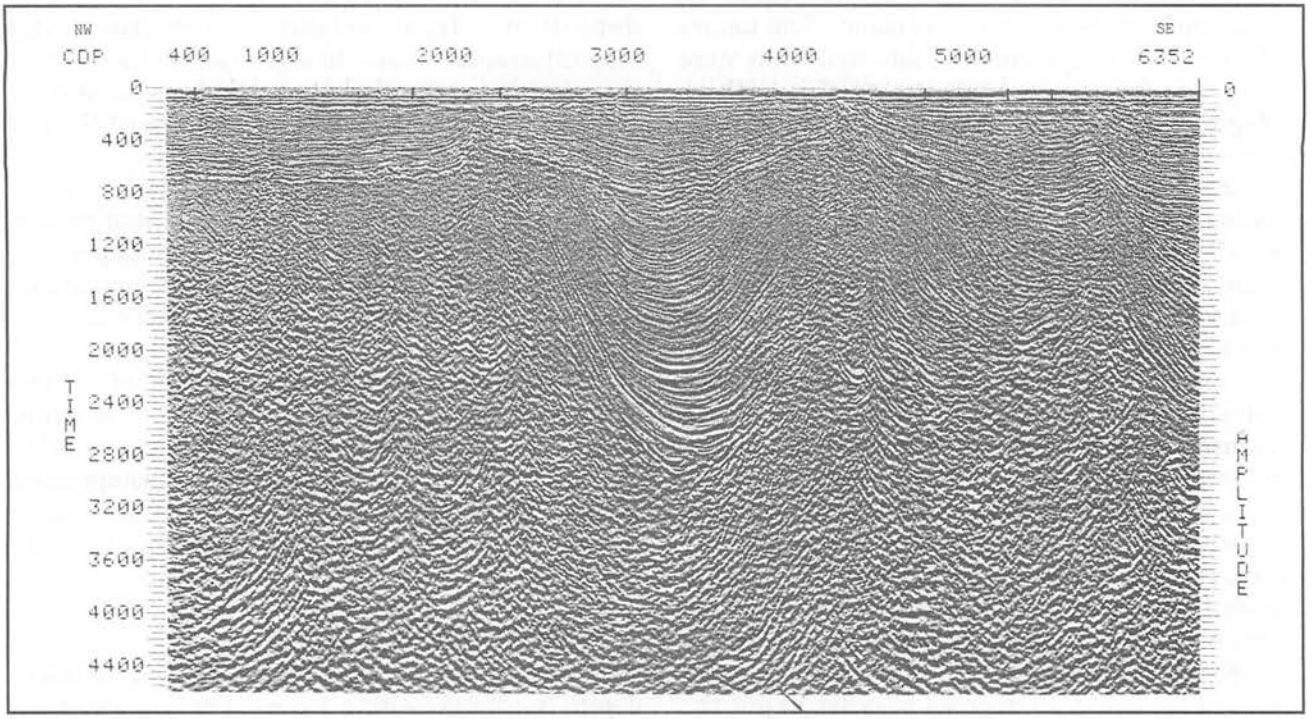

Figure 14a. Uninterpreted seismic line 1.

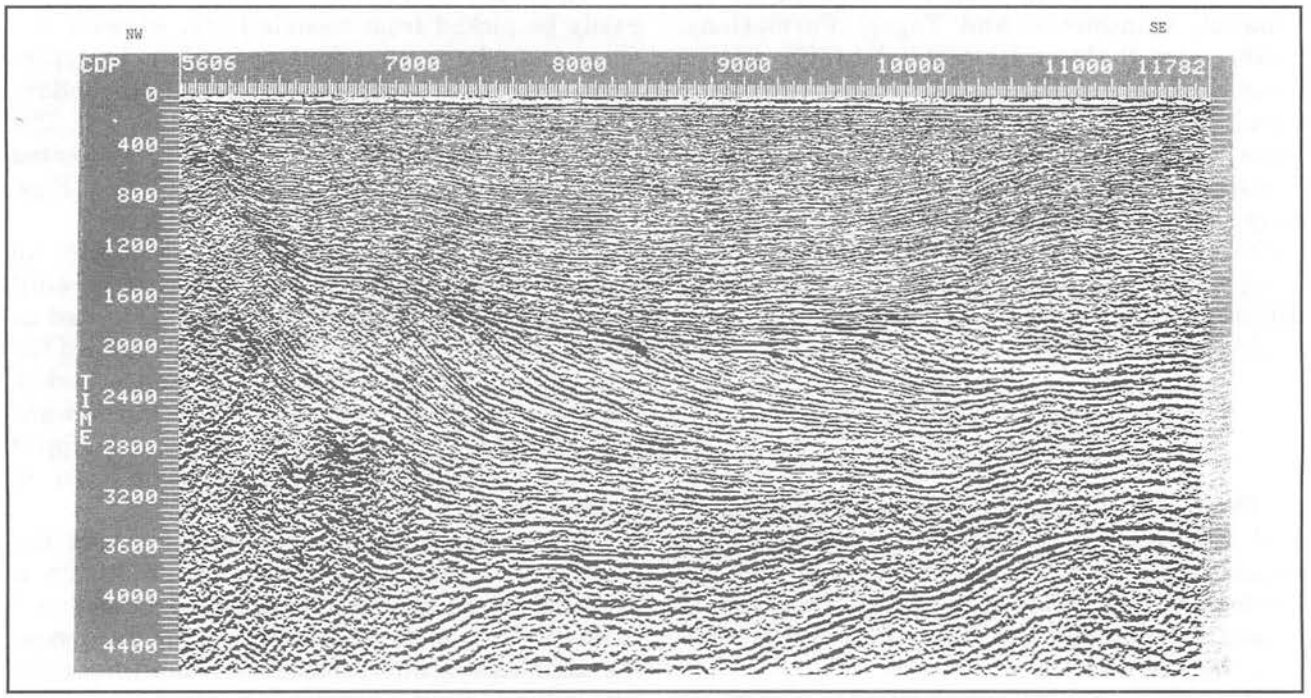

Figure 14b. Uninterpreted seismic line 1.

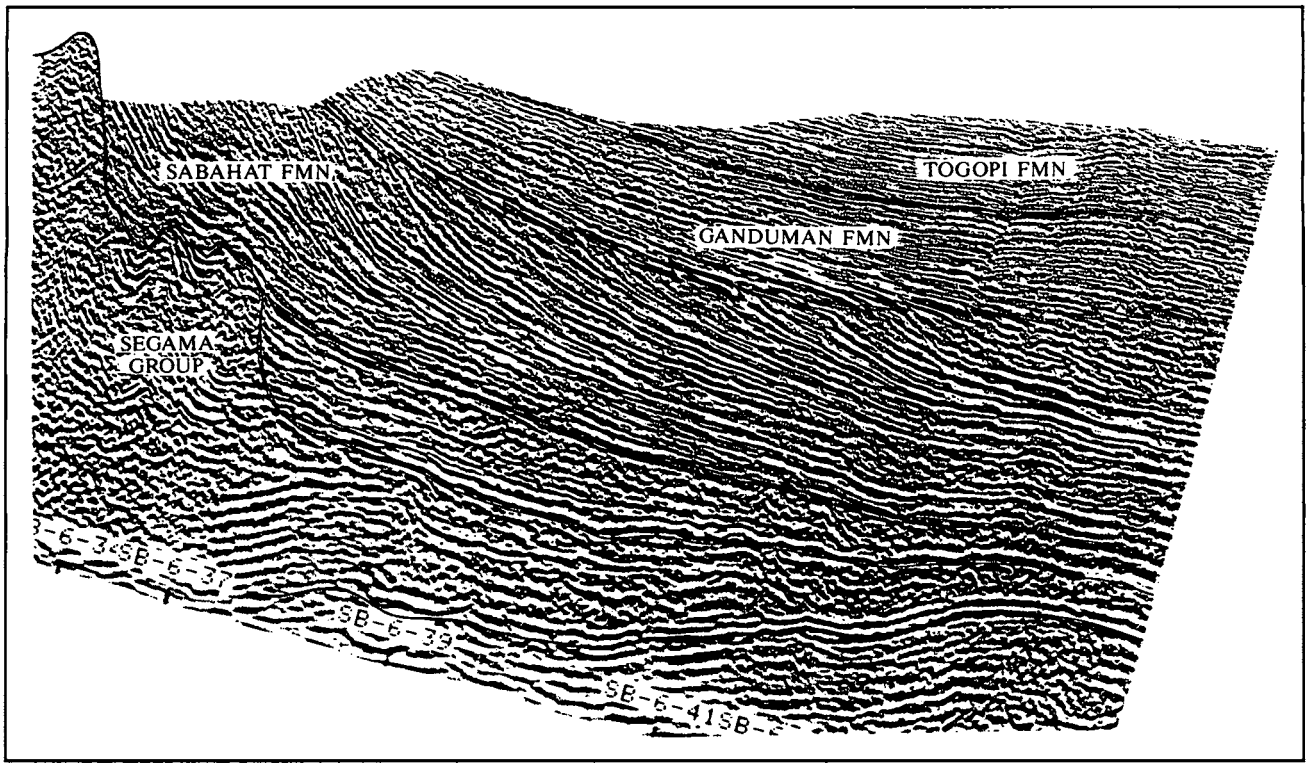

Figure 15. The eastern part of the seismic line 1, after the 20° eastward and top reflectors removal.

AGE		ONSHORE FMN (GSM)	OFFSHORE FMN (SNPA/ISC)
PLEISTOCENE		TOGOPI	TOGOPI
PLIOCENE	LATE		
	MIDDLE	GANDUMAN	GANDUMAN
	EARLY	SABAHAT	SABAHAT
MIOCENE	LATE		OLDER SABAHAT
	MIDDLE		
	EARLY	SEGAMA GROUP	SEGAMA GROUP
OLIGOCENE			

Figure 16. Proposed stratigraphic scheme for the onshore and offshore area of Block SB-6 (8).

This leads to the conclusion that the Sabahat and Ganduman Formations were deposited as a complete unit of the early-late Pliocene delta, as a result of erosion in the severely uplifted area to the north-west of the block. The distal unit is represented by the Sabahat Formation and the proximal unit is represented by the Ganduman Formation.

The Ganduman unit covers the whole offshore Kinabatangan area except to the north-west (Fig. 20). The thickest unit is in excess of 600 msec (about 600 metres) and it is terminated to the north-east due to the distal depositional limit and to the northwest by the eastern limit of the late Miocene unconformity.

Older Sabahat Formation

This formation was also called Sabahat Formation by the previous operator. The seismic correlation of this formation is shown on Figures 17 and 19. Both the seismic and biostratigraphic studies showed that this formation is relatively older than the Sabahat and the Ganduman Formations. Therefore, the name of Older Sabahat Formation was proposed for this formation.

Similar to the Ganduman and Sabahat Formations, the sedimentary succession of this formation commenced with marine shale deposits and gradually becoming more sandy the younger section. Seismic studies could also differentiate the sandy and the shaly facies of the Older Sabahat

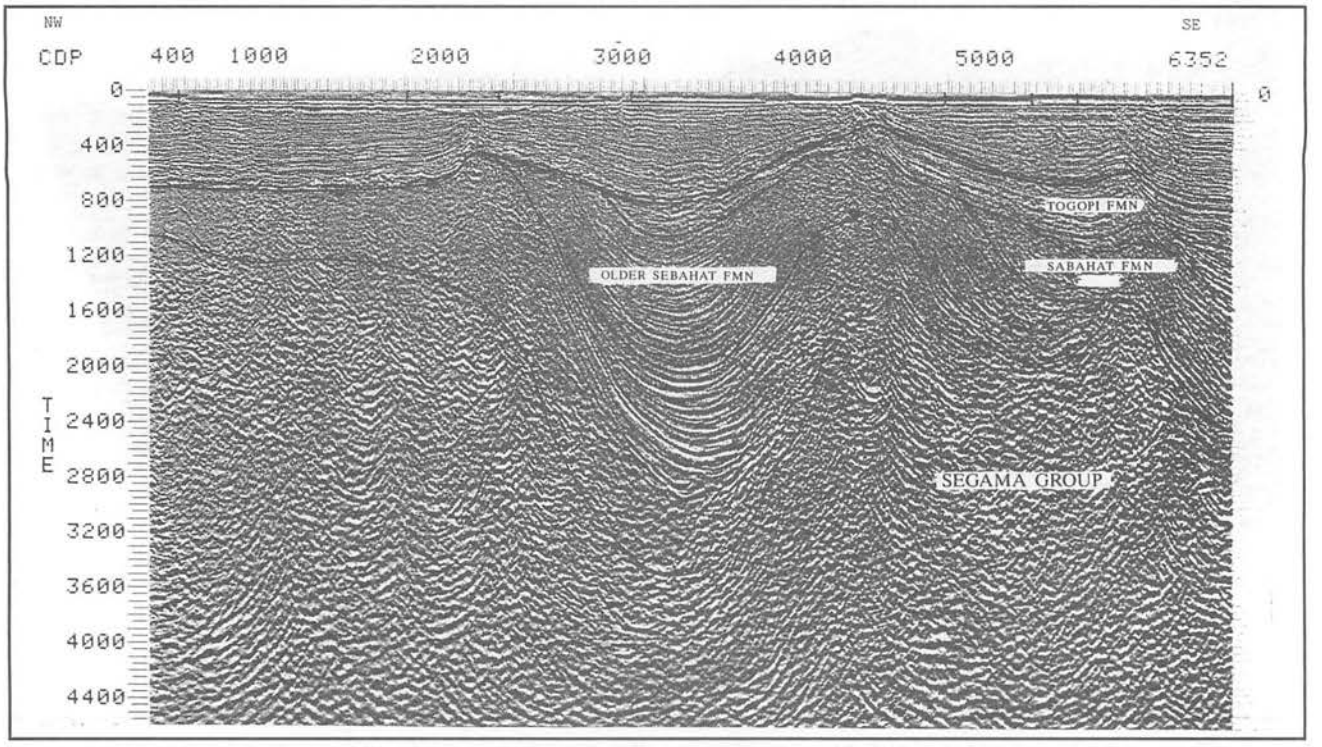

Figure 17a. Seismic line 1, showing the lateral extent of the Older Sabahat Formation.

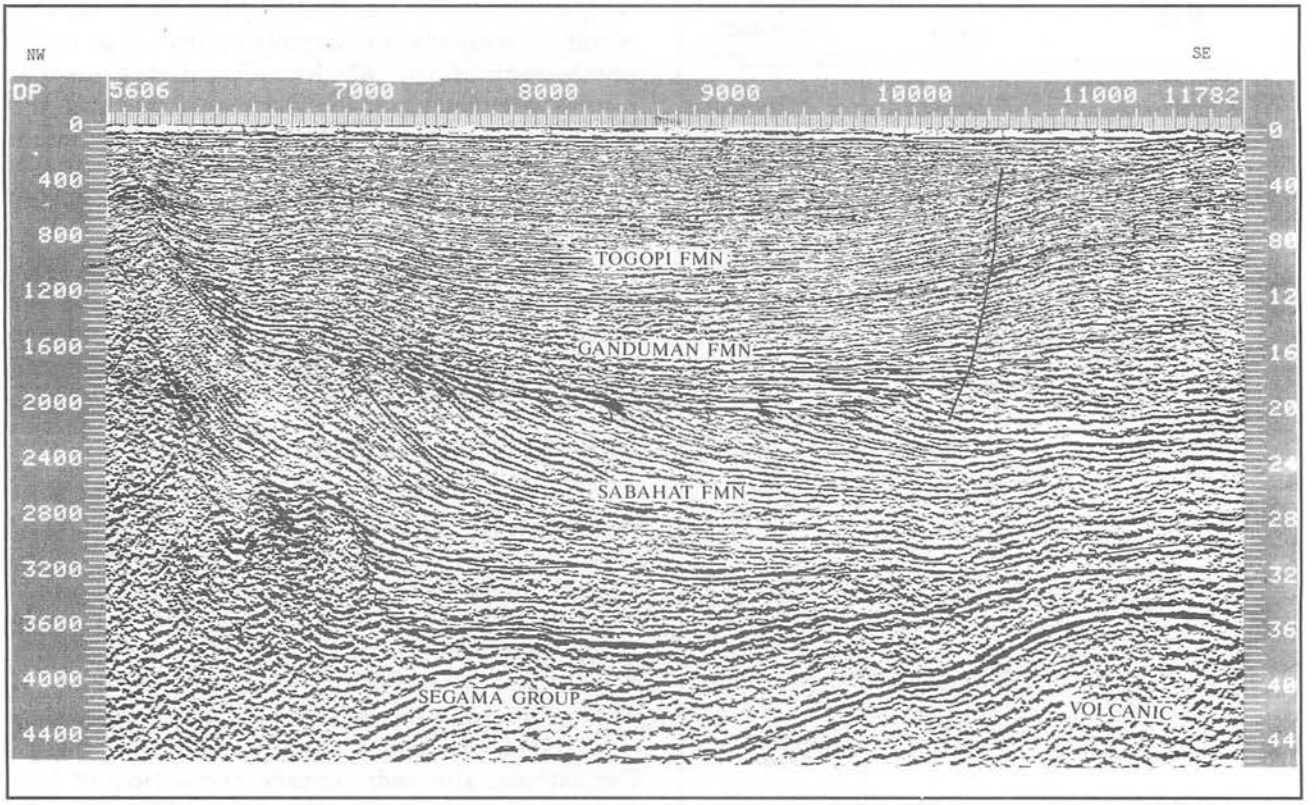

Figure 17b. Seismic line 1, showing the volcanic, Segama Group and the overlying Sabahat and Ganduman Formaitons.

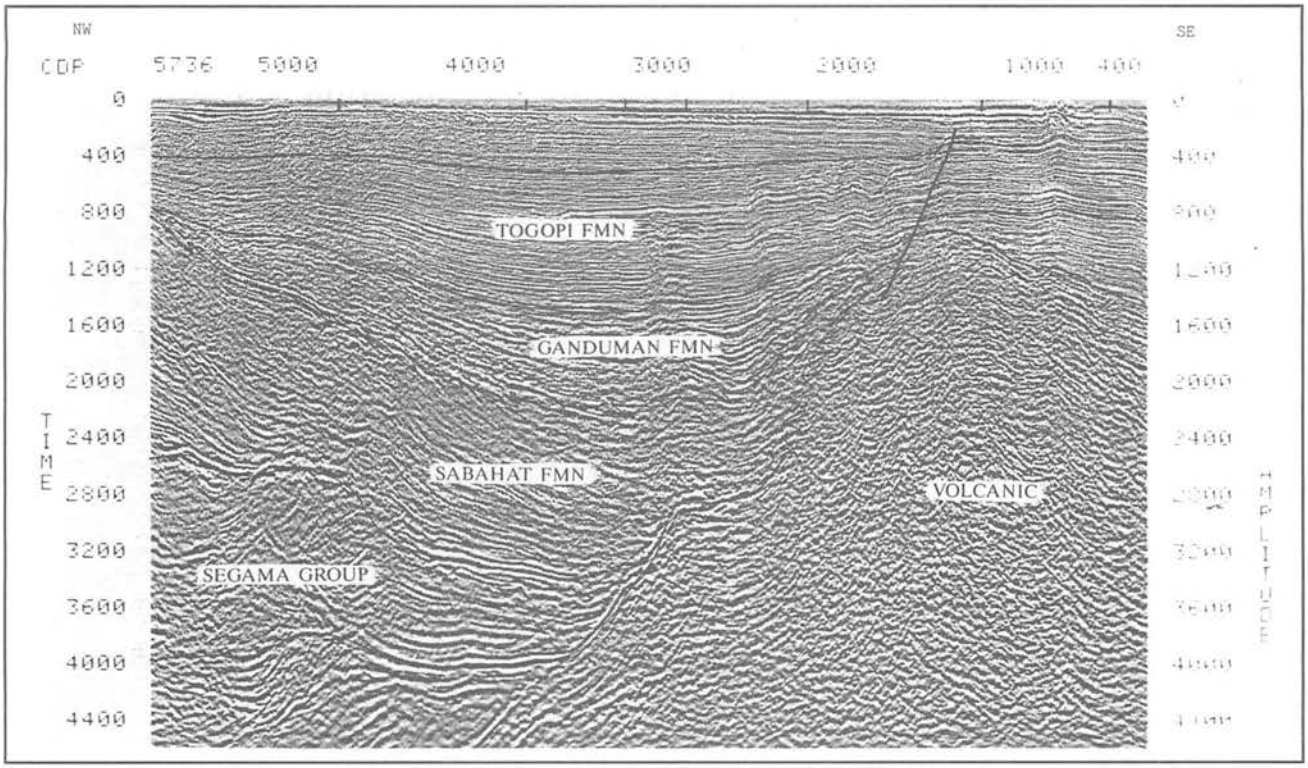

Figure 18. Seismic line 3, showing the relationship between volcanic Segama Group, Sabahat, Ganduman and Togopi Formations.

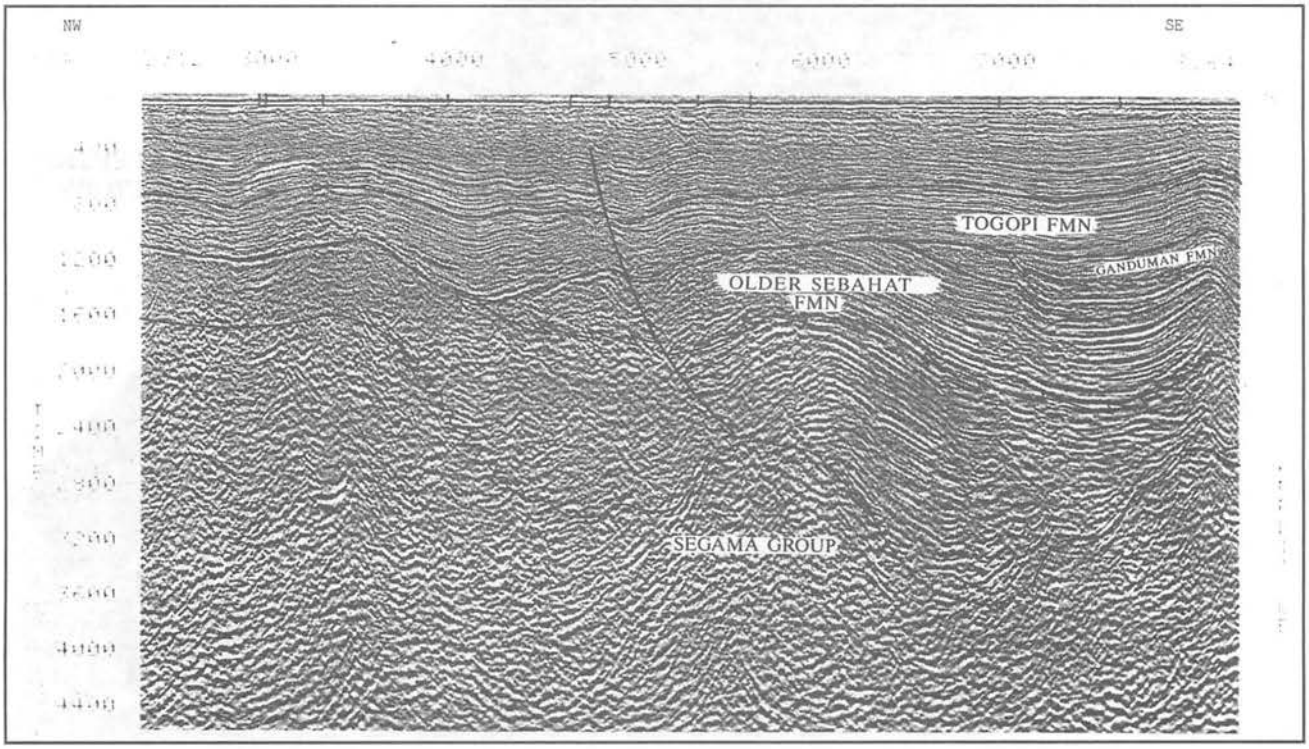

Figure 19a. Seismic line 2, showing the relationship between the Older Sabahat, Sabahat and Ganduman Formations.

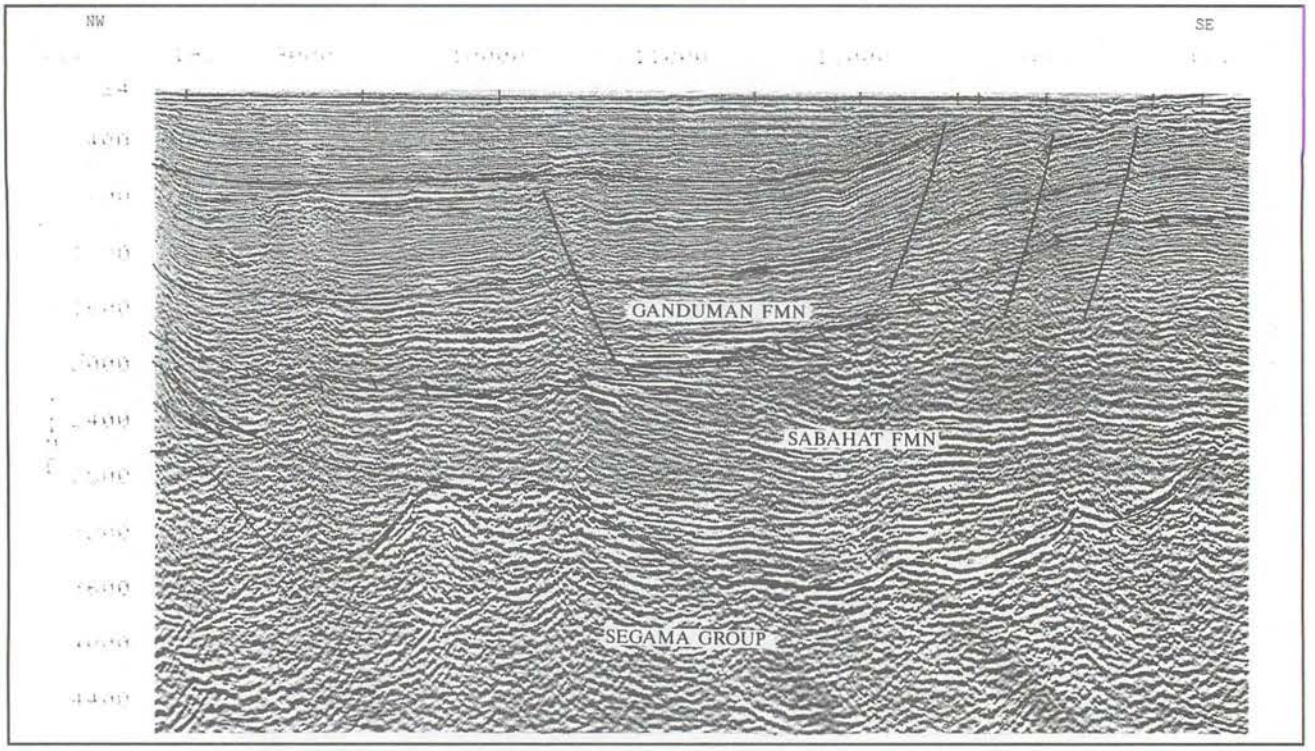

Figure 19b. Seismic line 2, showing the distal termination of the Ganduman Formation.

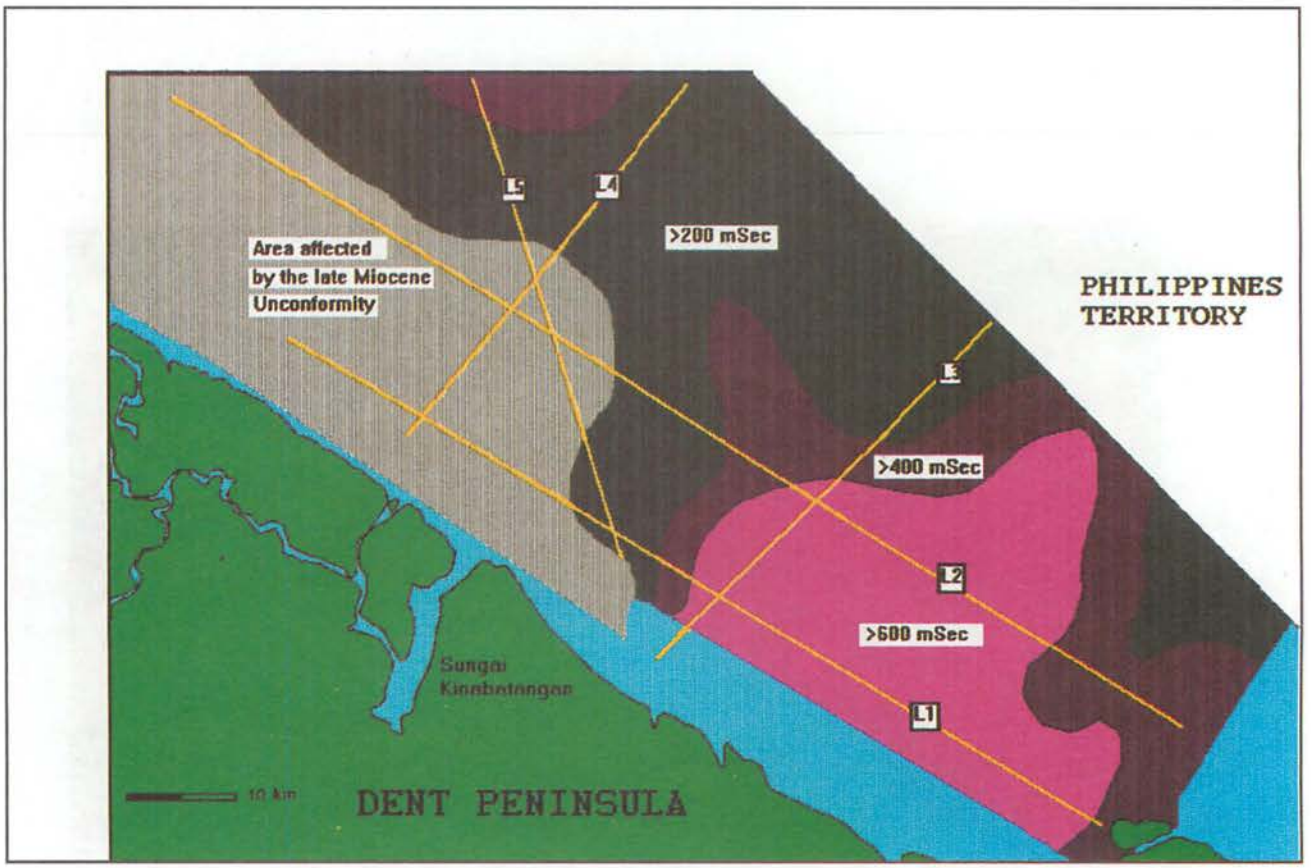

Figure 20. Map showing the lateral extent and thickness of the Ganduman Formation.

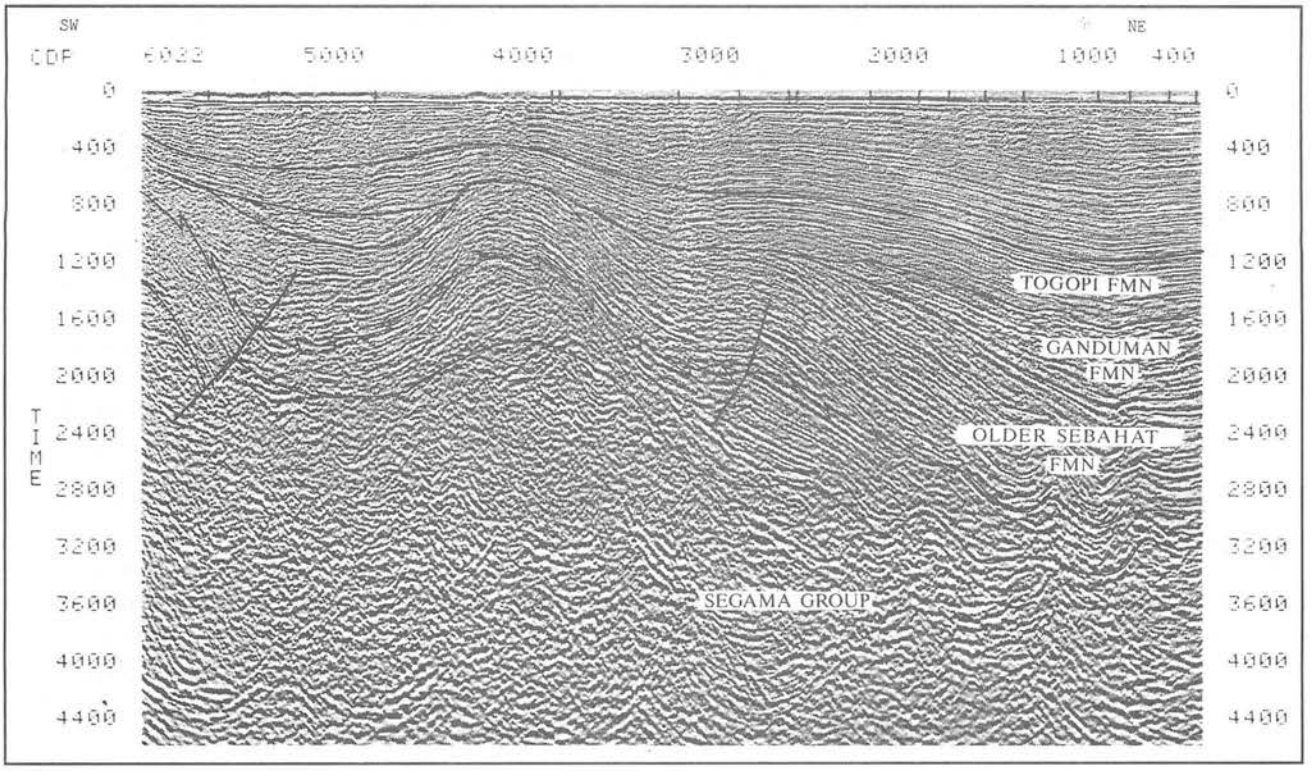

Figure 21. Seismic line 4, showing the topset and clinoform seismic facies of the Older Sabahat Formation.

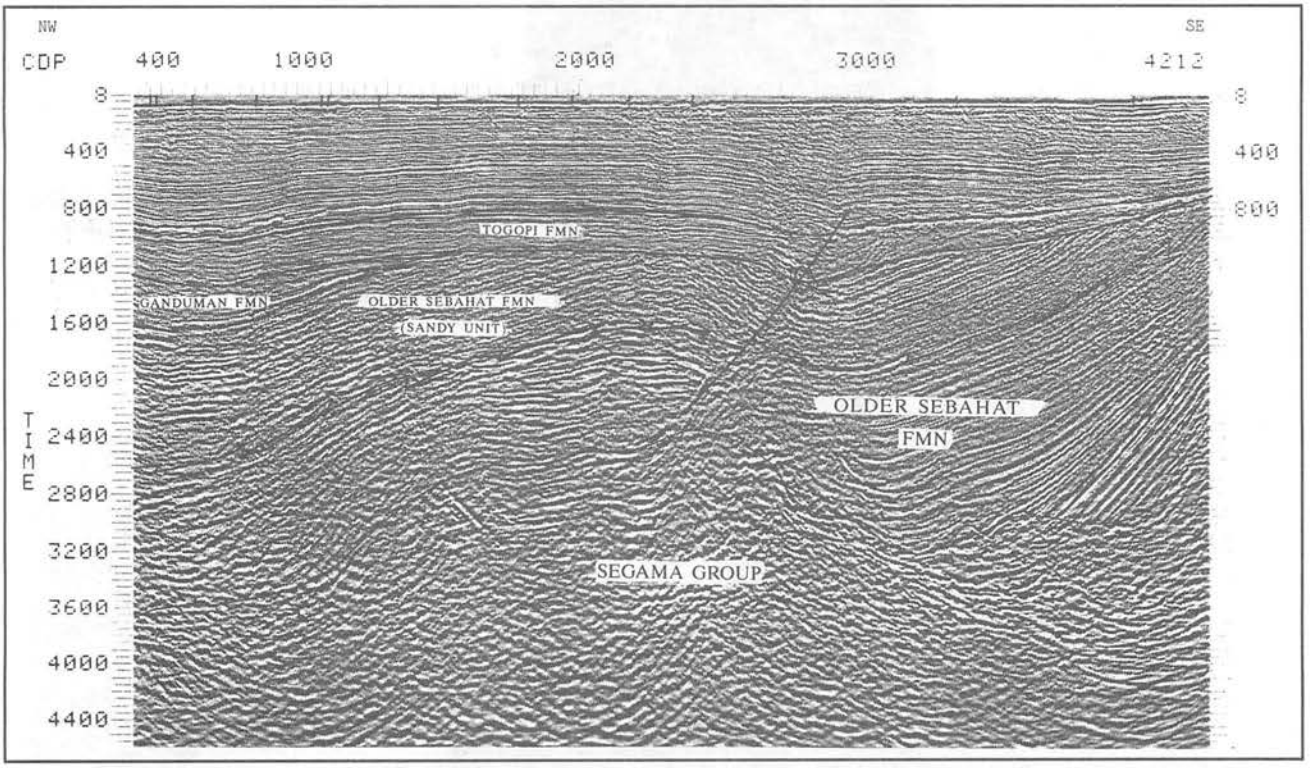

Figure 22. Seismic line 5 showing the topset and clinoform seismic packages of the Older Sabahat Formation.

Formation. The sandy facies is represented by the topset seismic package while the transitional boundary between the two is represented by the shingles. The shaly facies is represented by the bottomset seismic facies (Figs. 21 and 22).

The biostratigraphic study conducted on the Older Sabahat Formation, attested that the formation was deposited in a deltaic setting within the depositional environments ranging from delta plain, coastal fluvial and fluvial inner neritic. The age of the formation range from upper early Miocene to lower early Pliocene. By tracing the topset seismic facies which represents the sandy unit of the Older Sabahat Formation, an isochron map can be generated.

The sandy unit formed in front of the river mouth of the present Kinabatangan river. The thickest part of this unit is in excess of 800 msec (about 800 m). The extension of this unit to the west is terminated by the basement high and reaches its depositional limit to the north and to the east (Fig. 23). This leads to the interpretation that the paleo-Kinabatangan river was responsible for the deposition of the Older Sabahat Formation.

Volcanic and Segama Group

On seismic lines, the volcanic basement is characterised by chaotic seismic reflectors forming a huge domal structure (Fig. 18). A total of 636 ft of this sequence was penetrated by one of the wells. The basal most section of the well was reported to be made up of unweathered basalt and overlain by volcanic breccia.

The basalt was described as greenish, with frequently-twinned augite and labradorite phenocrysts, in a groundmass of plagioclase microlites. At least 8 flows were interpreted. The volcanic breccia was described as polymictic, consisting of poorly-sorted pebbles and cobbles of tuffs, andesite, serpentine, red claystone and chert embedded in slightly tuffaceous brown mudstone.

The Segama Group on seismic lines 1 and 2 formed a rugged terrain. In most places, this formation is represented by disturbed seismic facies, suggesting that the formation has undergone a series of severe compressional faulting. The formation is unconformably overlained by the Older Sabahat Formation in the north-western offshore Kinabatangan area.

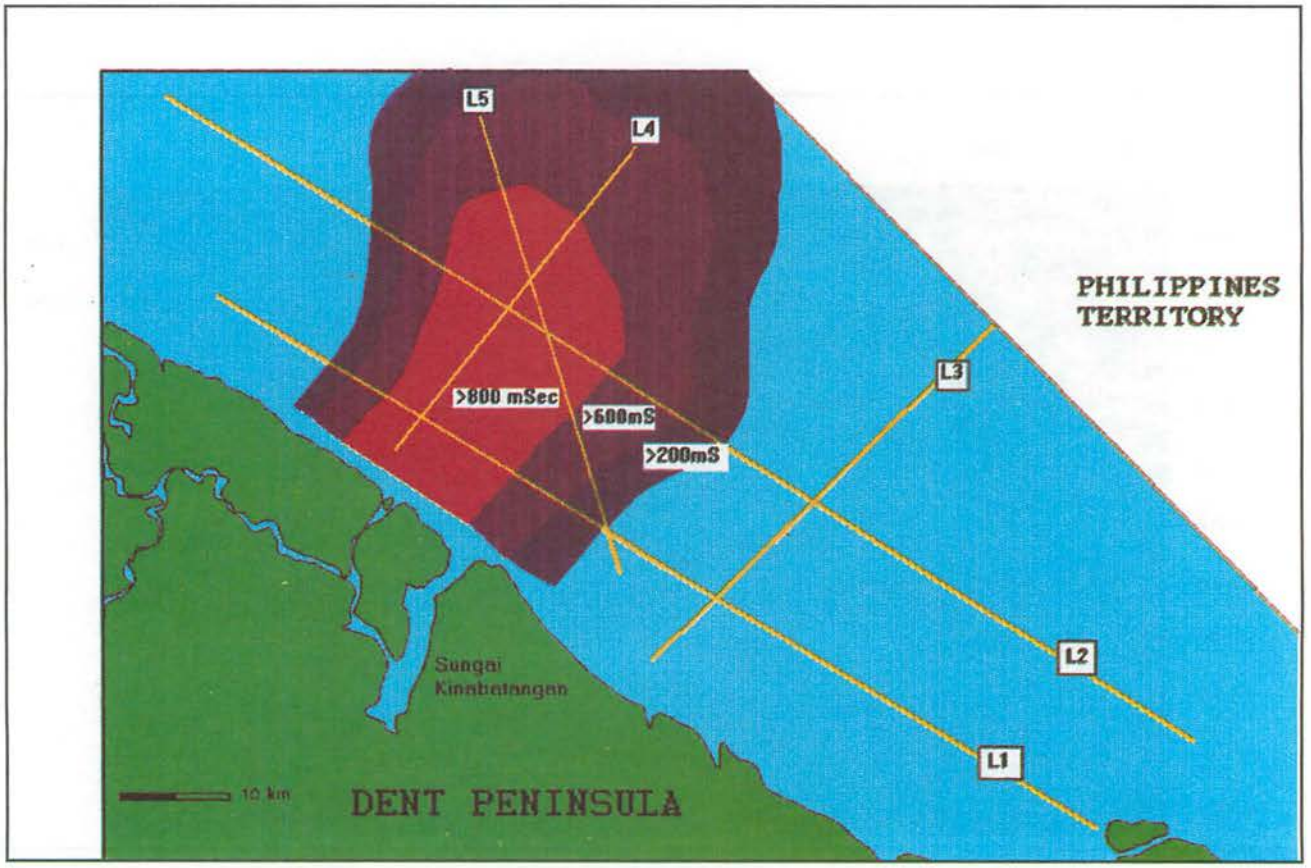

Figure 23. Map showing the lateral extent of the older Sabahat sands.

REGIONAL GEOLOGICAL INTERPRETATIONS

On the regional scale, the study area is located within the compressional tectonic domain between the north-eastern Borneo plate and the subduction of Luzon plate which was active during the Oligocene to late Miocene times and may still be active till present day (Murphy, 1991).

This study revealed that this area has undergone a series of intervening compressional uplift, followed by the subsequent erosions and depositions. Three major uplifts of regional significance occurred during the Early Miocene, Late Miocene and late Pliocene times.

The early Miocene event has resulted in the deformation and truncation of the Segama Group and subsequently the deposition of the Older Sabahat Formation during the upper Early Miocene to lower Early Pliocene times. This formation is only preserved in the offshore Kinabatangan area and it is not seen in the onshore Dent Peninsula. The position and the lateral extent of this formation is shown in Figure 24. The Older Sabahat Formation is of age equivalent to the Tanjung Formation which are preserved in the semi-circular basins in onshore Sabah (Fig. 25).

The late Miocene tectonic event has resulted in the deposition of the Sabahat and Ganduman Formations which represent the shaly and sandy facies of the late Miocene to late Pliocene delta respectively. The position and the lateral extent of the Ganduman Formation is shown in Figure 26. The Togopi Formation was deposited as a result of the late Pliocene tectonic event.

Besides these three events, another major event that could be inferred from this study is the Pleistocene event which is believed to be responsible for the emergence of the Dent Peninsula, the formation of Tabin Fault and other related

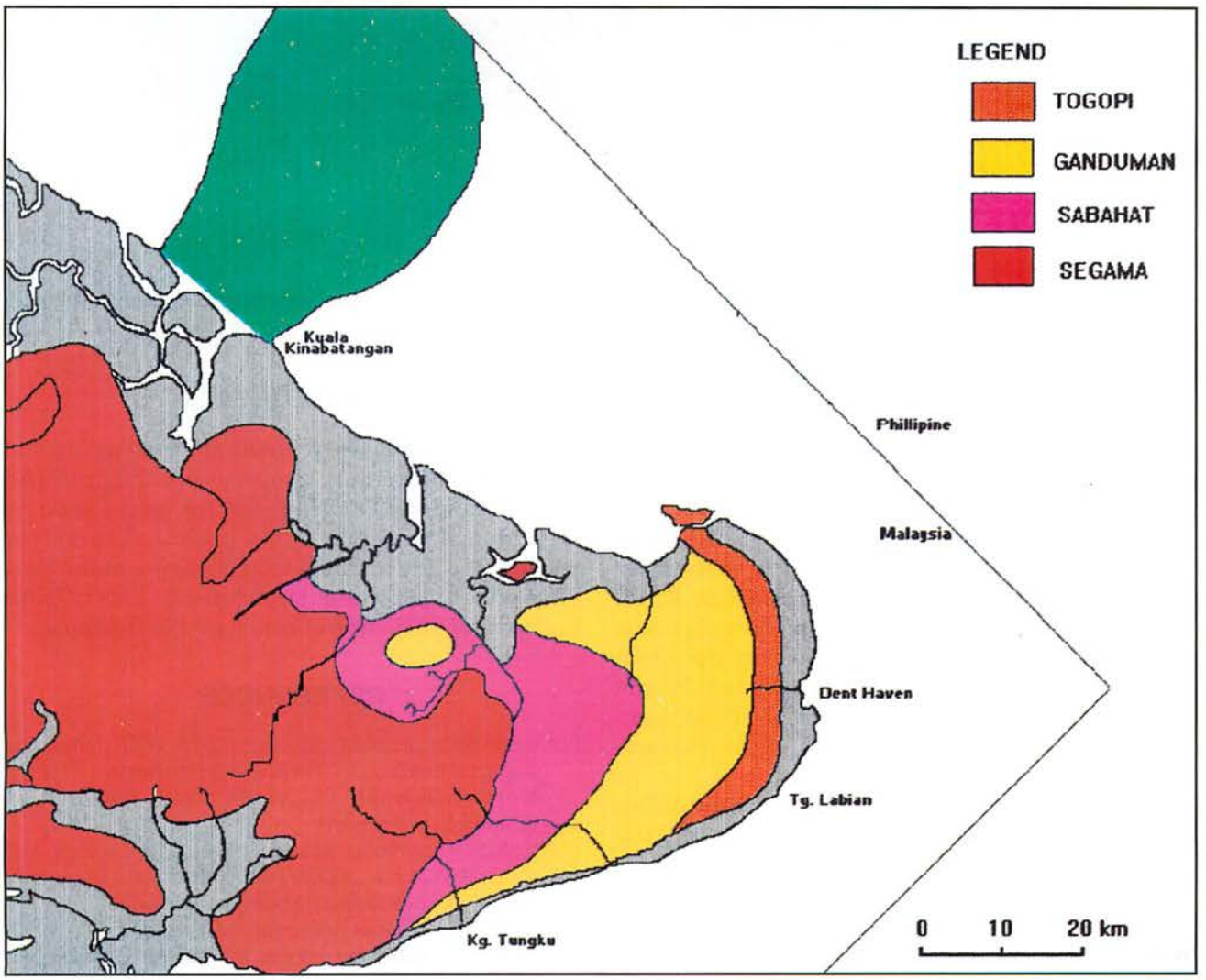

Figure 24. Map showing the position and the lateral extension of the older Sabahat formation.

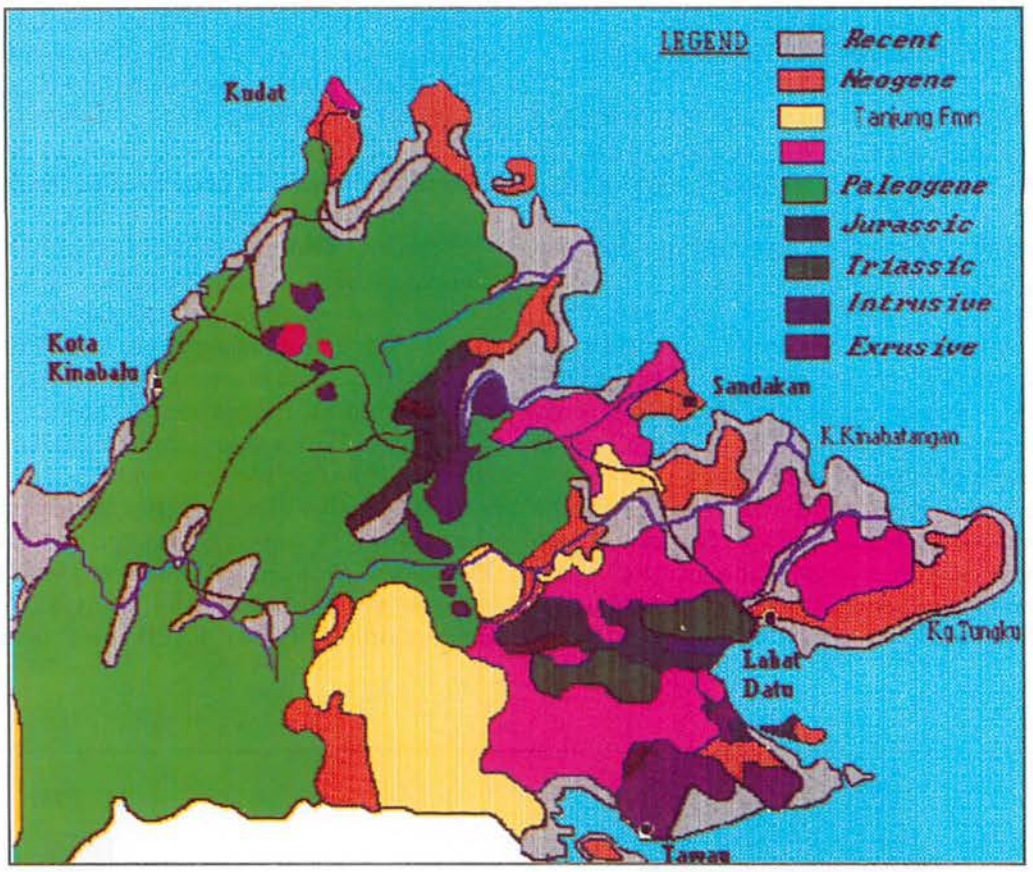

Figure 25. Geological map of Sabah (Yin, 1985). Note the distribution of the Tanjung Formation.

structures. In the offshore area, this event demarcated the top boundary of the Togopi Formation and is overlain by the onlap deposition of the Quaternary marine sediments.

CONCLUSIONS

The study reveals that two major Tertiary deltaic depositions had taken place in the area. The older sequence is represented by the Older Sabahat Formation of early-late Miocene age. Uplift and erosion during the late Miocene tectonic event has resulted in the subsequent deltaic deposition in the study area. This is represented by the Sabahat and Ganduman Formations which form the distal and the proximal units of the Pliocene delta respectively.

Both the Sabahat and the Ganduman Formations can be well correlated between the offshore Kinabatangan and the onshore Dent Peninsula areas. However, the Older Sabahat Formation is confined only to the north-western offshore area and it is not preserved in the onshore Dent Peninsula. This formation is of age equivalent to the Tanjung Formation which is preserved in the semi-circular basins in onshore Sabah.

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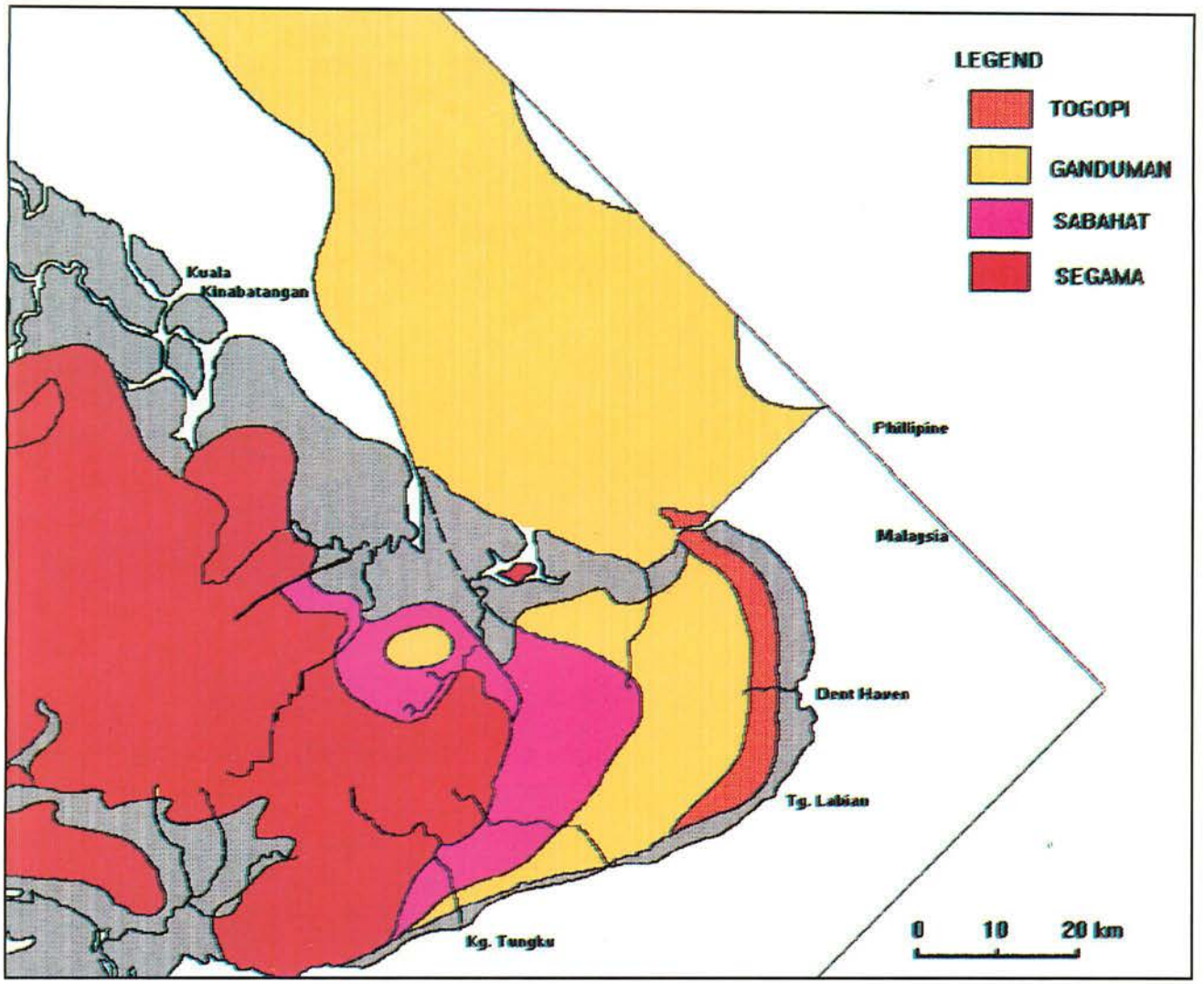

Figure 26. Map showing the Ganduman Formation and their subsurface equivalent in the offshore Kinabatangan area.

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