

Chronostratigraphy of Miocene turbiditic sequence of Sabah Basin from nannofossil assemblages

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Abstract: The Sabah Basin, Eastern Malaysia is a Neogene trench-associated sedimentary basin filled with progradational cycles of marine and coastal sediments that display spectacular arrays of facies changes. The strata also show a decreasing intensity of deformation resulting from an interplay of subsidence due to local extension and compression due to crustal convergence. Consequently, age determinations and correlation of these strata create various problems that require special biostratigraphic methods. More reliable age-determinations of Miocene strata in the Sabah Basin, especially in turbiditic sequences, have been achieved through quantitative nannofossils analysis. Foraminiferal assemblages in this type of sequences in the basin commonly indicate unreliable ages which seemingly reflect undetected floods of older, allochthonous forms masking lesser preserved younger autochthonous type. The analyses of nannofossils from sediments in five wells also show mixtures of nannofossils of different ages. Analysis of nannofossils abundance allow the recognition of the more common occurrence of indigenous forms as compared to fewer reworked older types. The abundance pattern thus reflects the nature of sedimentary facies and support the turbiditic depositional model. The dominant indigenous assemblages, as differentiated from the reworked assemblages through quantitative analysis are then quite useful in determining the ages of this problematic Miocene sequence of the Sabah Basin.

INTRODUCTION

Turbidite sequences are extensive and economically important in the Sabah Basin. At several places, such sequences have been proven to contain hydrocarbons. As exploration activities move further basinward within the Sabah Basin, most of the sand bodies encountered are of turbiditic origin. The biochronostratigraphy of these sequences are still poorly documented. Because of this, accurate correlation and chronostratigraphic interpretation of these sediments are extremely difficult with biostratigraphic data sometimes giving misleading results.

At the present time, no purely biochronological studies have been published from the Sabah Basin. Most of the chronostratigraphic documentation with respect to this basin, are supplementary to other geological studies with biostratigraphic input occurring in the form of biostratigraphic schemes, details of which are kept in-house by operators and cannot substantially be checked for accuracy.

Previously, the pollen and spores served as the main correlative tool in the Sabah Basin. This is because of their wide geographical dispersal compared to other microfossils (e.g. foraminifera and calcareous nannofossils). Furthermore, the impoverished nature of the calcareous microfossils

in the more proximal sediments in the area (mostly coastal facies) has deterred their application.

As exploration activities move farther offshore, the paleoenvironments within most stratigraphic levels become more marine. Instead of coastal sands, the main exploration targets are deep marine sands which are largely of gravity flow origin. In this realm, calcareous microfossils, such as foraminifera are of greater biostratigraphic significance. Besides providing clues for paleoenvironments, they are also better tools for biochronology compared to pollen and spores. The distribution of calcareous nannofossils in this environment is controlled mainly by sedimentary facies. They are scarce in sandy facies and limited only to bigger specimens; the smaller species are easily washed away as their sizes are smaller than the sand grains. In contrast, muddy facies yields abundant of calcareous nannofossils.

Calcareous nannofossils are very useful in dating the deep marine turbiditic facies, such as those which occur in the Sabah Basin. In this facies, calcareous nannofossils have often proven to be the more significant biostratigraphic tool than foraminifera. Besides the favourable facies, they are also more resistant to dissolution compared to foraminifera (Bukry, 1971). Part of their resistance, may be the result of incorporation of a shield of

acid-resistant, fibrillar, a cellulose-like polysaccharide material with the skeletal calcite (Franke and Brown, 1971). For this reason, it has been observed that at several localities in the Sabah Basin, while there are still significant numbers of calcareous nanofossils, the planktic foraminifera are absent or impoverished, presumably as a result of dissolution of their calcareous test. This dissolution is thought to occur in the turbiditic settings of the Miocene of the Sabah Basin even though deposition occurs above the calcite saturation limit. It is thought that this is due to the presence of acidic bottom waters which may develop at bathyal water depths where terrigenous input is high.

In addition to the problem of dissolution, the biochronological documentation of the turbiditic sequences of the Sabah Basin has been confused as a result of the presence of reworked fossils from older strata, which were eroded and subsequently redeposited through various turbiditic processes.

The reworked forms were concealed within the redeposited sediments, and were subsequently protected from the corrosive water that partially or completely consumed the exposed *in situ* calcareous fossils. The result is that within the turbiditic facies the reworked microfossils are found to be mixed with the *in situ* fossils in various proportions, and where cuttings are analysed from well sections, emphasis is given to older forms as younger ones are assumed to be contamination as a result of caving. The inability to differentiate which assemblages are *in situ* will obviously lead to misleading chronostratigraphical conclusions.

This paper is concerned with the chronostratigraphy of the Upper Miocene turbiditic strata of Sabah Basin. A method is proposed which utilises the quantitative analysis of nanofossils flora to differentiate reworked forms from the *in situ* assemblages, in order to solve an intriguing biochronological puzzle within the Sabah Basin.

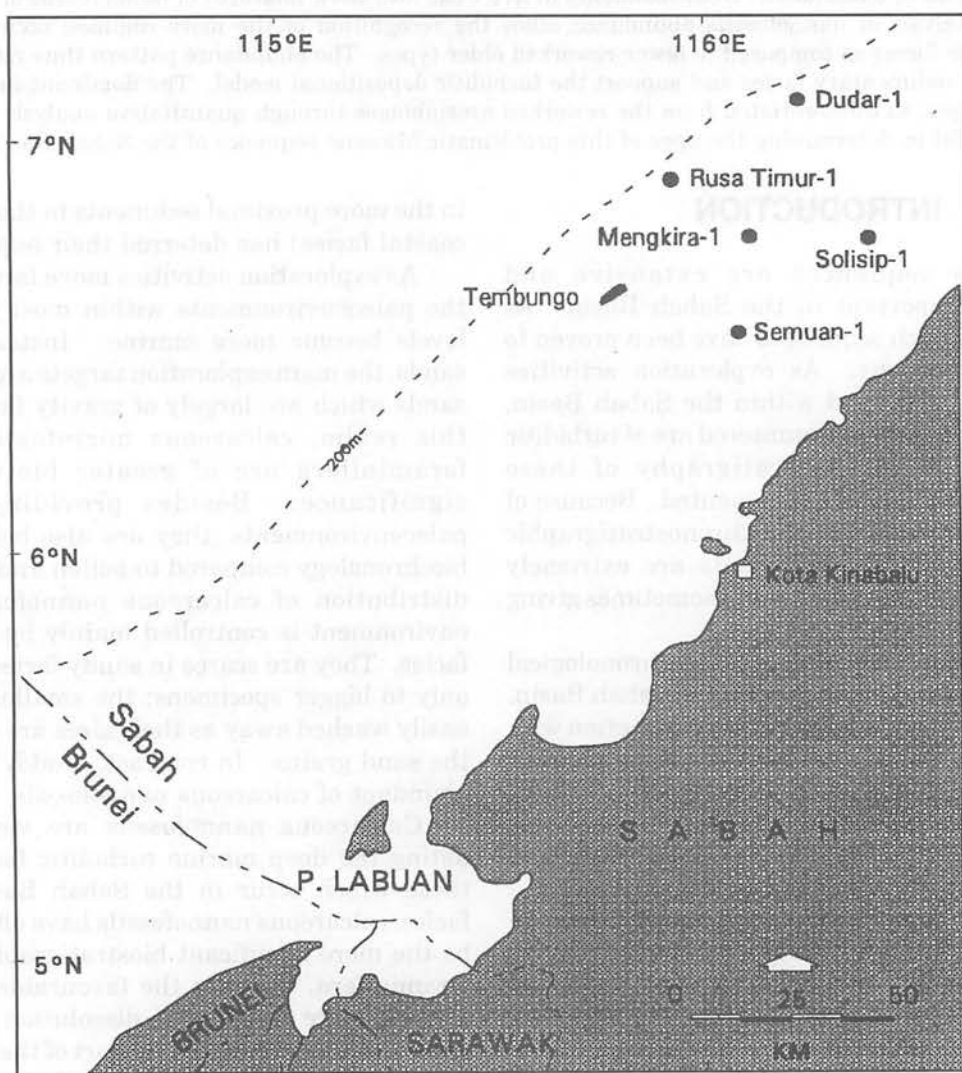


Figure 1. Location map of the studied wells.

Selected wells and intervals

The five wells examined for calcareous nannofossils in this study are Tembungo-1, Tembungo-2, Tembungo-3, Dudar-1 and Rusa Timur-1 (Fig. 1). These wells are located in western and northwestern part of the Sabah Basin. The samples were selected to cover the full range of the Miocene strata penetrated in each well.

Samples preparation and analytical technique

The analyses were carried out mostly on ditch-cutting samples, as only a small selection of core samples were obtained from available sections. On average, samples were collected at 30' intervals although some were obtained at intervals up to 100'.

Slides were prepared following the standard procedure described by Lord (1982) with a slight modification; in that, the cleaning processes by ultrasonic and centrifuge were omitted. This was to avoid the destruction or loss of nannofossil specimens that might influence the results and interpretations. The slides were studied using an optical microscope (Olympus Model BH-2).

As noted above, a quantitative technique was used in this study. The technique involved documentation of every specimen observed within three randomly selected slide traverses on a 100 mm x 100 mm cover slip. The three traverses are equivalent to approximately 300 microscopic views at 1,250X enlargement.

The data were then computed to obtain a graphic saw-blade diagram of species frequencies. These data and diagram were used and manipulated for zonal and chronological interpretations.

The standard nannoplankton zonation scheme proposed by Martini (1971) is used in this study. In addition, information from the schemes of Bukry (1971), Okada and Bukry (1980) and Perch-Nielsen (1985) are also referred to where appropriate.

GENERAL GEOLOGY OF SABAH BASIN

Northwest Sabah, is an extensive post-collisional out-building continental margin (Fig. 2). Its sediments have been divided by Sabah Shell (SSPC) into four main sedimentary units, namely Stages I-IV (Fig. 3). This study concerns only Stage IV. Deposition of Stage III sediments, prior to early Middle Miocene was in deep marine environments (Rice-Oxley, 1991). This was followed by rapid and massive north-westerly progradation of a marine shelf and slope as subduction along the continental margin ceased. The thick Stage IV sequence reflects the strong hinterland uplift and

erosion that prevailed throughout the Late Miocene.

The deposition of Substages IVA-IVC was a result of erosion resulting in the formation of the two major unconformities, the deep regional unconformity (DRU) and shallow regional unconformity (SRU). According to Ismail (1992), Stage IV is characterised by distal packages of holomarine to bathyal deposits assigned as substage IVA. Substage IVB represents the maximum transgressive period in offshore west Sabah (Bol and van Hoorn, 1980). The subsequent regressive phase is represented by substage IVC. This phase is characterised by a large north-westerly prograding delta system developed initially in the southern part of the Sabah Basin (Rice-Oxley, 1991). During the deposition of substage IVD, wrenching and block rotation occurred in the Bunbury-St. Joseph area (Ismail, 1992). Erosion associated with the uplift provided a tremendous amount of sediments feeding the turbidite system within the Tembungo-Bunbury basin.

MIOCENE NANNOFOSSILS BIOCHRONOSTRATIGRAPHY

A) Tembungo area

The Tembungo field which was discovered by Esso Production Malaysia Inc. (EPMI) in 1971, is located offshore West Sabah (Fig. 1). EPMI produced hydrocarbons from this field from 1974 to 1986 and then relinquished it to PETRONAS Carigali.

Biostratigraphical analysis of the Tembungo area has been carried out previously as part of the geohistory project of the Tembungo area (K.D.M., 1991). This 1990's project was a collaboration between ONGC (Oil and Natural Gas Commission of India) and PRSS (PETRONAS Research and Scientific Services).

The nannofossil analyses of Tembungo-1, 2 and 3 have contributed partly to the establishment of the biochronology of the area, together with palynology and foraminiferal studies. Through corroboration of the three disciplines, the chronostratigraphy of the Tembungo area was established. The lowermost interval in each of the three wells studied was interpreted as Middle Miocene (Figs. 7, 8 and 9). This was achieved through the interpretation of NN 6 and NN 7 nannoplankton zones, N 13 or N 14 foraminiferal zones and palynological partial range zone *Magnastriatites howardii*. The occurrence of younger NN 9 and NN 10 nannofossil marker species within the basal intervals was interpreted

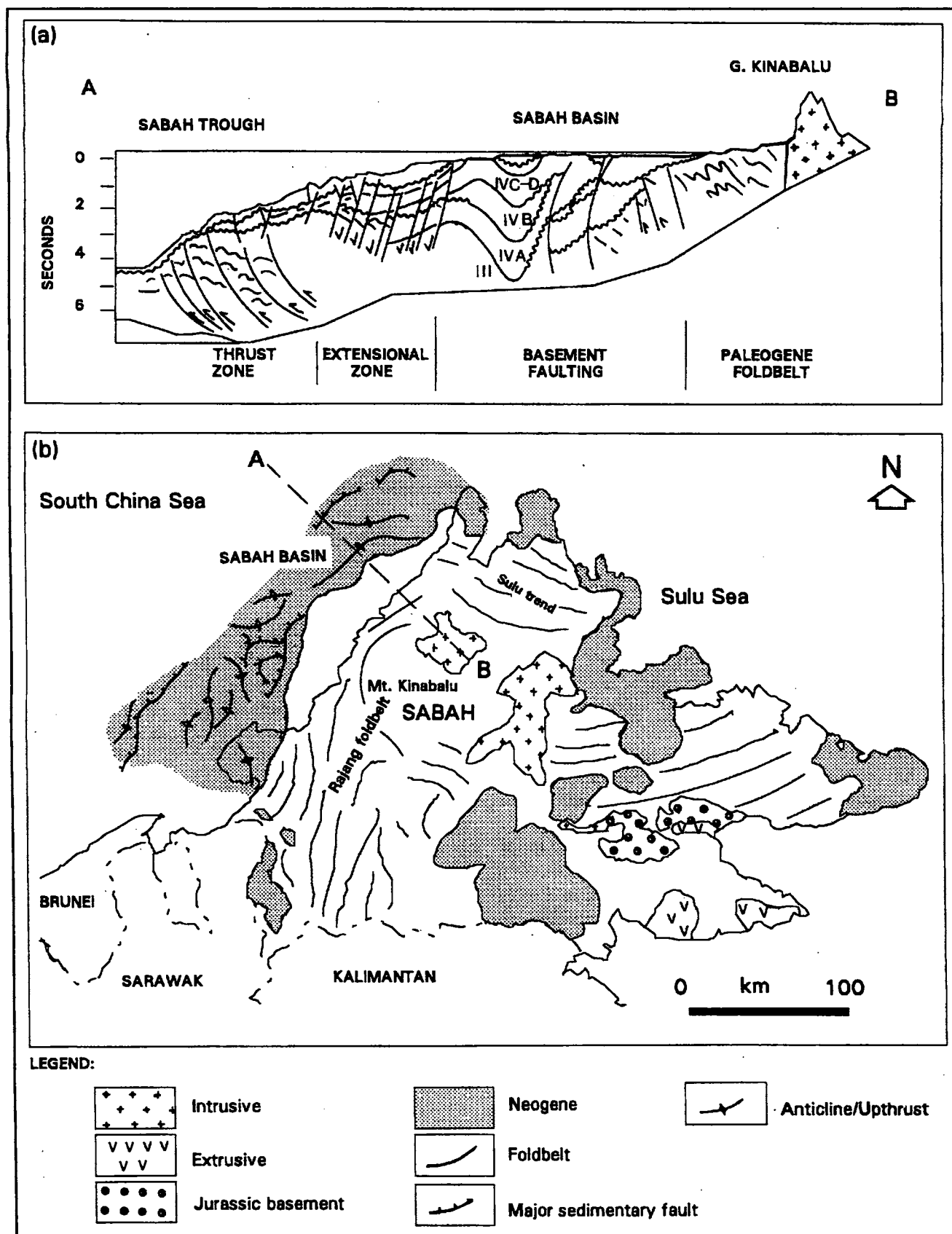


Figure 2. a) Regional cross section along A-B line. b) Schematic geological map of Sabah (modified after Bol and van Hoorn, 1980).

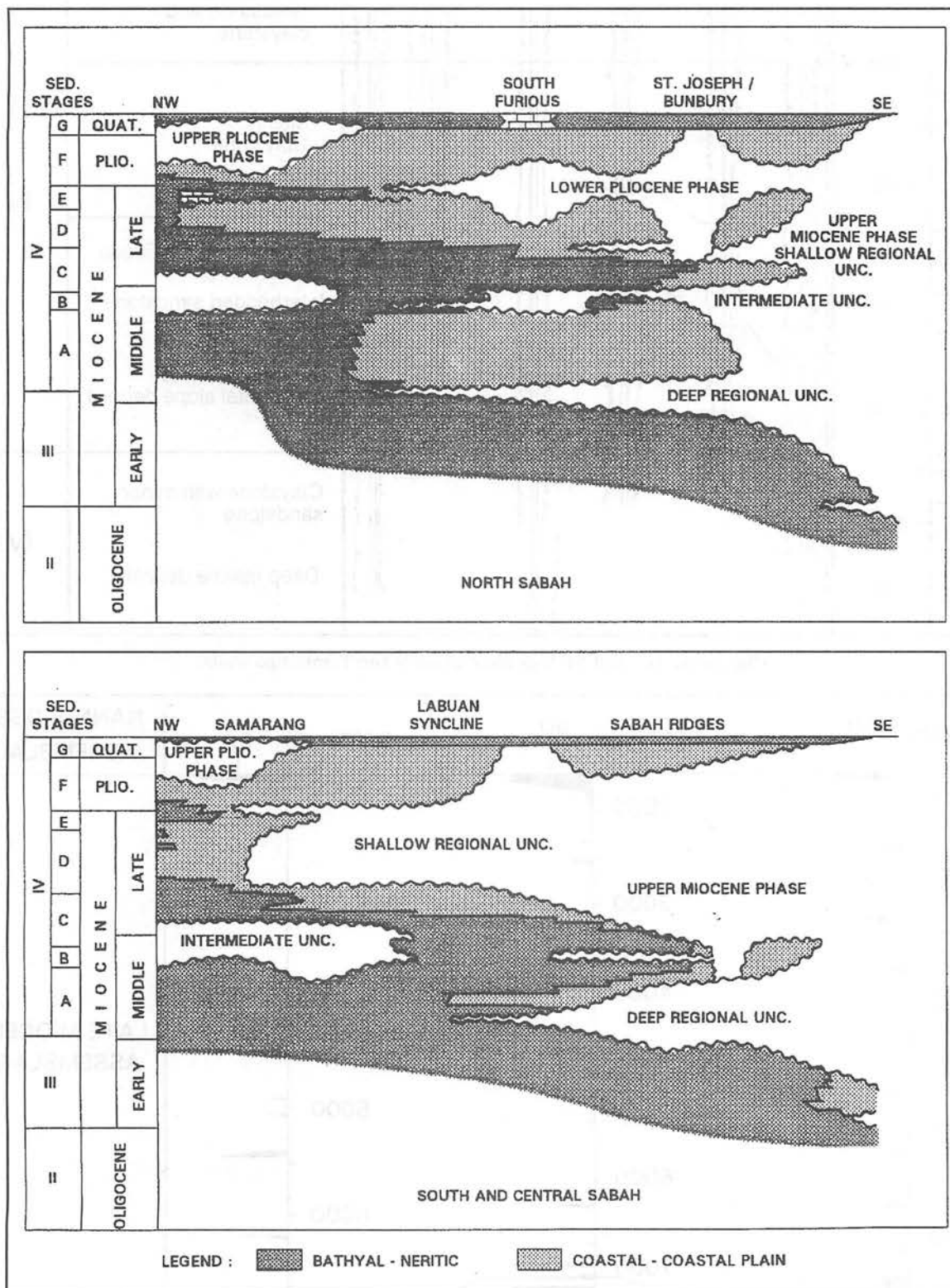


Figure 3. Generalized time stratigraphy of Sabah Basin.

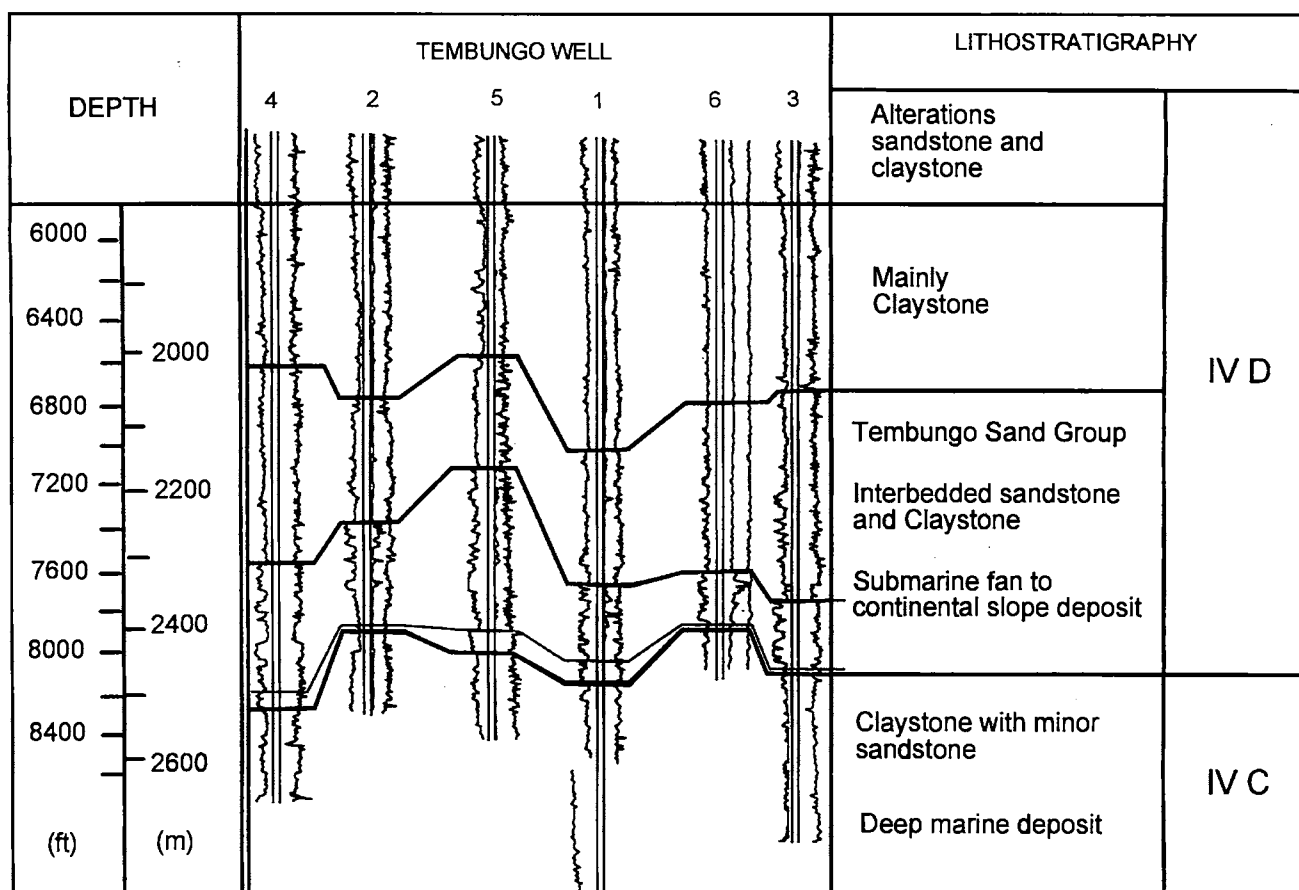


Figure 4. GR and SP logs correlation of the Tembungo wells.

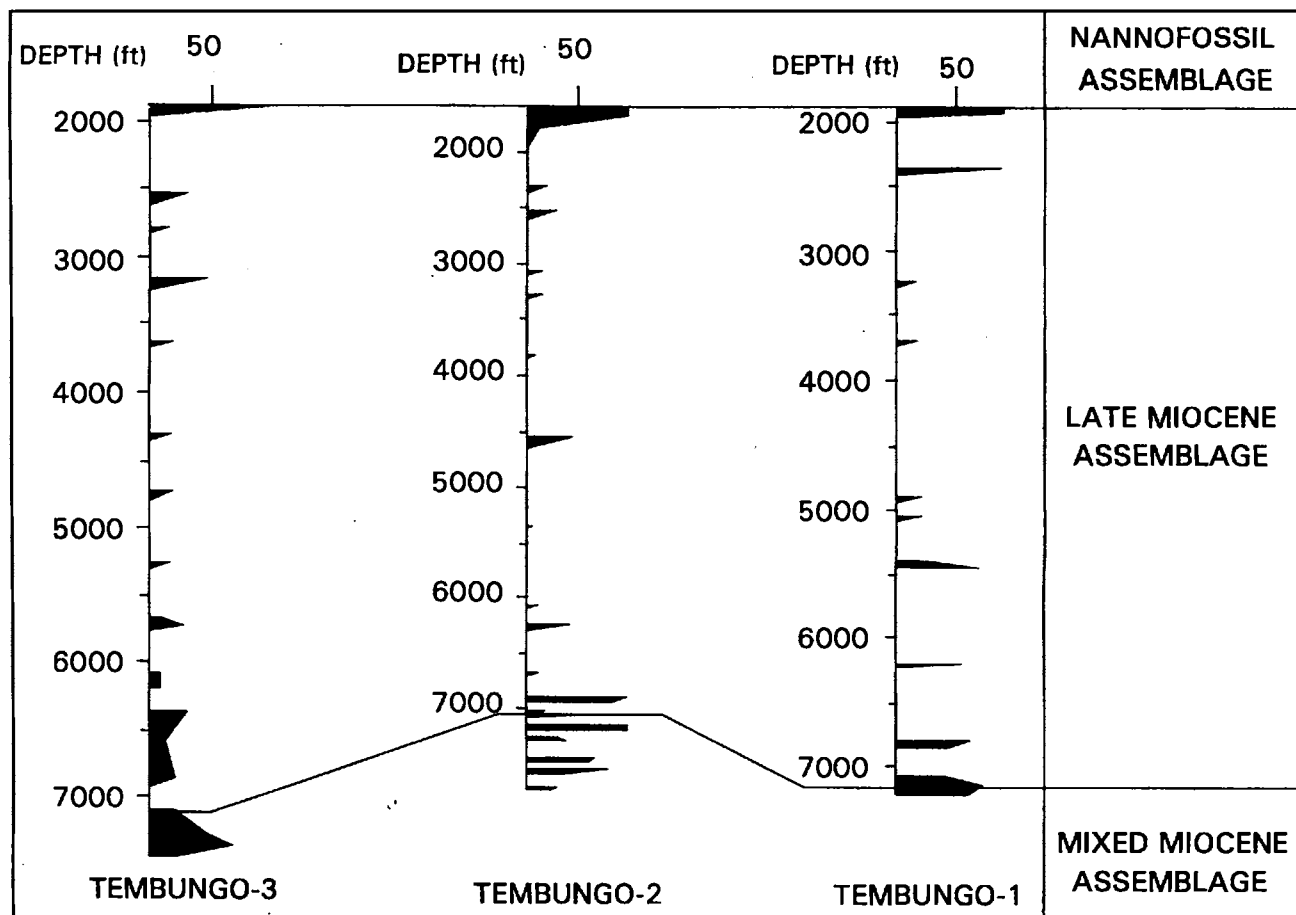


Figure 5. Nannofossil assemblages identified in the Tembungo area.

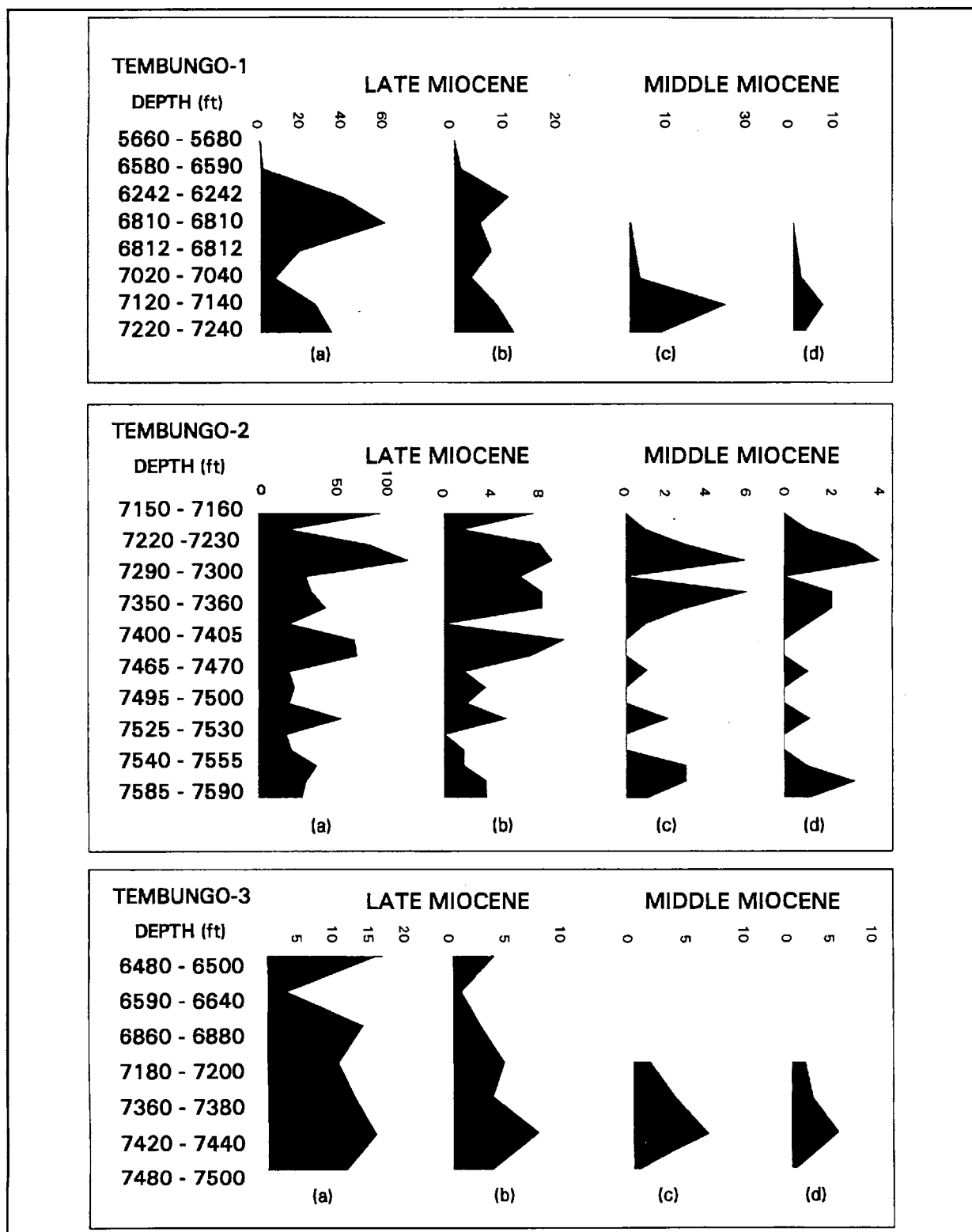


Figure 6. Distribution of nannofossil groups within the mixed Miocene assemblage of the Tembungo wells (a — Individuals count; b — Specific diversity; c — Individuals count; d — Specific diversity).

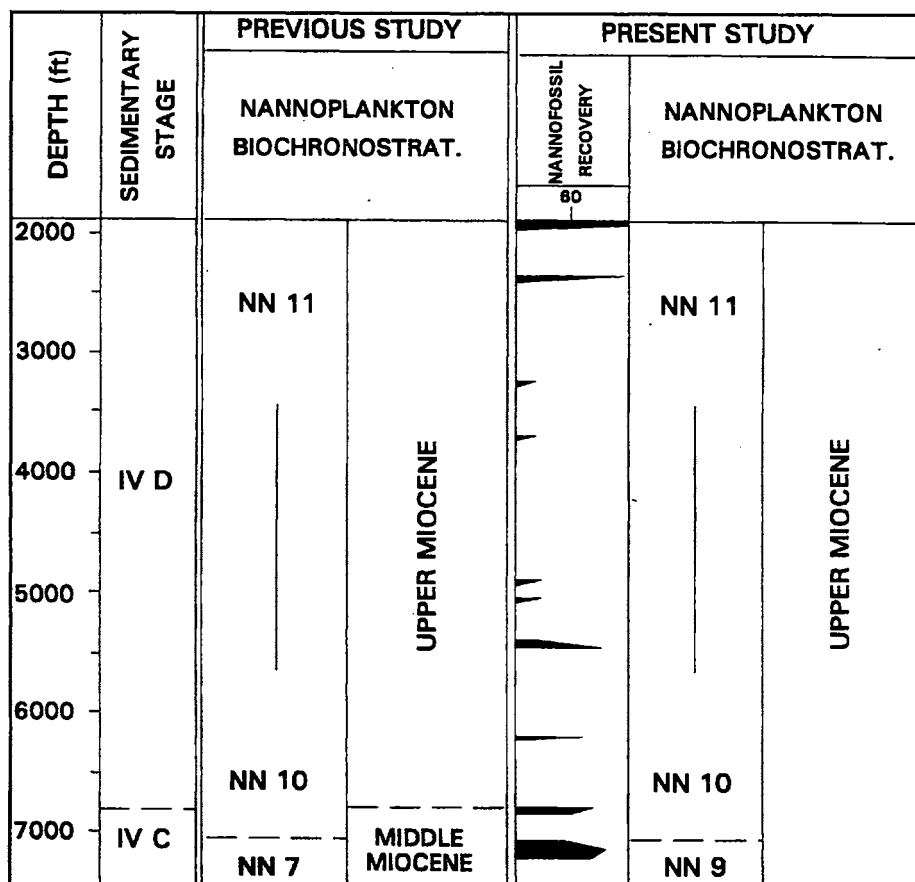


Figure 7. Nannofossils biochronostratigraphy of the Tembungo-1 well.

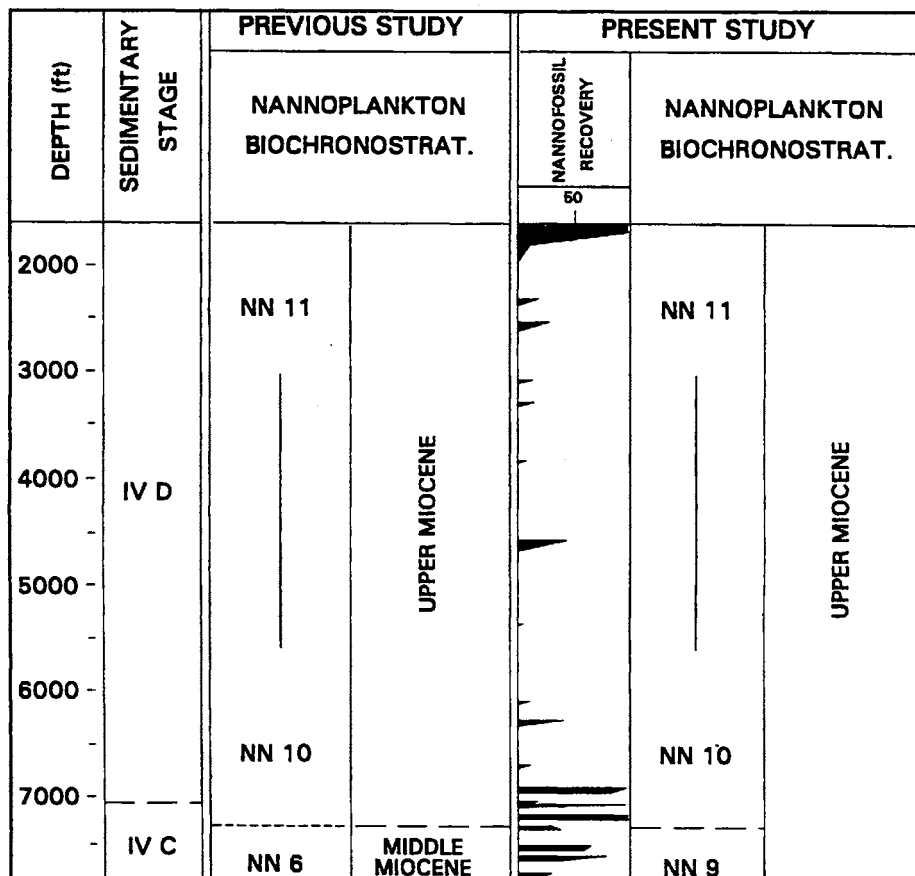


Figure 8. Nannofossils biochronostratigraphy of the Tembungo-2 well.

as due to contamination.

The results presented here are based on the integration of nannofossil data from three Tembungo wells (Tembungo-1, 2 and 3). The Miocene nannofossil assemblages observed, a good Late Miocene assemblage and a mixed assemblage of Late, Middle and Early Miocene forms (Fig. 5). The assemblage without mixing occur in the upper part of the Miocene and the 'mixed' assemblage is observed in the lower sections. This pattern is evident in each of the three wells studied.

The Miocene assemblage without mixing is composed of Late Miocene species of NN 10 to NN 11 zones. The prominent markers from this group are *Discoaster quinquaramus* and *Discoaster berggrenii*. They are associated with other Late Miocene species such as *Discoaster intercalaris*, *Discoaster pentaradiatus*, *Discoaster neohamatus*, *Discoaster calcaris*, *Discoaster prepentaradiatus* and *Mynilitha convalis* (Plate 1 and 2). The older Middle to Early Miocene species, *Cyclicargolithus floridanus* is also present but in negligible amounts (Tables 1, 2 and 3).

The mixed Miocene assemblage is characterised by the extensive mixing of the Late Miocene assemblages with older, mainly Middle Miocene assemblages. The Middle to Early Miocene marker, *Cyclicargolithus floridanus* is consistently present

through the lower part of each well in significant amounts. This species is commonly regarded as the marker for top NN 6 zone (Middle Miocene) on the basis of its highest occurrence (Chi, 1978; Varol, 1983). Associated with this marker are other Middle Miocene species such as *Discoaster exilis*, *Helicosphaera intermedia*, *Helicosphaera scissura* and *Discoaster kugleri*. This association of nannofossils, suggests nannoplankton zones NN 6 to NN 7 (Middle Miocene).

In addition to the Middle Miocene specimens, there are also older species present in the mixed Miocene assemblage. They include *Discoaster druggii* (NN 2-4), *Helicosphaera euphratis* (NP 21-NN 2), *Helicosphaera ampliaperta* (NN 2-NN 6), *Sphenolithus belemnus* (NN 2-3), *Calcidiscus formosus* and *Discoaster adamanteus* from the Early Miocene, and *Watznaueria barnesae*, *Heliolithus riedelli* and *Zygrhabdolithus bijugantus* from the Paleogene and Upper Cretaceous.

Among the Late Miocene species present are *Discoaster calcaris*, *Discoaster pentaradiatus*, *Discoaster pseudovariabilis*, *Discoaster intercalaris*, *Discoaster surculus*, *Discoaster neohamatus*, *Discoaster neorectus*, *Discoaster bellus*, *Discoaster bollii* and *Discoaster giganteus*. Besides the Discoasters, other coccolith and nannolith species present are *Sphenolithus abies*, *Catinaster*

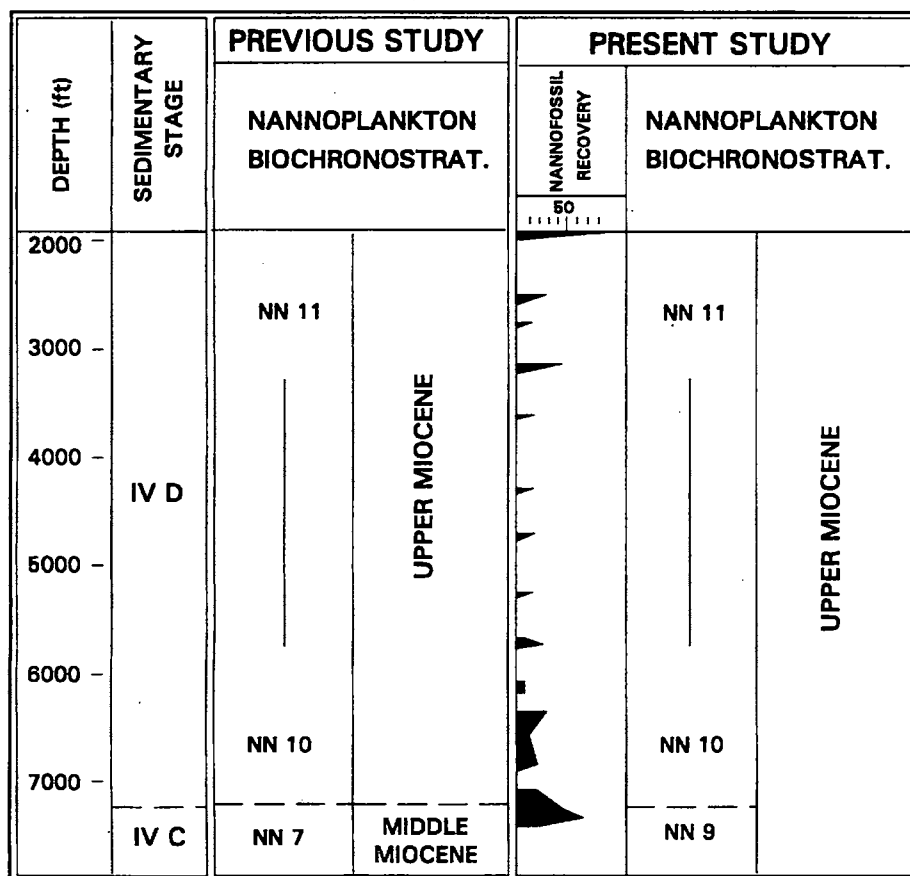


Figure 9. Nannofossils biochronostratigraphy of the Tembungo-3 well.

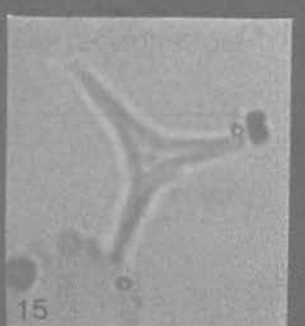
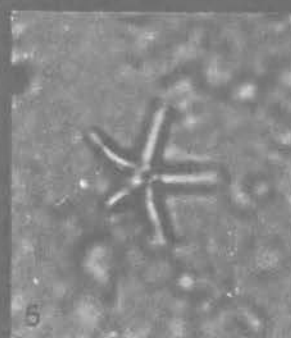
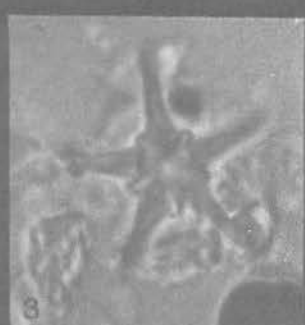


Table 1. Individuals count of nannofossils species within the mixed Miocene assemblage of the Tembungo-1 well.

DEPTH (ft)	LATE MIOCENE MARKER SPECIES														MIDDLE MIOCENE & OLDER MARKER SPECIES									
	<i>R. minuta</i>	<i>S. abies</i>	<i>D. prepentaradiatus</i>	<i>D. brouweri</i>	<i>D. variabilis</i>	<i>D. bollii</i>	<i>D. bellus</i>	<i>D. intercalaris</i>	<i>D. calcaris</i>	<i>D. neohamatus</i>	<i>H. pentaradiatus</i>	<i>D. laeblichii</i>	<i>D. neorectus</i>	<i>M. convalis</i>	<i>D. surculus</i>	<i>D. quinqueremus</i>	<i>D. druggii</i>	<i>C. floridanus</i>	<i>S. moriformis</i>	<i>D. exilis</i>	<i>Z. bijugatus</i>	<i>H. riedelli</i>	<i>H. ampliaperta</i>	<i>H. scissura</i>
5660 - 5680	1																							
6580 - 6590	1	1																						
6242 - 6242		5	2	7	1	2	3			7				1		8								
6810 - 6810	1	3	23	6		1	1	2	1	3	2					27			1					
6812 - 6812	6	2	9			2																		5
7020 - 7040	1		1			3								1				6	5				1	
7120 - 7140			4	6		4	1	1	3								1	16	15			1		
7220 - 7240	1	10	13	1	3	8	2	3	1			1	3	3	1			5	2	1	1			

Table 2. Individuals count of nannofossils species within the mixed Miocene assemblage of the Tembungo-2 well.

DEPTH (ft)	LATE MIOCENE MARKER SPECIES															MIDDLE MIOCENE & OLDER MARKER SPECIES											
	<i>D. calcaris</i>	<i>C. pentaradiatus</i>	<i>D. pseudovariabilis</i>	<i>S. abies</i>	<i>C. mexicanus</i>	<i>D. intercalaris</i>	<i>D. surculus</i>	<i>D. variabilis</i>	<i>M. convalis</i>	<i>D. prepentaradiatus</i>	<i>D. hamatus</i>	<i>D. neohamatus</i>	<i>D. bellus</i>	<i>D. neorectus</i>	<i>D. bollii</i>	<i>D. brouweri.</i>	<i>H. euphratis</i>	<i>T. challengerii</i>	<i>C. floridanus</i>	<i>H. scissura</i>	<i>D. exilis</i>	<i>H. ampliaperta</i>	<i>D. adamantinus</i>	<i>H. intermedia</i>	<i>W. barnesae</i>	<i>C. luminis</i>	<i>H. riedellii</i>
7150 - 7160	1	2	2	32						20		1				5									2		
7220 - 7230	2	5		30				3		3			2	1		1	1		1	1					1		
	8		1	30				3	4	30			5	2	2	18			1	3							
7290 - 7300	1					1		2		5			2			10											
7350 - 7360	5			3	1			2		3			1		2	4				1							
	2			12		4		1		2			3	1		12				1							
7400 - 7405	1		1				2	1		45	2		3	2		10									1		
	2			1						13	3		4			30											
7465 - 7470										1		2															2
	2									1			1			2											
7495 - 7500										1						2											
7525 - 7530	1			5						13		1				10				2							
	1			7																3							
7570 - 7575	1			7										1		6				3		1			1		
	1						1				1		1			2								1			
7665 - 7670										1			1												1		

Plate 1: All the photographs of magnifications x2,500

- 1, 2 & 5. *Discoaster quinquaramus*
- 3 & 4. *Discoaster berggrenii*
6. *Triquetrorhabdulus* sp.
7. *Discoaster sanmiguellensis*
8. *Discoaster neohamatus*

- 9, 10, 11, 13, 14 & 16. *Discoaster bellus*
12. *Discoaster asymmetricus*
15. *Discoaster* sp. cf. *D. hamatus*
17. *Discoaster hamatus*
- 18 & 19. *Discoaster prepentaradiatus*

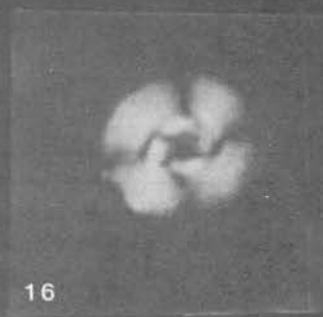
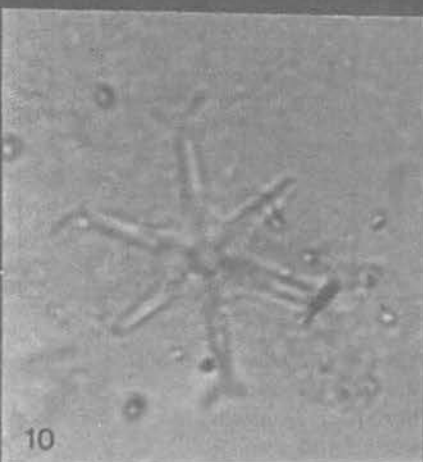
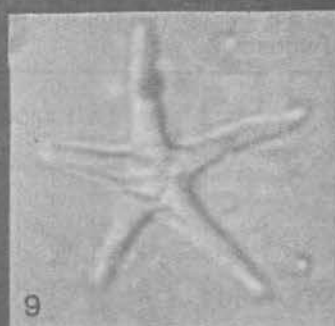
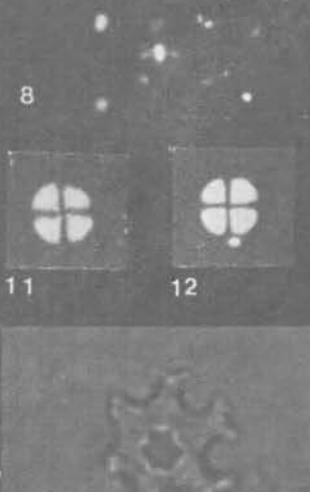
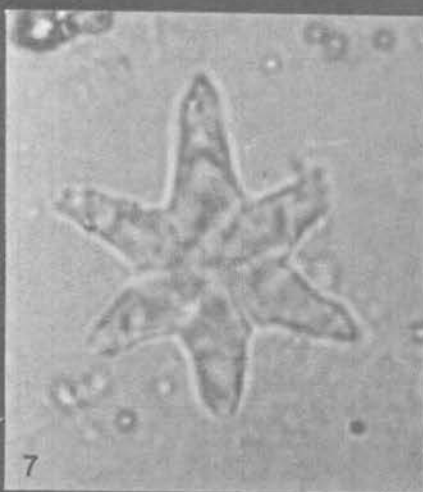
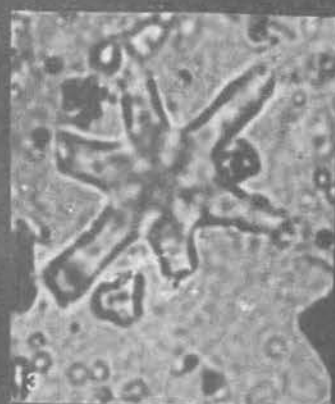


Table 3. Individuals count of nannofossils species within the mixed Miocene assemblage of the Tembungo-3 well.

DEPTH (ft)	LATE MIOCENE MARKER SPECIES										MIDDLE MIOCENE & OLDER MARKER SPECIES							
	<i>D. bellus</i>	<i>S. abies</i>	<i>D. brouweri</i>	<i>R. minuta</i>	<i>D. hamatus</i>	<i>D. calcaris</i>	<i>D. bollii</i>	<i>D. blackstockae</i>	<i>D. intercalaris</i>	<i>H. euphratis</i>	<i>D. scissura</i>	<i>D. exilis</i>	<i>D. kugleri</i>	<i>D. floridanus</i>	<i>C. abisectus</i>	<i>C. luminis</i>	<i>S. belemnus</i>	<i>E. formosus</i>
6480 - 6500	2	2																
6590 - 6640	1	5	1	2						1	1							
6860 - 6880																		
7180 - 7200	1	1	1							1	1							
7360 - 7385	3		1									1	1					
7420 - 7440		5		5	1	1	1	1	2		1				1	1	1	1
7480 - 7500		3	2		4						1							

Table 4. Individuals count of nannofossils species within the mixed Miocene assemblage of the Dudar-1 well.

DEPTH (ft)	LATE MIOCENE MARKERS														MIDDLE MIO. MARKERS				EARLY MIOCENE MARKERS									
	<i>D. bellus</i>	<i>C. mexicanus</i>	<i>D. bollii</i>	<i>S. abies</i>	<i>D. calcaris</i>	<i>D. neorectus</i>	<i>D. challengeri</i>	<i>D. loeblichii</i>	<i>R. pseudoumbilica</i>	<i>D. pensus</i>	<i>D. pentaradiatus</i>	<i>D. neohamatus</i>	<i>D. intercalaris</i>	<i>D. hamatus</i>	<i>D. tribrachiatus</i>	<i>D. kugleri</i>	<i>D. musicus</i>	<i>D. exilis</i>	<i>C. floridanus</i>	<i>D. deflandrei</i>	<i>C. abisectus</i>	<i>D. druggii</i>	<i>D. adamentus</i>	<i>H. ampliaperia</i>	<i>S. anarrhophus</i>	<i>S. belemnus</i>	<i>S. heteromorphus</i>	<i>T. carinatus</i>
6370 - 6380	1	2	1	6	2	3										5	2											
6500 - 6520																												
6560 - 6580																												
6740 - 6760							1											16		7								
6780 - 6790			1	5	2	1		4										4		1	2							
6810 - 6820																												
6930 - 6940																												
7020 - 7030			2	50					7	1						8		2	2	10								
7620 - 7630	23		2	10		4		1	4		2	1								1	8							
7920 - 7930				2	2	4		1			1							1			2							
7980 - 7990		1	3	50					30							8		1		10	7	2	1					
8100 - 8110	1			8		12			7				4			4					2							
8250 - 8260				7		1			20											5		2	2	2				
8370 - 8380				1					2									3		1								
8700 - 8710																												
8820 - 8830									1							1				2								
9220 - 9230	1		2	24	2	4			12	5	1	1	5			1		2		1	3			1	1	1		
9350 - 9360																			1									
9470 - 9480			2	13	4	3		1	2	4				1		1				1	1			1			1	2
9530 - 9540												1	1			2		17	1		2	3	2					
9550 - 9560			1	12	4													1			1							

Plate 2: All the photographs of magnification x2,500

- 1 & 14. *Discoaster bollii*
2. *Discoaster aulakos*
3. *Discoaster giganteus*
- 4 & 7. *Discoaster druggii*
5. *Reticulofenestra pseudoumbilica*
6. *Discoaster brouweri*
8. *Sphenolithus heteromorphus*
9. *Discoaster quinqueramus*
10. *Discoaster exilis*
- 11 & 12. *Cyclococcolithus luminis*
13. *Discoaster asymmetricus*
15. *Discoaster subsurculus*
16. *Cyclicargolithus floridanus*

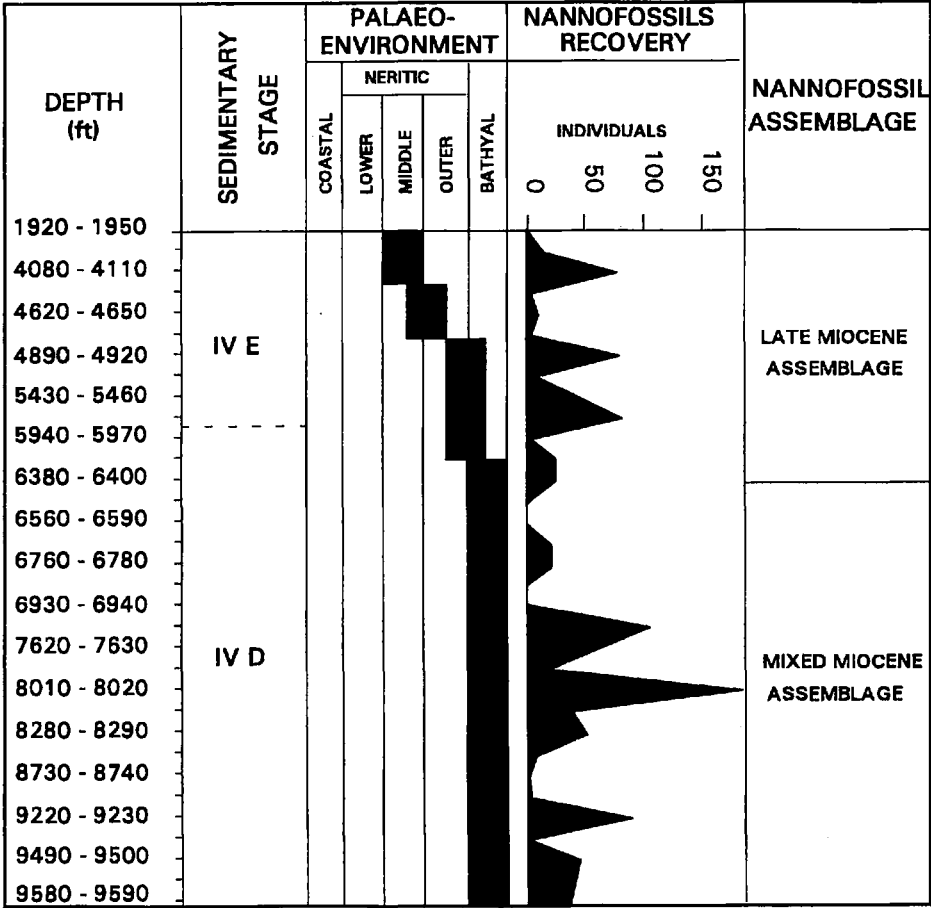


Figure 10. Nannofossil assemblages identified in Dudar-1 well.

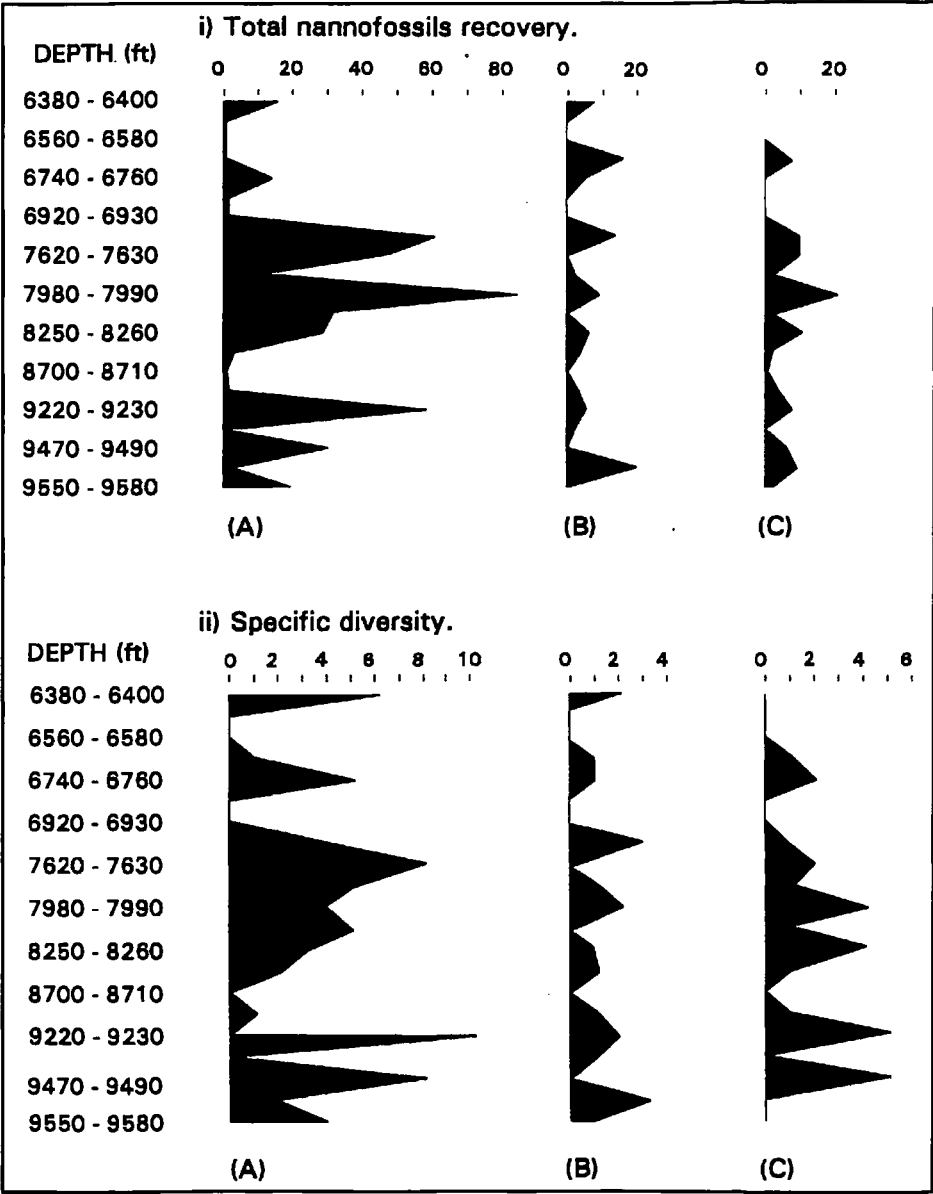


Figure 11. Distribution of nannofossil groups within the mixed Miocene assemblage of Dudar-1 well (A — Late Miocene markers; B — Middle Miocene markers; C — Early Miocene markers).

mexicanus, *Mytilitha convalis* and *Reticulofenestra* spp. Most of the Discoasters recovered, appear as non-typical forms which sometimes are very difficult to identify. They seem to have undergone partial dissolution which has altered their original outline. They are therefore morphologically different from those forms observed above where pre-Late Miocene nannofossils are virtually absent.

The present conclusion for the age of the lowermost interval of the Tembungo wells is based on the quantitative nannofossil data. These data permit the differentiation between the indigenous forms and the contaminants. The high individual frequency, specific diversity and preservational evidence for dissolution are taken as criteria for determining the indigenous assemblage. The Late Miocene nannofossil forms within the mixed Miocene assemblage are dominant in each the studied wells (Fig. 6). Their individual frequency and specific diversity are higher than that of older nannofossil groups and because of this, it is concluded that the Late Miocene nannofossils assemblages are indigenous and that the older forms are the result of reworking. By considering the species content within the Late Miocene assemblage, the appropriate nannoplankton

zonation for this interval is NN 9 zone.

B) Dudar-1 Well

Dudar-1 well was drilled in 1971 by EPMI (Esso Production Malaysia Inc.) in the offshore area of north-west Sabah (EPMI, 1971) (Fig. 1). The chronostratigraphy of this well was initially based on foraminiferal analysis. It was suggested that this well penetrated Middle and Lower Miocene strata (Fig. 12). In this study quantitative calcareous nannofossil analysis was undertaken covering the entire Miocene sections of the well (1,920' to 9,590').

The recovery of nannofossils throughout the studied section is fairly good. Assemblages were again dominated by Late Miocene species. However, in the lower section of the well, Late Miocene species are again associated with common Early Miocene, Middle Miocene and Paleogene nannofossils (Fig. 10 and Table 4). Based on these assemblages, the section studied is divided into an upper interval of Late Miocene unmixed assemblage and a lower interval of mixed assemblage. The upper interval is identified from 4,080' to 6,400' and the mixed assemblage occur from 6,400' to 9,590'.

The Upper Interval contains the marker species

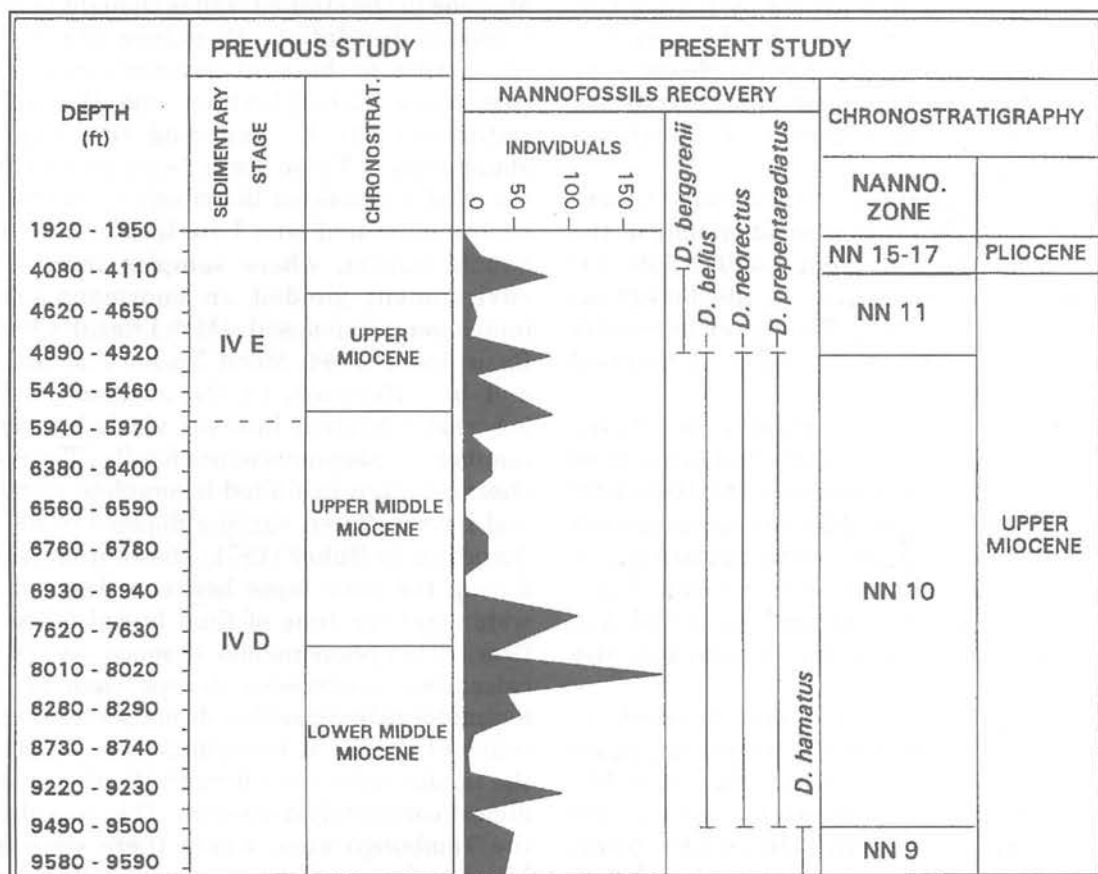


Figure 12. Nannofossils biochronostratigraphy of the Dudar-1 well.

Discoaster berggrenii, *Discoaster quinqueramus*, *Discoaster bellus* and *Discoaster neorectus*. On the basis of these forms, the interval can be divided into two zones, zones NN 11 and NN 10 of Upper Miocene (Fig. 12).

Quantitative nannofossil analysis on the lower mixed interval shows traces of major assemblages of Late Miocene, Middle Miocene and Early Miocene (Fig. 11 and Table 4). Older Paleogene specimens are also present, but in minor quantities.

Comparison of the diversity and frequency of the above groups clearly shows the dominance of the Late Miocene assemblage over the other two assemblages, and suggests that the more diverse Late Miocene assemblage is indigenous and that the other two groups are due to reworking (Fig. 11).

Examination of the Late Miocene assemblages suggest that the mixed interval can be referred to the following nannofossil zones: the interval from 4,890' to 9,500' is assigned to zone NN 10 by the presence of *Discoaster neorectus*, *Discoaster bellus*, *Discoaster neohamatus*, *Discoaster calcaris*, *Discoaster loeblichii*, *Discoaster bollii* and *Catinaster mexicanus*, whereas the underlying interval from 9,490' to 9,590' is assigned to zone NN 9 by the presence of *Discoaster hamatus* (Fig. 12).

C) Rusa Timur-1

The Rusa Timur-1 was drilled by British Gas Malaysia in 1990. The well has been reported to penetrate the substage IV A of Middle Miocene age through an integrated biostratigraphical analysis, involving mainly foraminifera and calcareous nannofossils (Fig. 15).

In general, the calcareous nannofossils recovery is good (Fig. 13). They are more abundant in the upper section of the well from 1,420'–3,510' but they are comparatively scarce in the lowermost interval, from 5,500'–7,450'. This lower interval is separated from the upper interval by an interval without nannofossils recovery.

The upper fossiliferous interval, is dominated by Late Miocene species. This interval is assigned to NN 11 zone by the dominance of *Discoaster quinqueramus*. Other Late Miocene forms present are *Discoaster berggrenii*, *Discoaster pentaradiatus*, *Sphenolithus abies* and *Discoaster brouweri* (Table 5). Besides the Late Miocene species, the Middle Miocene species, *Cyclicargolithus floridanus* is also present, but rare.

The lower interval is characterised by comparatively rare nannofossils, which are again dominated by a Late Miocene assemblage (Fig. 14). Late Miocene species present are *Discoaster neorectus*, *Mynilitha convalis*, *Discoaster bollii*, *Discoaster intercalaris*, *Discoaster prepentaradiatus*, *Discoaster calcaris*, *Discoaster braarudi* and

Tetralithoides symmeonidesii. Older nannofossil species are also present. These include *Cyclicargolithus floridanus* and *Discoaster kugleri*. Considering the higher specific diversity and individual frequency of the components of the Late Miocene assemblage, this interval is assigned to zone NN 10.

DISCUSSION AND CONCLUSION

There are two obvious nannofossil assemblages in the Upper Miocene of the studied wells; the 'unmixed' and the mixed Miocene assemblage. The unmixed assemblage that is found within the upper section of Upper Miocene sequence, reflects the true indigenous nannofossils content of the Upper Miocene with minimum contaminations. Accordingly, the chronostratigraphic interpretation of the upper section of Upper Miocene can be done without much difficulty. However, for the mixed lower sections, a reasonable chronostratigraphic interpretation is only possible with the aid of quantitative data. This is due to the presence of high amounts of reworked nannofossil specimens together with an impoverished indigenous assemblage.

The impoverishment of indigenous calcareous nannofossils in the lower sections of the Upper Miocene in the studied well is thought to be related to partial dissolution. By nature, the sea water in the neritic or bathyal environments is rich in calcareous nannoplankton and the underlying sediments can be expected to contain them abundantly. These have been proven from the study of nannofossil distributions in the modern environment and on a Late Quaternary section of Sabah margin, where samples from a bathyal environment yielded an enormous amount of indigenous nannofossils (Mohd Razali Che Kob and Basir Jasin, 1994; Mohd Razali Che Kob, 1993 a and b). However, in the studied sections the lowermost bathyal interval yielded a very small number of indigenous nannofossils. The specimens observed often exhibited incomplete morphologies and have suffered varying degrees of dissolution. According to Bukry (1971), dissolution takes place during the time lapse between death in surface water and the time of final burial below the sea floor. This phenomenon is more severe in other calcareous microfossil groups such as planktic foraminifera because they do not possess any organic celluloid shields as in nannofossils. In most cases, the *in situ* calcareous foraminiferal specimens are almost completely dissolved. This was observed in the Tembungo area, where there were few Late Miocene foraminifera preserved in the lowermost interval, but had significant amounts of

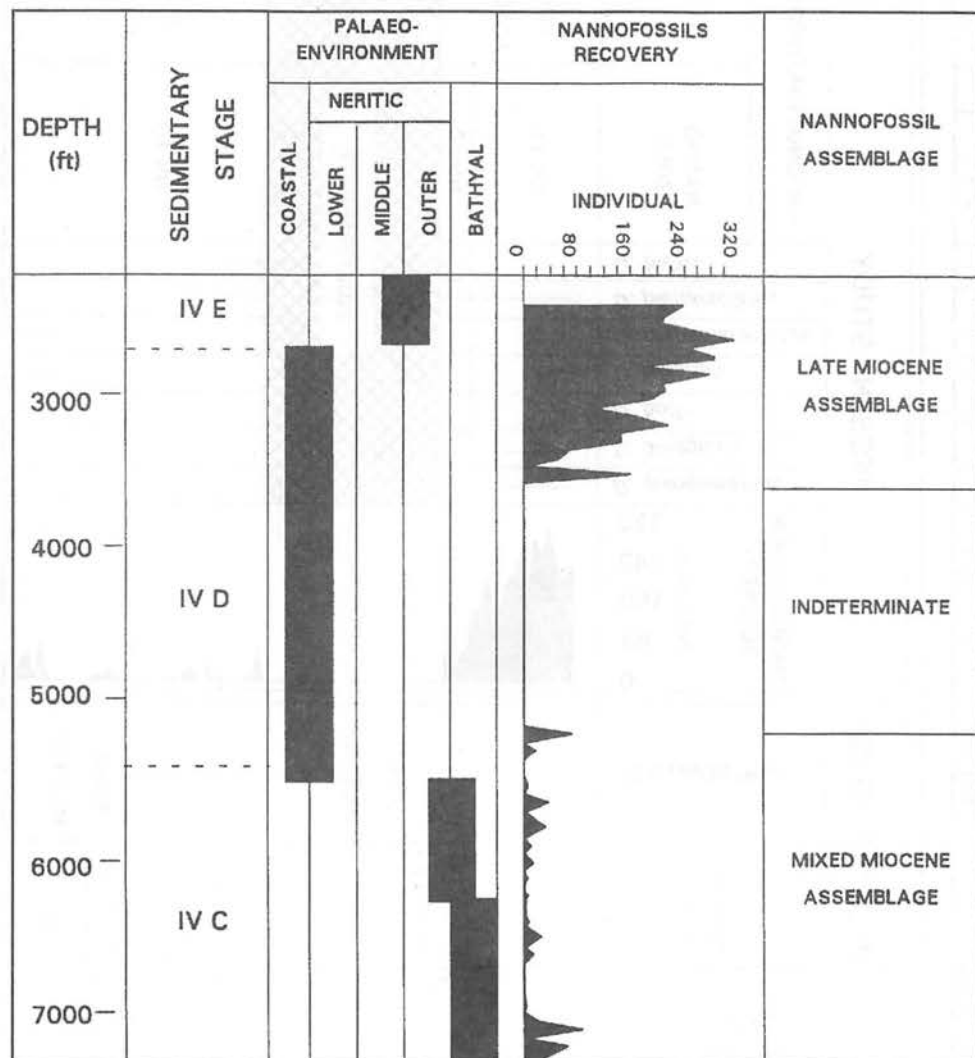


Figure 13. Nannofossil assemblages identified in the Rusa Timur-1 well.

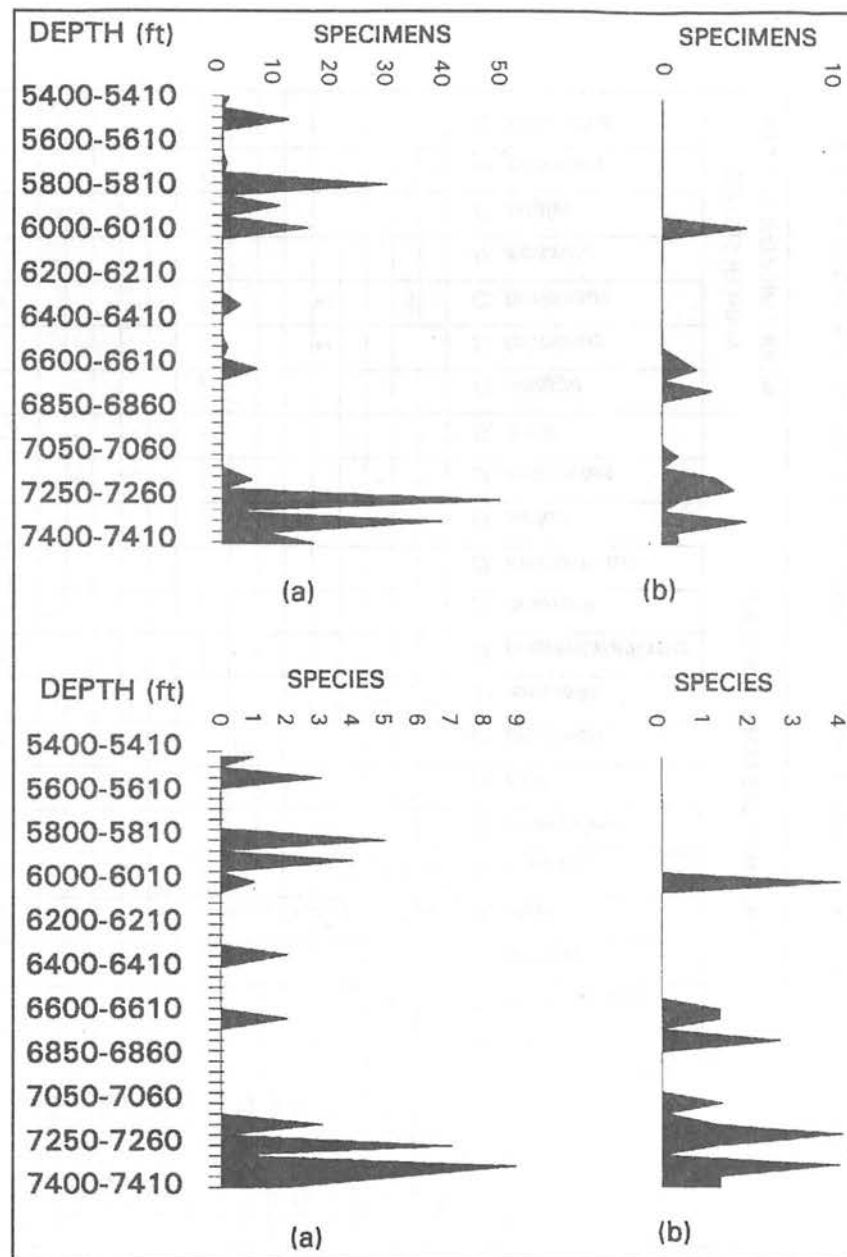
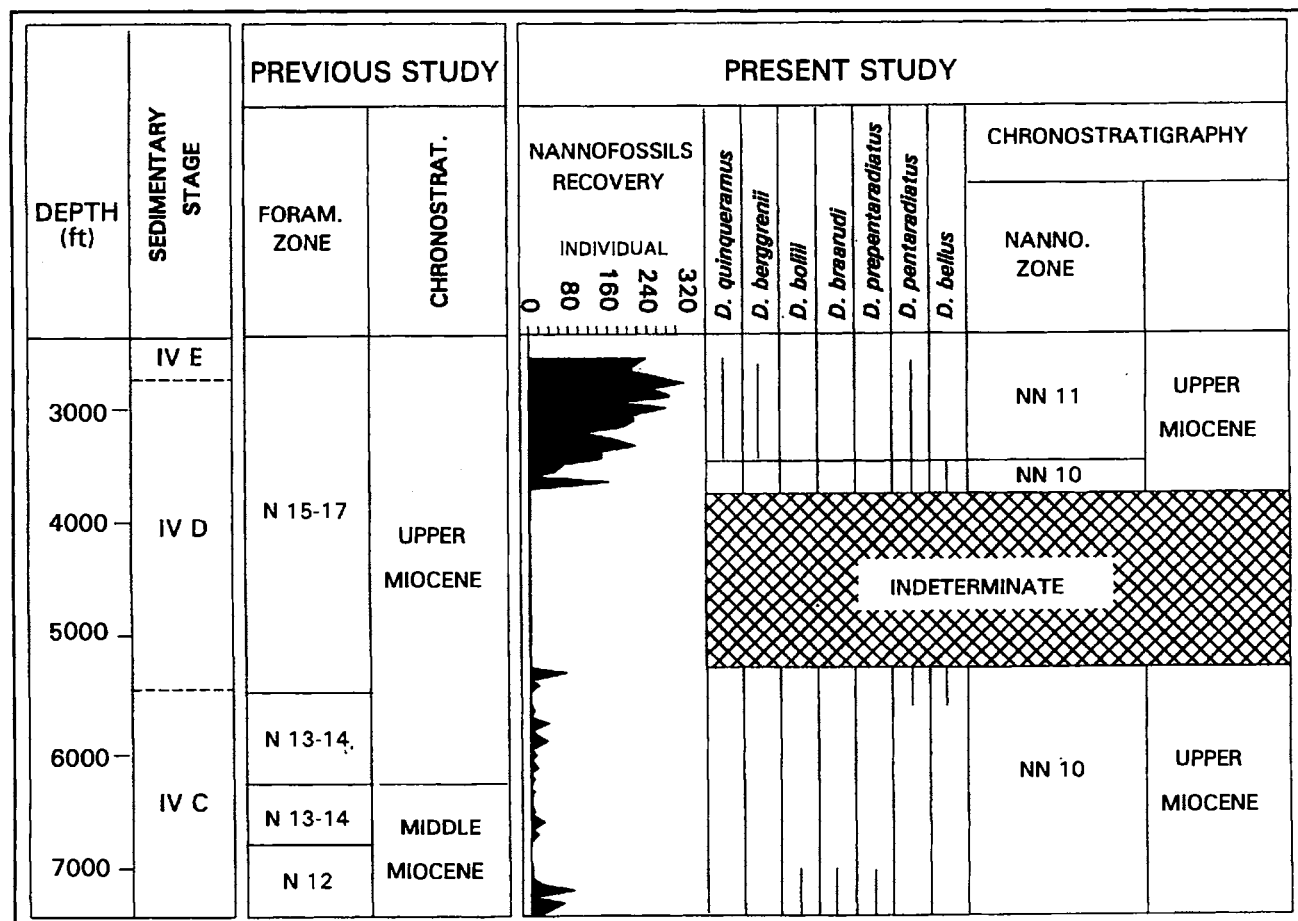


Figure 14. Distribution of nannofossil groups within the mixed Miocene assemblage of the Rusa Timur-1 well (a — Individuals count; b — Specific diversity).

Table 5. Individuals count of nannofossils species within the mixed Miocene assemblage of the Rusa Timur-1 well.

DEPTH (ft)	LATE MIOCENE MARKER SPECIES														MIDDLE MIOCENE & OLDER MARKER SPECIES							
	<i>D. calcaris</i>	<i>C. pentaradiatus</i>	<i>A. primus</i>	<i>S. abies</i>	<i>R. minuta</i>	<i>D. intercalaris</i>	<i>D. raoi</i>	<i>D. brouweri</i>	<i>M. convalis</i>	<i>D. prepentaradiatus</i>	<i>D. braarudi</i>	<i>D. neohamatus</i>	<i>D. bellus</i>	<i>D. neorectus</i>	<i>D. bollii</i>	<i>D. druggii</i>	<i>E. formosus</i>	<i>C. floridanus</i>	<i>H. scissura</i>	<i>D. kugleri</i>	<i>W. barnesae</i>	<i>D. deflandrei</i>
5400 - 5410	1			2	1				1													
5700 - 5710				5	10																	
5800 - 5810				16	10		1		1					1								
5900 - 5910				4	15																	
6000 - 6010				16	3												2	2				
6100 - 6110				2																		
6200 - 6210				5	1																	
6300 - 6360				2				2														
6400 - 6410																						
6550 - 6560									2													
6700 - 6710				4			5											2				
6800 - 6810					2													1				
6900 - 6910																						
7210 - 7220				2										2	1					2		1
7250 - 7260				27	16	1		1	1		2			5					1	2		1
7300 - 7310																						
7350 - 7360		1		30	2			4		1	1				1			3		3		
7380 - 7410				10	4				3					1				1			1	

**Figure 15.** Nannofossils biochronostratigraphy of the Rusa Timur-1 well.

nannofossils. As a result of this, the older reworked foraminifera deposited as a result of gravity flow processes were mistaken for *in situ* forms.

The presence of abundant redeposited older fauna and flora in younger strata is a common feature in the Sabah Basin. Sedimentological studies in Tembungo field revealed a series of turbidite sequences in the lowermost interval of each well (Fig. 4). Together with these sediments are their biotic components in the form of reworked fossils, which can be misinterpreted as indigenous especially when occurring in abundance. Previously, the lesser indigenous forms were generally regarded as caved contaminants. Quantitative approach adopted in this study allows the caved species assemblages peak to be easily recognised. Abnormal abundance peaks could also be related to caving. This is quite common at or around the casing points in the drilled holes. Critical sampling, by cross-checking selected samples with the electric log patterns also help in determining levels of possible contamination.

Reworking of older sediments is a natural process occurring continuously throughout geologic periods. The question that arises is how extensive is the reworking. The presence of rare reworking is common in the fossil records, and can easily be recognised. The reworked fossils may be differentiated easily from the indigenous by their secondary features such as rolled features in foraminiferal tests. In the case of calcareous nannofossils, secondary features are difficult to determine and only correct species identification and quantitative documentation may help to overcome this.

The extensive reworking of calcareous nannofossils in Dudar-1 and Tembungo wells is related to the active regional tectonic activity during Late Miocene. Extensive down slope movements have been reported to occur in the form of slumps, slides, debris flow or turbidites (Levell and Kasumajaya, 1985; Ismail, 1992; Levell, 1987 and Rice-Oxley, 1991). A few unpublished reports have shown some degree of fossils mixing of various ages. The wells Solisip-1 and Semuan-1 for example are reported to penetrate the Middle Miocene strata (Musa Musbah and Hagemen, 1986). Closer examination of the reported fossils revealed a mixture of Middle and Late Miocene nannofossils within the lower most interval. Hence, it is believed that the older nannofossils are reworked fossils and the well did not penetrate the Middle Miocene section.

According to Levell and Kasumajaya (1985), traces of slump scars are known from various localities along the 250 km long Late Miocene shelf-edge in offshore Sabah (Figs. 16 and 17). It is likely

that the reworking scenario can be expected throughout the Upper Miocene of Sabah Basin. Considering this, it is crucial to acquire nannofossils quantitative data in order to accurately define the chronostratigraphy of this basin.

In conclusion, the difficulties in zonal and chronological assignments in the lowermost admixed intervals are due to the mixing of impoverished indigenous nannofossils and the extensive occurrence of reworked specimens. The former is believed to be related to partial dissolution, whereas the latter is related to the extensive down-slope movement in Sabah Basin during Late Miocene as a result of gravity flow processes. Hence, most of the previous chronological assignments for the Miocene turbiditic sequences of Sabah Basin are believed to have been misinterpreted and in need of revision. Through quantitative calcareous nannofossil analysis the right chronology for these sequences can be obtained.

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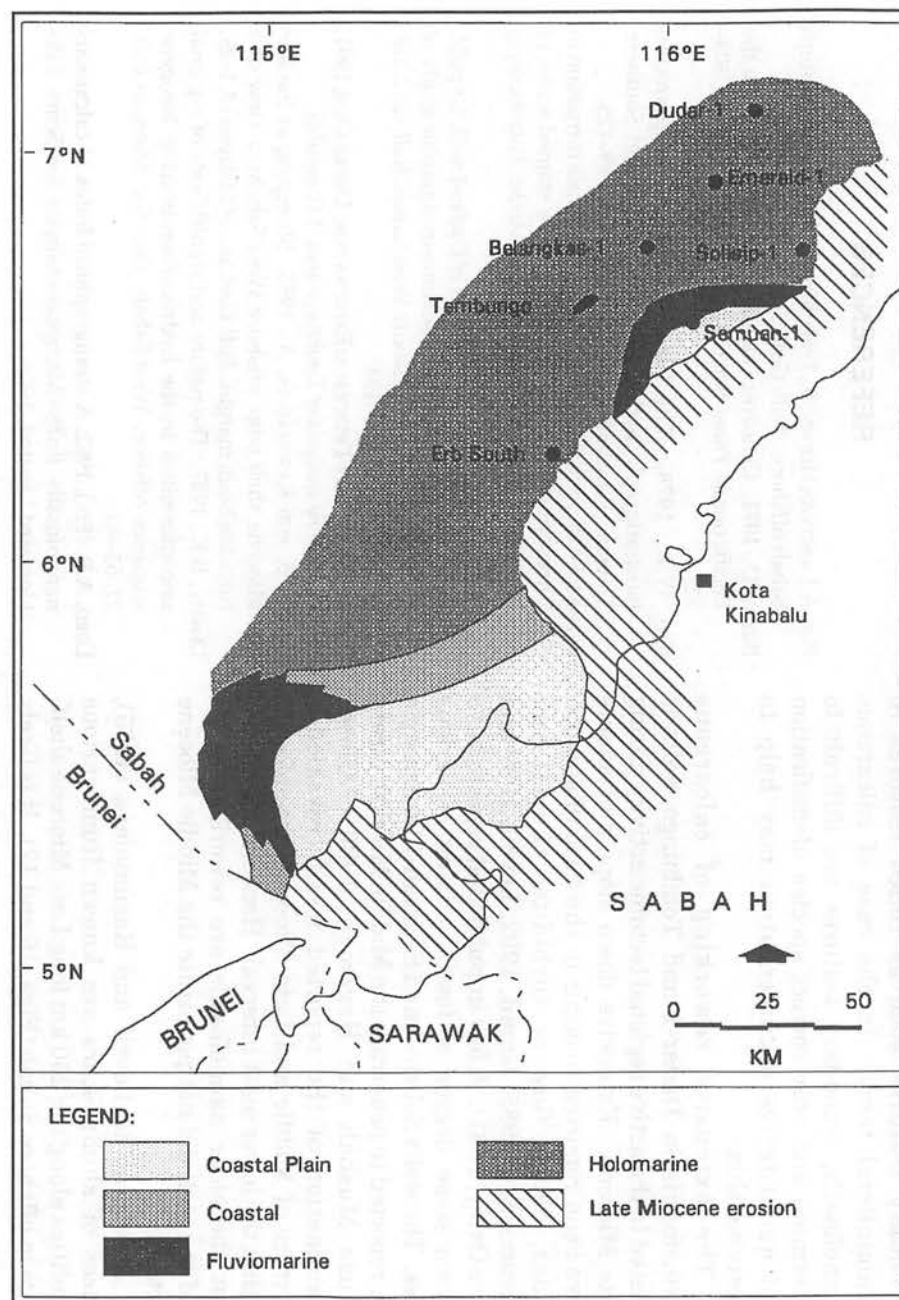


Figure 16. The Late Miocene paleofacies map of Sabah Basin (modified after Rice-Oxley, 1991).

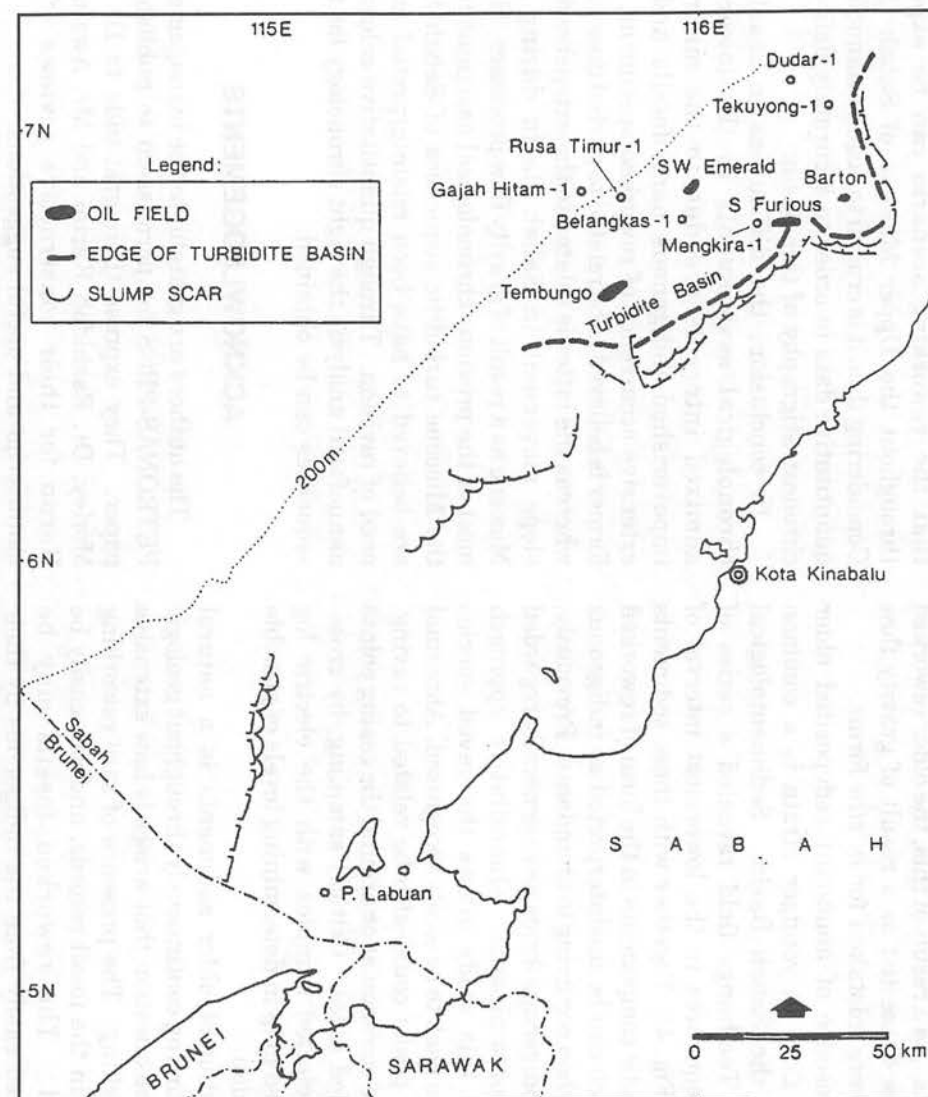


Figure 17. The Late Miocene/Pliocene shelf edge of Sabah Basin (after Levell and Kasumajaya, 1985).

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