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Dinoflagellate cyst biostratigraphy of Tertiary and Quaternary deposits of offshore NW Borneo

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Abstract: Palynological investigations in the Tertiary and Quaternary of SE Asia traditionally have been focussed upon the interpretation of quantitative and qualitative changes in the successive pollen and spore spectra of the fossil record. These changes have been used to establish detailed (inter) regional stratigraphical correlations and to interpret the depositional environment of the predominantly coastal plain to shallow marine sequences. Microplankton (dinoflagellate cysts and acritarchs) played a minor role in these palynological investigations. However, preliminary results of recent palynological investigations focussed upon microplankton from offshore Tertiary and Quaternary deposits of NW Borneo, demonstrate that the potential of especially dinoflagellate cysts in stratigraphical correlations has not been fully exploited.

This paper presents the stratigraphic ranges of selected microplankton taxa from 56 wells in the Late Paleocene to Quaternary interval, offshore NW Borneo. In addition, published dinoflagellate cyst and acritarch records from SE Asia s.l. are summarized.

The dinoflagellate cysts generally are a minor constituent of the palynological assemblages. Most of the taxa recorded are long-ranging and well-known from other low, mid and high latitude areas. The data available suggests the presence of seven informal dinoflagellate cyst assemblage groups in the Late Paleocene to Quaternary interval. Preliminary results on environmental preferences of dinoflagellate taxa suggests that representatives of the *Cribroperidium-Apteodinium* complex, *Homotryblium* spp., *Hystrichokolpoma* spp., *Achomosphaera* spp. and non-tabulate chorate cysts like *Lingulodinium ?pycnospinosum* and *Operculodinium* spp. show relationships with specific depositional environments.

INTRODUCTION

This paper discusses the potential of microplankton (dinoflagellate cysts and acritarchs) as a tool to date and correlate marginally to fully marine Tertiary-Quaternary deposits in offshore NW Borneo (Fig. 1). It furthermore focuses on the application of especially dinoflagellate cysts as an additional parameter to assess depositional environments in the marine regime.

Traditionally palynological investigations in tropical Tertiary and Quaternary deposits of SE Asia have been focussed on the interpretation of the qualitative and quantitative changes in pollen and spores spectra of successive assemblages (Germeraad *et al.*, 1968; Muller, 1972; Morley, 1976; 1978; 1988; 1991; Chow, 1977; Zaklinskaya, 1978, Barre de Cruz, 1982; Caratini and Tissot, 1987, 1988; Poumot, 1989; Watanasuk, 1990; Somboon, 1990). The application of microplankton in biostratigraphical investigations has been very limited. Generally microplankton has not been subdivided into taxonomic entities and only the combined presence of representatives of this group was used to indicate marine environments (Barre de Cruz, 1982; Caratini and Tissot, 1985; Poumot, 1989; James, 1984).

Despite the vast amount of literature on Tertiary dinoflagellate cysts which has become available over the last decade (AASP, 1986, 1992), information from SE Asia is rather restricted (Fig. 1). The presence of dinoflagellate cysts in the Cretaceous to Eocene deposits of SW Sarawak was reported by Muller (1968). Two new species from Early Miocene and Middle Miocene to Pliocene deposits of north central Sumatra were described by Drugg (1970). The dinoflagellate cysts from the Paleogene and Miocene of Central Java and the Late Pleistocene to Holocene of the northern Philippine Sea were discussed by Matsuoka (1981a, b, 1983a, 1984). The papers by these authors mainly present an inventory of dinoflagellate cysts encountered in the Tertiary to Quaternary strata but do not provide a comprehensive biozonal framework which can be used within SE Asia. Brown carried out detailed investigations within the Neogene of Sumatra and the Late Eocene-Oligocene of Southeast Kalimantan (Brown, 1988; in prep., Morley, 1991). Based on LADs of specific dinoflagellate cysts Brown (1988) outlines an

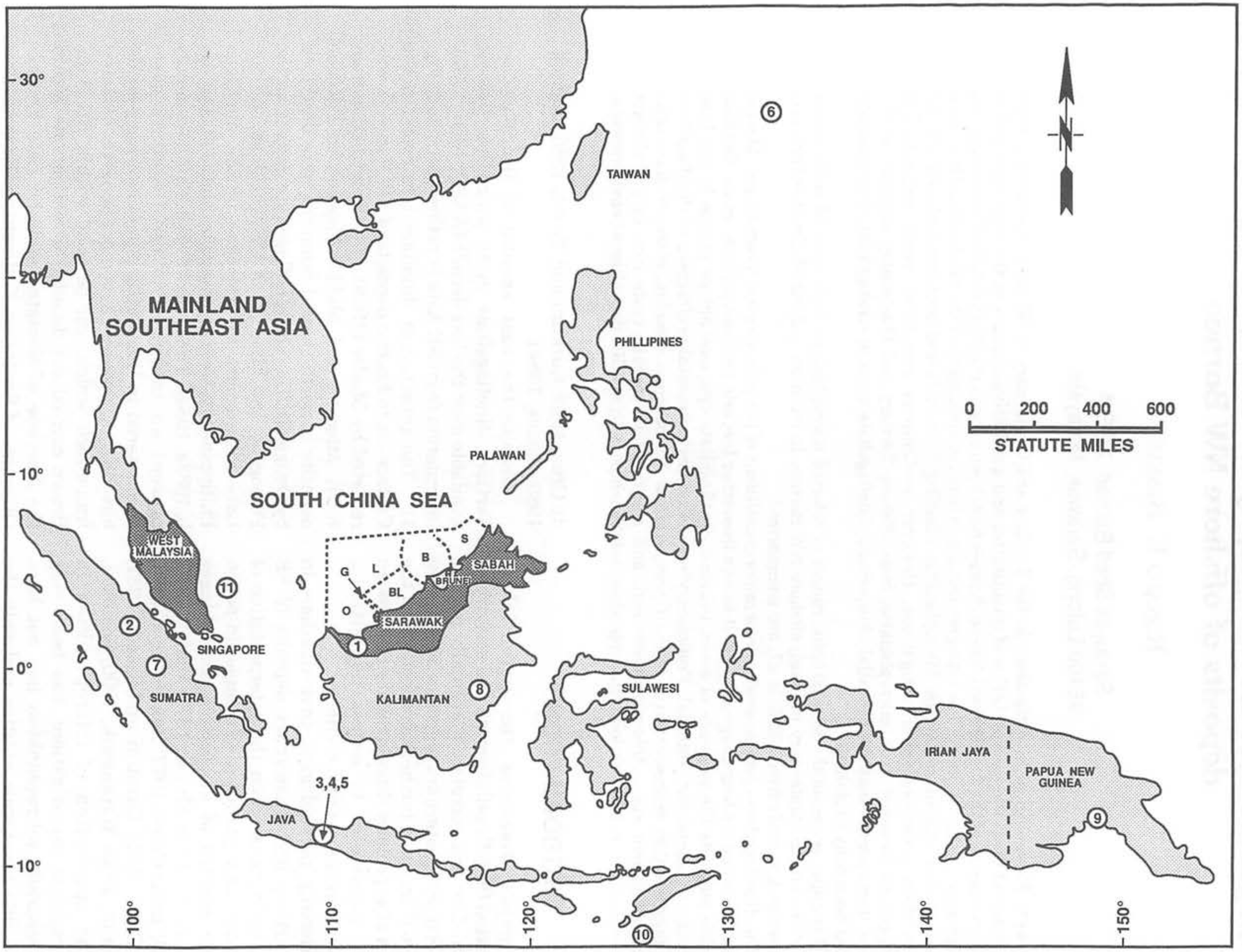


Figure 1. Location map of SE Asia and adjacent Papua New Guinea showing the areas from where Tertiary and Quaternary dinoflagellate cysts and acritarchs have been reported, the area of investigation and the geological provinces in offshore NW Borneo (simplified after Hutchison, 1989). (1) Muller, 1968; (2) Drugg, 1970; (3) Matsuoka, 1981a; (4) Matsuoka, 1983a; (5) Matsuoka, 1984; (6) Matsuoka, 1981b; (7) Brown, 1988; (8) Brown, in prep.; (9) Khan, 1974; (10) Zaklinskaya, 1978; (11) Cole, 1992; S – Sabah province; B – Baram province; BL – Balingian province; L – Luconia province; G – Tatau Horst and Graben province; O – Other provinces.

informal zonal scheme for the Neogene of Sumatra which comprises 4 zones and 6 subzones. Unfortunately, details have not been published yet. Zaklinskaya (1978) illustrates some acritarchs from the Late Pliocene-Pleistocene of offshore Timor. Fresh water dinoflagellate and acritarchs from the Oligocene and Neogene of the South China Sea are described by Cole (1992).

Within SSB/SSPC the potential of microplankton in Tertiary and Quaternary deposits offshore NW Borneo was already evaluated in the late 1960's and early 1970's by the Shell palynologists J. van Niel, Chen F. Wong, and H. Barten. Due to the overwhelming dominance of pollen and spores in the palynological assemblages, the chronostratigraphical resolution of microplankton could not compete with that obtained from pollen and spores (Fig. 2). Because of the overall poor content in the palynological assemblages no formal microplankton zonal framework was established by the early Shell palynologists. However, the application as a marine indicator was acknowledged and microplankton has been used over the last decades as a primarily environmental tool. Their presence and frequencies were included in the calculation of the microplankton/ sporomorph (M/S) ratios. This ratio provided an estimate of water depth and distance from the paleoshore: an increase of the M/S ratio generally indicates an increase in waterdepth and a greater distance from the paleocoast.

As part of the current investigations to improve the available high resolution biostratigraphical framework of SSB/SSPC, which integrates sporomorph, calcareous nannoplankton, larger foraminiferal zones and benthonic foraminiferal data, the potential of microplankton is currently being reconsidered. The promising high resolution biostratigraphical subdivision which was achieved in the Tertiary of Europe (Brinkhuis *et al*, 1992, Brinkhuis, 1990; Powell, 1986a, b, c; Manum *et al.*, 1989; Versteegh, *in prep.*), and the increasing information which has become available on environmental preferences of dinoflagellate cysts (AASP, 1986; LPP, 1992) suggests that the full potential of this group has not been used in palynological investigations in SE Asia.

PUBLISHED MICROPLANKTON RECORDS IN SE ASIA AND ADJACENT PAPUA NEW GUINEA

Published information on dinoflagellate cysts and acritarchs from SE Asia is rather limited (Figs. 1, 3). Some papers specifically discuss dinoflagellate cysts (Drugg, 1970, Matsuoka, 1981, 1983, 1984). Other papers concentrate on pollen and spores, and the information on dinoflagellate cysts and acritarchs is obscured (Muller, 1968; Khan, 1974; Zaklinskaya, 1978). Although Papua New Guinea is not part of SE Asia *sensu stricto*, the dinoflagellate record is included here because its palynological record has been compared to that of SE Asia (Morley, 1978).

Dinoflagellate cyst classification has been changed frequently over the last decades. To date the classification of Lentin and Williams (1985) is a generally accepted one. For easy reference, the reported dinoflagellate cysts from SE Asia and Papua New Guinea have been classified according to this classification scheme. For acritarch classification the Index of Fensome *et al.* (1990) has been used.

SW Sarawak

In some samples from Cretaceous to Eocene deposits of SW Sarawak, the presence of badly preserved dinoflagellate cysts was reported by Muller (1968). The dinoflagellate cysts occur in the *Cicatricosisporites* and *Araucariacites* sporomorph zones of Cretaceous (Cenomanian-earliest "Senonian") age, and in the *Proxapertites* sporomorph zone of late "Senonian" to Paleocene age (Fig. 3). However, it should be emphasized here that the zonal age assessments in this area are not based on firm biostratigraphical evidence.

Dinoflagellate genera from SW Sarawak identified by Muller (1968) include *Odontochitina* Deflandre, 1935, *Dinogymnium* Evitt *et al.*, 1967, *Spiniferites* Mantell, 1850 emend. Sarjeant, 1970 and *Hystrichosphaeridium* Deflandre, 1937b. Muller (1968) includes the latter two genera in his informal group of "hystrichospheres", which are characterized by distally furcating processes. Illustrations of *Dinogymnium* and ?*Spiniferites* are presented in his paper.

Odontochitina and *Dinogymnium* are very rare elements (0.5%) in the *Proxapertites* zone and they occur only in 4 out of a total of 36 samples. They are absent in the underlying *Rugubivesiculites* sporomorph zone and are best represented in the *Araucariacites* sporomorph zone (0.5-3.5%), where they occur in 4 of the 9 samples. In the *Cicatricosisporites* zone they are present (0.5–2 %) in 2 out of 10 samples.

According to Williams and Bujak (1985), *Odontochitina* and *Dinogymnium* are exclusively Cretaceous genera. Their presence in the Paleocene of the of SW Sarawak is therefore most likely due to reworking.

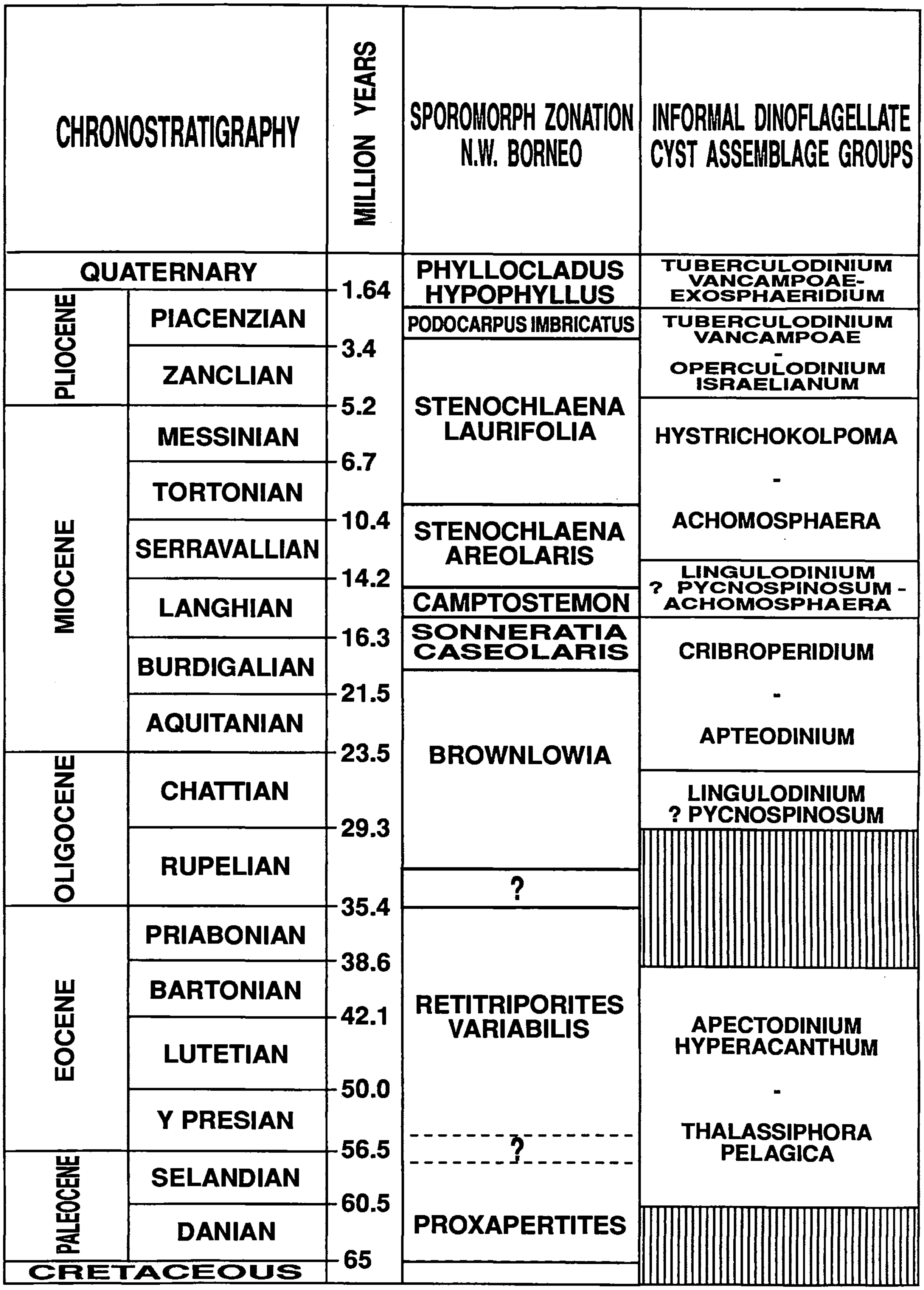


Figure 2. Simplified sporomorph zonation of NW Borneo (modified after James, 1984, and Muller, 1968) and informal dinoflagellate assemblage groups.

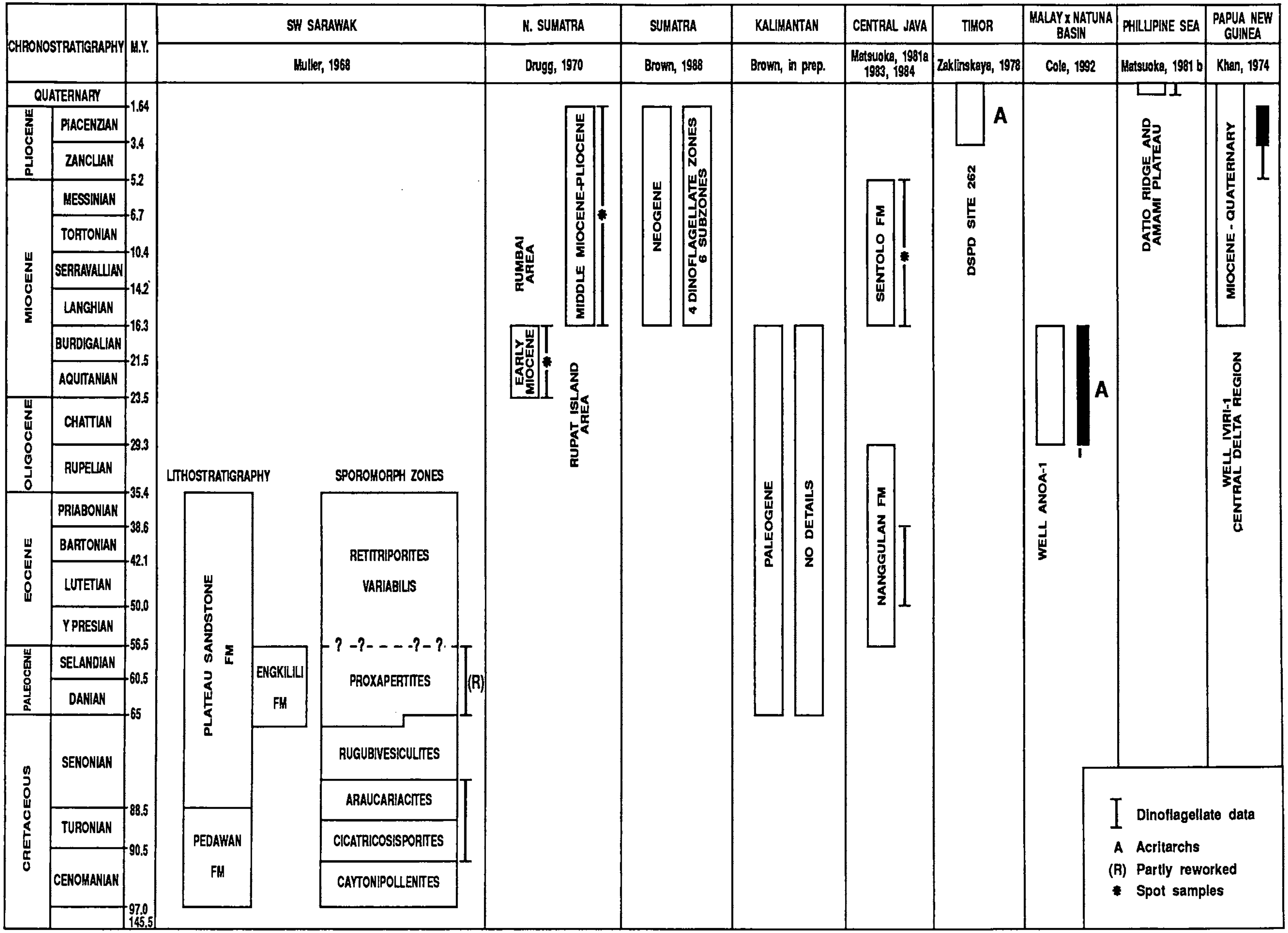


Figure 3. Summary of stratigraphical distribution of SE Asian Tertiary and Quaternary dinoflagellate cyst and acritarch records.

Central Java

In 1981 Matsuoka presented a list of dinoflagellate cysts and *Pediastrum* from the Eocene Nanggulan Formation and the Miocene Sentolo Formation (Matsuoka, 1981a). Identified taxa from the Nanggulan Formation include: *Batiacasphaera* sp. , *Danea*? sp., *Diphyes spinulum* (Drugg, 1970b) Stover and Evitt, 1978, *Glaphyrocysta* sp., *Homotryblium floripes* (Deflandre and Cookson, 1955) Stover, 1975, *Homotryblium* cf. *pallidum*, *Homotryblium vallum* Stover, 1977, *Hystrichokolpoma* cf. *eisenackii*, *Operculodinium* cf. *hirsutum*, *Operculodinium* spp., *Phthanoperidium* sp., *Spiniferites cornutus* (Gerlach, 1961) Sarjeant, 1970 and *Spiniferites* spp. Taxa reported from the Sentolo Formation includes *Operculodinium* sp. and *Spiniferites* sp.

In 1983, the age of the Nanggulan Formation was discussed in more detail and was reported to range from Middle Eocene to Middle Oligocene (Matsuoka, 1983a). Samples from the Middle Eocene part of this formation were restudied and the taxon *Danea?* sp. of Matsuoka, 1981 was described as *Danea heterospinosa* Matsuoka, 1983.

In 1984 Matsuoka described 13 additional dinoflagellate cyst species, including 4 new species, from the same part of the Nanggulan Formation. Described taxa include *Batiacasphaera explanata* (Bujak in Bujak *et al.*, 1980) Islam, 1983, *Batiacasphaera micropapillata* Stover, 1977, *Kallosphaeridium* sp., *Caligodinium* cf. *amiculum*, *Glaphyrocysta circularis* Matsuoka, 1984a, *Glaphyrocysta dentata* Matsuoka, 1984a, *Diphyes spinulum* (Drugg, 1970b) Stover and Evitt, 1978, *Exosphaeridium reticulatum* Matsuoka, 1984a, *Exosphaeridium brevispinosum* Matsuoka, 1984a, *Operculodinium uncinispinosum* (De Coninck, 1969) Islam, 1983b, *Homotryblium* cf. *oceanicum*, *Homotryblium pallidum* Davey and Williams, 1966b, and *Homotryblium plectilum* Drugg and Loeblich, 1967.

North Central Sumatra

Two new dinoflagellate cyst species from two wells in North Central Sumatra were described by Drugg (1970): an Early Miocene sample from a well near Rumbai yielded *Tuberculodinium rossignoliae* Drugg, 1970a; a Middle Miocene-Pliocene sample from the Rupat Island area contained *Sumatradinium hispidum* (Drugg, 1970a) Lentin and Williams, 1976. No further details were presented (Fig. 3).

Timor

From Late Pliocene-Pleistocene core samples from Site 262 of the Deep Sea Drilling Project, offshore Timor, some acritarchs were illustrated by Zaklinskaya (1978). However, no details were presented. Illustrated specimens include *Veryhachium valensii* Downie and Sarjeant, 1965 and Microphytoplankton. The latter strongly resembles *Cymatiosphaera* cf. *nuda* of NW Borneo (Plate 6, Figs. 6, 7).

South China Sea

Late Oligocene to early Middle Miocene freshwater dinoflagellate cysts and acritarchs from the Malay and Natuna Basins are recently described by Cole (1992). Three samples from well Anoa-1 were studied. Identified dinoflagellate taxa include *Bosedinia granulata* (He and Qian) He 1984 emend. Chen *et al.* 1988, *Bosedinia infragranulata* He, 1984, *Bosedinia kuantanensis* Cole, 1992, *Bosedinia whelkaris* Cole, 1992, and *Bosedinia* sp. A of Cole, 1992. Identified acritarchs include *Granodiscus staplinii* (Pocock, 1972) Jiabo 1978.

The taxa recorded are rare in marine strata where they probably represent allochtonous elements. They are abundant in deep lacustrine deposits of the lower Miocene Ledang, Barat and Telukbutun formations (Cole, 1992).

Northern Philippine Sea

Dinoflagellate cysts from the Late Pleistocene and Holocene of the Northern Philippine Sea were discussed by Matsuoka (1981b). A total of 13 samples from pelagic deposits in the Daito Ridge area and the Anami Plateau were investigated (Figs 1, 3).

Dinoflagellate cyst taxa identified include *Impagidinium aculeatum* (Wall, 1967) Lentin and Williams, 1981, *Impagidinium paradoxum* (Wall, 1967) Stover and Evitt, 1978, *Impagidinium patulum* (Wall, 1967) Stover and Evitt, 1978, *Impagidinium strialatum* (Wall, 1967) Stover and Evitt, 1978, *Impagidinium* spp., *Hystrichokolpoma rigaudiae* Deflandre and Cookson, 1955, *Lingulodinium* cf. *machaerophorum*, *Nematosphaeropsis labyrinthea* (Ostenfeld, 1903) Reid, 1974, *Operculodinium centrocarpum* (Deflandre and Cookson, 1955) Wall, 1967, *Operculodinium israelianum* (Rossignol, 1962) Wall, 1967, *Spiniferites* cf. *bentorii* , *Spiniferites bulloideus* (Deflandre and Cookson, 1955) Sarjeant, 1970, *Spiniferites mirabilis* (Rossignol, 1962) Sarjeant, 1970, *Spiniferites ramosus* (Ehrenberg, 1838) Loeblich and Loeblich, 1966, *Spiniferites* spp., *Brigantedinium* spp., *Multispinula quanta* Bradford, 1975, *Quinquecuspis concreta* (Reid, 1977) Harland, 1977b, *Stelladinium stellatum* (Wall and Dale, 1968) Reid, 1977, *Trinovantedinium capitatum* Reid, 1977, *Votadinium calvum* Reid, 1977, *Tuberculodinium vancampoae* (Rossignol, 1962) Wall, 1967.

Most of the samples are dominated by *Impagidinium*, whilst in few samples *Spiniferites* is predominant. All other taxa are minor constituents.

Papua New Guinea

Microplankton from the Pliocene interval in well Iviri-1, Central Delta region of Papua New Guinea, were recorded by Khan (1974; Fig. 1). No differentiation of dinoflagellate cysts was presented in the "pollen diagram". However, dinoflagellate cysts are sporadically present in the Early Pliocene and clearly more abundant in the Late Pliocene (Fig. 3).

Genera identified include *Wetzeliella* Eisenack, 1938, emend. Williams and Downie, 1966b, emend. Lentin and Williams, 1976, *Hystrichosphaeridium* Deflandre, 1937b, emend. Davey and Williams, 1966b, *Spiniferites* Mantell, 1850, emend. Sarjeant, 1970, *Gonyaulax* Diesing, 1866, *Gonyaulacysta* Deflandre, 1964, emend. Sarjeant, 1969, emend. Stover and Evitt, 1978, emend. Sarjeant, 1982, *Operculodinium* Wall, 1967 and *Palaeotetradinium* Deflandre, 1936b, emend. Deflandre and Sarjeant, 1970, emend. Stover and Evitt, 1978.

No illustrations of these taxa were given by Khan (1974), but the presence of specimens referred to *Wetzeliella*, and *Palaeotetradinium*, suggests either the presence of (1) new species, (2) reworking of known species, or (3) of extended ranges of known species. Records of species of *Wetzeliella* and related genera are predominantly found in the Palaeogene and only some species are reported from the Early Miocene where they have a FAD (Williams and Bujak, 1985; Wilson and Clowes, 1980; Lentin and Williams, 1985). Known species from *Palaeotetradinium* and related genera have a FAD in the Oligocene (Williams and Bujak, 1985; Wilson and Clowes, 1980; Lentin and Williams, 1985).

The presence of *Gonyaulacysta* and *Gonyaulax* in the Papua New Guinea record may also be subject to different interpretations. *Gonyaulacysta* has been studied in great detail and numerous genera originally included in this taxon are now excluded (Sarjeant, 1982). Excluded genera with Pliocene representatives are a.o *Apteodinium* Eisenack, 1958, ?*Cribroperidium* Neale and Sarjeant, 1962, emend. Davey, 1969a, emend. Sarjeant, 1982, *Hystrichosphaeropsis* Deflandre, 1935, emend. Sarjeant, 1966b emend. Gocht, 1976, *Impagidinium* Stover and Evitt, 1978 and *Leptodinium* Klement, 1960, emend. Sarjeant, 1966b, emend. Wall, 1967, emend. Sarjeant, 1969, emend. Stover and Evitt, 1978, emend. Sarjeant, 1982. *Gonyaulax* represents a modern genus defined from the motile stage. Lentin and Williams (1985) provide a generic assessment of the fossil dinoflagellate cysts which were previously included in this modern genus. Pliocene representatives of these genera are similar to those which were excluded from *Gonyaulacysta*.

Specimens from Papua New Guinea referred to *Gonyaulacysta* and *Gonyaulax* therefore may be assigned to one or more of the excluded genera (Sarjeant, 1982; APLF, 1986, Lentin and Williams, 1985).

MICROPLANKTON DISTRIBUTION IN TERTIARY AND QUATERNARY DEPOSITS OF OFFSHORE NW BORNEO

Material

During routine palynological investigations from 1968 to 1972 approximately 1750 samples from the Oligocene to Quaternary interval in 56 wells were investigated on their microplankton content. These wells are located in the different geological provinces which are recognized in offshore NW Borneo (Fig. 1; Hutchison ,1989, James, 1984): viz. 14 wells in the Baram province, 12 wells in the Balingian province, 19 wells in the Luconia province, 3 wells in the Tatau Horst and Graben province, 6 wells in the Sabah province, and 2 wells in offshore Sarawak (others).

The stratigraphical distribution of these well sections, the number of samples per stratigraphical interval as well as the depositional environments from where the microplankton data originate is presented in Figures 4 and 5. A key to the depositional environments is illustrated in Figure 6.

In 1992, a number of samples, rich in microplankton, was subject of a pilot study in order to test the feasibility of applying microplankton to stratigraphical investigations (Fig. 4).

Data acquisition

Originally 60 types were included in the SSB/SSPC's type collection of Tertiary microplankton. The bulk of these types represents dinoflagellate cysts (40); acritarchs (10) and indeterminable palynological morphotypes (10) are minor constituents. These 60 microplankton type were systematically recorded in the 56 wells during routine palynological analysis between 1968 and 1972. This analysis was carried out on 10–15 mu sieved oxidized slides and was focussed upon the counts of a fixed number of stratigraphical diagnostic pollen and spore taxa. As a result of this procedure microplankton types appear relatively rarely and irregularly represented throughout the Oligocene to Quaternary fossil record.

CHRONOSTRATIGRAPHY		M.Y.	SPOROMORPH ZONATION N.W. BORNEO	BALINGIAN (TOTAL WELLS: 12)		OTHER (TOTAL WELLS: 2)		TATAU HORST AND GRABEN (TOTAL WELLS: 3)		BARAM (TOTAL WELLS: 14)		LUCONIA (TOTAL WELLS: 19)		SABAH (TOTAL WELLS: 6)		TOTAL 56	
				NO. WELLS	NO. SAMPLES	NO. WELLS	NO. SAMPLES	NO. WELLS	NO. SAMPLES	NO. WELLS	NO. SAMPLES	NO. WELLS	NO. SAMPLES	NO. WELLS	NO. SAMPLES	NO. WELLS	NO. SAMPLES
QUATERNARY		1.64	PHYLLOCLADUS HYPOPHYLLUS							(1)	(?)	3	12	[1]	[2]	4	12
PLIOCENE	PIACENZIAN		PODOCARPUS IMBRICATUS			1	2			(4)	(?)	9	116	2	11	16	129
	ZANCLIAN	3.4 5.2	STENOCHLAENA LAURIFOLIA	9	28	1	7	2	10			13	ca. 153	3	8	29	189
MIOCENE	MESSINIAN TORTONIAN	6.7								1 (9)	6 (?)	8	ca. 98	1 [1]	19 [2]	22	140
		10.4	STENOCHLAENA AREOLARIS	2	7					1	7	2	16	2	36	6	66
	SERRAVALLIAN	14.2		6	54	1	2	3	45	[1]	[1]	3	18	4	107	17	226
	LANGHIAN		CAMPTOSTEMON	9	21			2	11			2	10	1	12	14	54
		16.3	SONNERATIA CASEOLARIS	9	103							2[1]	12[2]	2	18	13	133
	BURDIGALIAN AQUITANIAN	21.5 23.5	BROWNLOWIA	9 [2]	54 [3]					[1]	[1]	1	1			10	54
OLIGOCENE	CHATTIAN	29.3		6 [1]	12 [1]							1[3]	1[5]			7	13
	RUPELIAN	35.4		1	1											1	1
EOCENE	PRIABONIAN	38.6	RETITRIPORITES VARIABILIS														
	BARTONIAN LUTETIAN YPRESIAN	42.1 50.0 56.5	-?-?-?-?-?-					[1]	[8]							1	8
PALEOCENE	SELANDIAN	60.5	NO DATA -?-?-?-?-?-														
	DANIAN	65	PROXAPERTITES - - - - - - - -														
CRETACEOUS																	

Figure 4. Stratigraphical distribution of well sections studied in the Tertiary and Quaternary of NW Borneo. 56 wells studied in 1968-1972. ( ) no data available from original data set of 1968-1972. [ ] wells and samples examined in 1992.

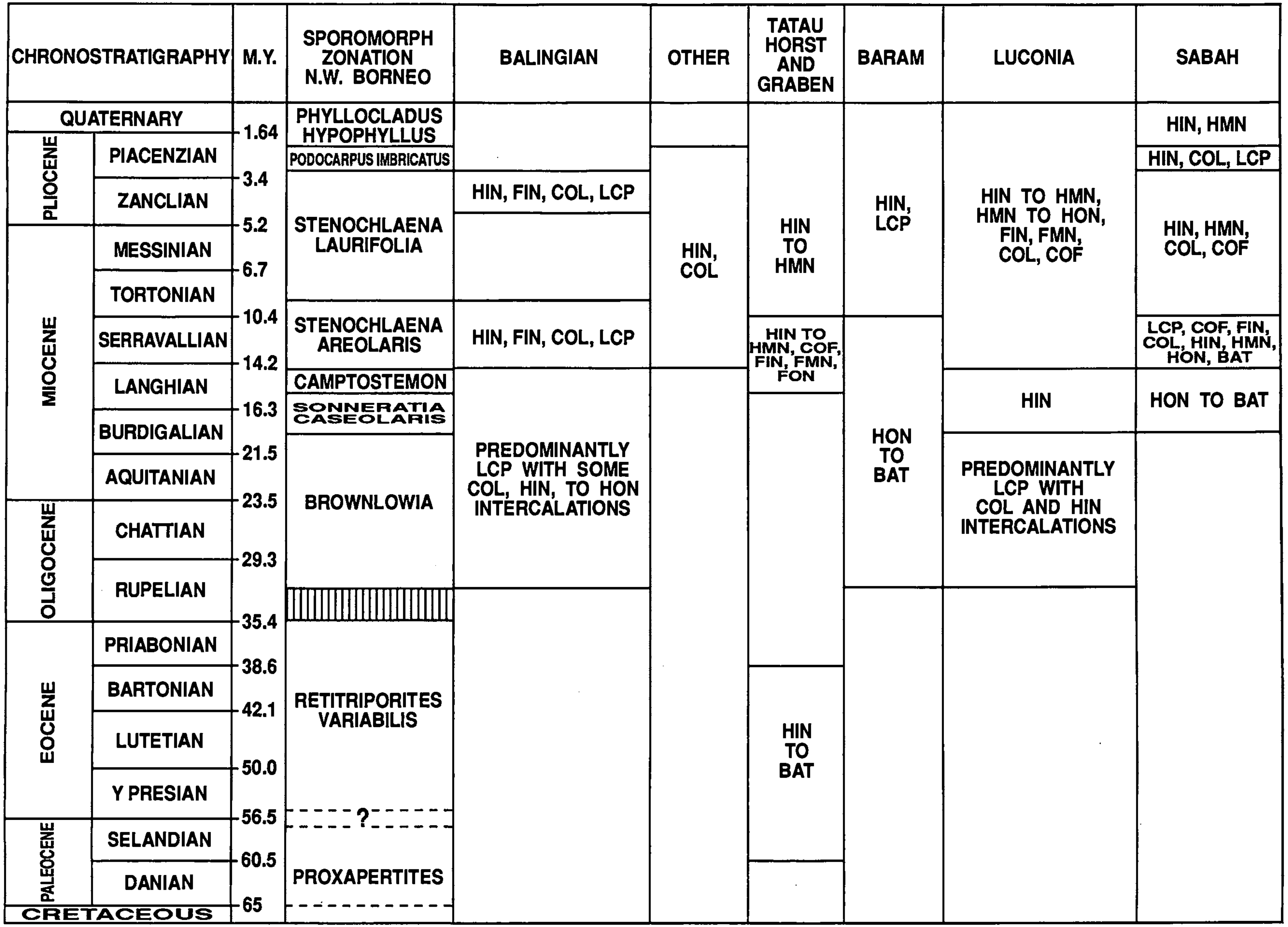


Figure 5. Stratigraphical distribution of depositional environments in the Tertiary and Quaternary interval from which microplankton data originates.

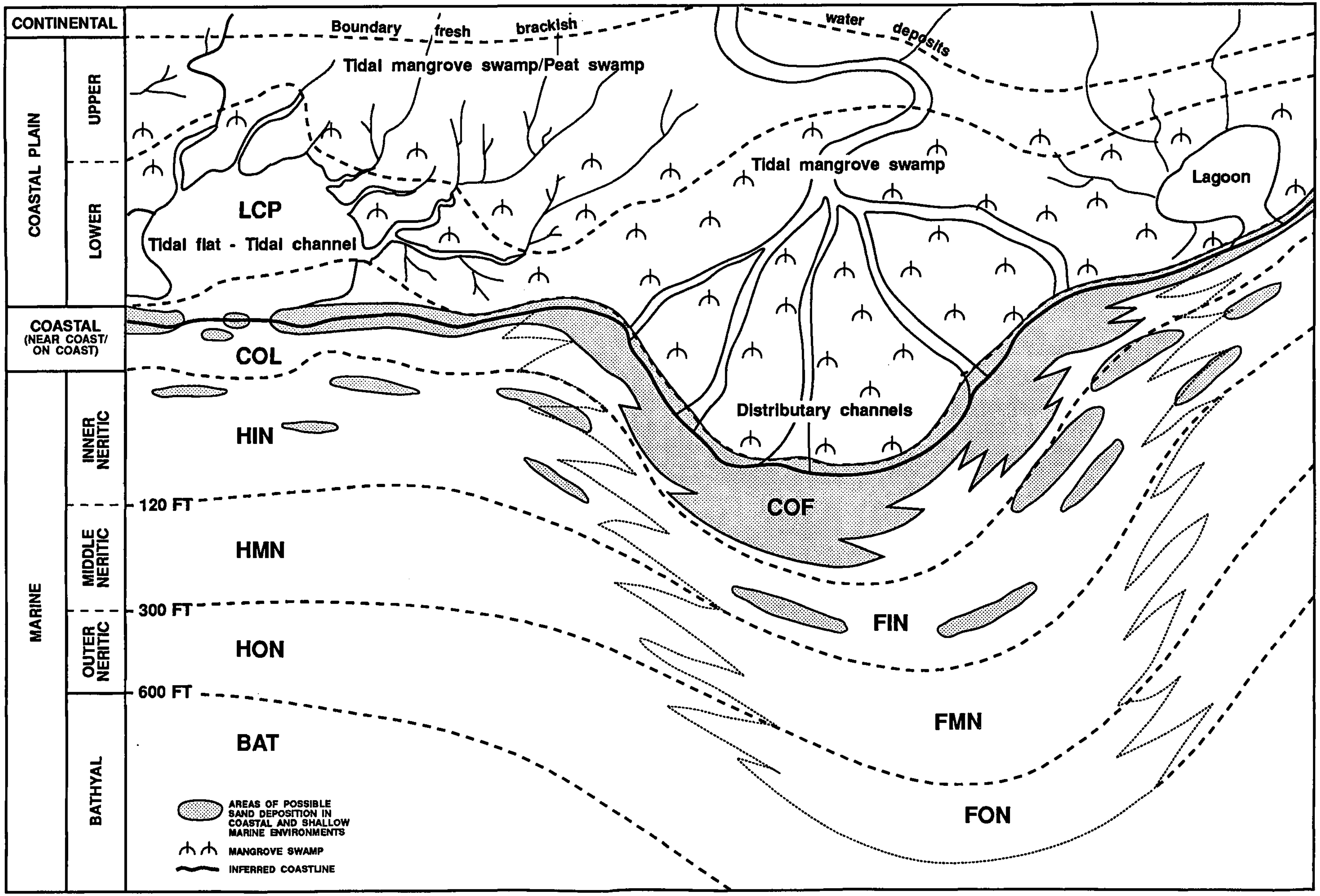


Figure 6. Schematic outline of NW Borneo environmental units.

The microplankton distribution (frequencies and percentages) was originally expressed as an average of a sporomorph (sub) zone, and subsequently the stratigraphical ranges were plotted against the sporomorph zonal framework(Fig. 2). As a consequence of this procedure all LADs and FADs of microplankton taxa coincide with sporomorph (sub) zonal boundaries and any existing differences in intrazonal ranges of microplankton taxa have been obscured.

As the ranges of the dinoflagellate types (Fig. 3) result from calculations which includes data from all possible environments within a specific time-slice (Fig. 5), environmental preferences of specific taxa may have been obscured.

The 1992 pilot study of Late Paleocene to Miocene deposits reveals that:

(1) some of the original microplankton types include more than 1 species as currently understood. Although the individual species have now been identified, their full stratigraphical range has not be assessed. Examples of such types are e.g. the Cribrop*eridium-Apteodinium* complex, *Hystrichokolpoma* spp., and *Homotryblium* spp.

(2) a number of types could be attributed to a single species. The different types represent variations within one species. Examples are *Lingulodinium machaerophorum, Spiniferites ramosus* and *Spiniferites pseudofurcatus.*

(3) a number of types proved to be unsuitable for stratigraphical purposes. These include a.o. too poorly preserved microplankton, and palynological enigmas. They are excluded in this paper.

(4) an additional number of dinoflagellate taxa and other palynomorphs (e.g. Scolecodonts) could be added to the database.

Annotated species list

The taxa identified to date are presented in the species list below and illustrated on Plates 1-9. Classification of the taxa has been achieved by following Lentin and Williams (1985) for dinoflagellate cysts and Fensome *et al.* (1990) in the case of acritarchs.

Dinoflagellate cysts

— *Achomosphaera* spp. (Plate 1. Fig. 1)

— *Adnatosphaeridium* spp. (Plate 1, Figs. 3, 5)

— *Apectodinium hyperacanthum* (Cookson and Eisenack, 1965b) Lentin and Williams, 1977b (Plate 1, Figs. 2, 4)

— *Apteodinium* spp. (Plate 1, Fig. 6)

— *Areosphaeridium multicornutum* Eaton, 1971 (Plate 2, Fig. 1)

— *Areoligera* sp. (Plate 2, Fig. 2)

— *Cannosphaeropsis* cf. *utinensis* (Plate 2, Fig. 3)

— *Cometodinium* spp. (Plate 2, Fig. 4)

— *Cordosphaeridium* cf. *fibrospinosum* (Plate 2, Fig. 5)

— *Cordosphaeridium gracile* (Eisenack, 1954) Davey and Williams, 1966b (Plate 2, Fig. 6)

— *Cordosphaeridium inodes* (Klump, 1953) Eisenack, 1963b, emend. Morgenroth, 1968 (Plate 9, Fig. 2)

— *Cribroperidium* spp. (include specimens strongly resembling *Cribroperidium ?granomembranaceum* (Matsuoka, 1983b) Lentin and Williams, 1985, and *Cribroperidium tenuitabulatum* (Gerlach, 1961) Helenes, 1984 (Plate 3, Figs. 1-4)

— *Danea* sp. (Plate 3, Fig. 5)

— *Dapsilidinium pastielsii* (Davey and Williams, 1966b) Bujak *et al.*, 1980 (Plate 3, Fig. 6)

— *Exophaeridium* spp. (Plate 3, Fig. 7)

— *Glaphyrocysta* sp. (Plate 4, Fig. 1)

— *Hafniasphaera* sp. (Plate 4, Fig. 2)

— *Homotryblium* spp. (includes a.o. *Homotryblium floripes* (Deflandre and Cookson, 1955) Stover, 1975 , and *Homotryblium plectilum* Drugg and Loeblich, 1967) (Plate 4, Figs. 3, 4)

— *Hystrichokolpoma* spp. (includes a.o. *Hystrichokolpoma rigaudiae* Deflandre and Cookson, 1955, *Hystrichokolpoma denticulatum* Matsuoka, 1974 and *Hystrichokolpoma* cf. *cinctum*) (Plate 4, Figs. 5, 6; Plate 5, Figs. 1, 2; Plate 9, Fig. 6))

— *Impagidinium* cf. *patulum* (Plate 5, Fig. 3)

— *Impagidinium* sp. (Plate 9, Figs. 3, 4)

— *Lingulodinium machaerophorum* (Deflandre and Cookson, 1955) Wall, 1967 (Plate 5, Figs. 4, 5)

— *Lingulodinium* spp.

— *Lingulodinium ?pycnospinosum* (Benedek, 1972) Stover and Evitt, 1978, emend. Benedek and Sarjeant, 1981 (Plate 5, Fig. 6; Plate 9, Fig. 7)

— *Nematopsphaeropsis* spp.

— *Operculodinium israelianum* (Rossignol, 1962) Wall, 1967 (Plate 6, Figs. 1, 3, 4)

— *Operculodinium microtriainum* (Klump, 1953) Islam, 1983a (Plate 6, Figs. 2, 5)

— *Operculodinium* spp. (include specimens resembling *Operculodinium centrocarpum* (Deflandre and Cookson, 1955) Wall, 1967)

— cf. *Phthanoperidium comatum* (Morgenroth, 1966b) Eisenack and Kjellstroem, 1971a (Plate 7, Fig. 1)

— *Phthanoperidium* sp. (Plate 7, Fig. 2)

— *Polysphaeridium* spp. (includes *Polysphaeridium zoharyi* (Rossignol, 1962) Bujak *et al.*, 1980)

— Protoperinoid cysts

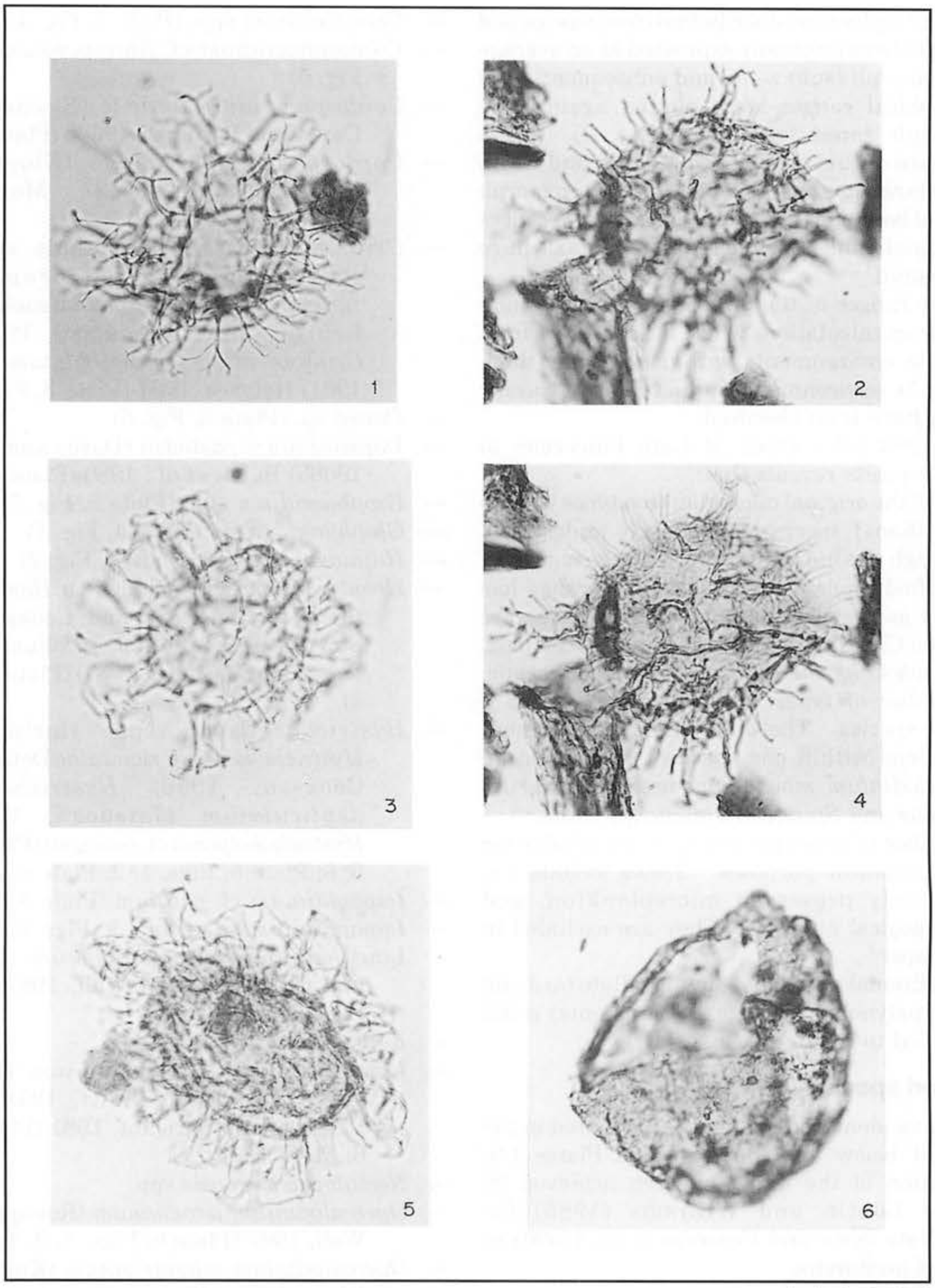
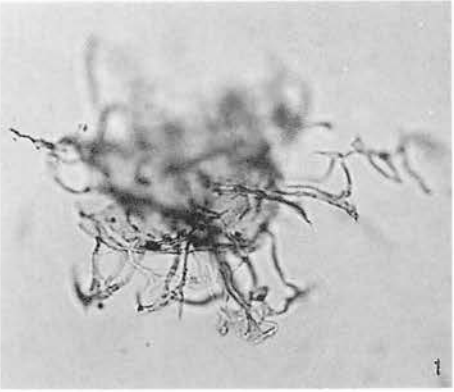
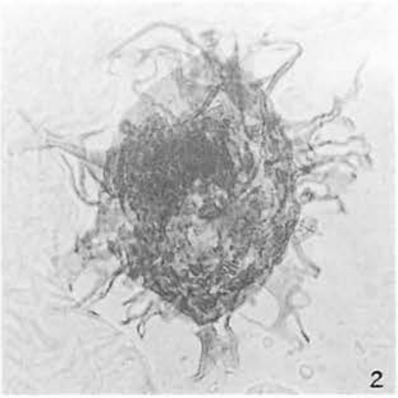
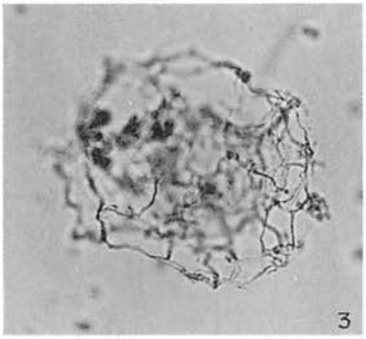
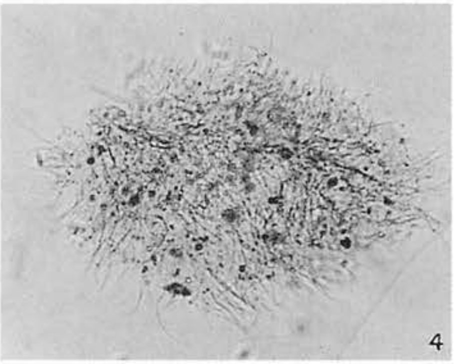


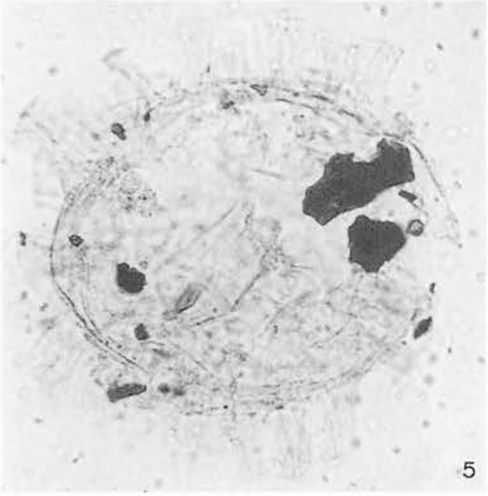
Plate 1. Fig. 1. *Achomosphaera* sp.
Luconia province, Early Pliocene
Figs. 2, 4. *Apectodinium hyperacanthum*
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Figs. 3, 5. *Adnatosphaeridium* spp.
Fig. 3. Sabah province, early Late Miocene
Fig. 5. Baram province, Middle Miocene-Early Pliocene
Fig. 6. *Apteodinium* sp.
Balingian province, Early Miocene











0.05 mm

Plate 2. **Fig. 1.** *Areosphaeridium multicornutum*
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Fig. 2. *Areoligera* sp.
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Fig. 3. *Cannosphaeropsis* cf. *utinensis*
Luconia province, Late Miocene
Fig. 4. *Cometodinium* sp.
Sabah province, Early Miocene
Fig. 5. *Cordosphaeridium* cf. *fibrospinosum*
Luconia province, Early Pliocene
Fig. 6. *Cordosphaeridium gracile*
Tatau Horst and Graben province, Late Paleocene-Middle Eocene

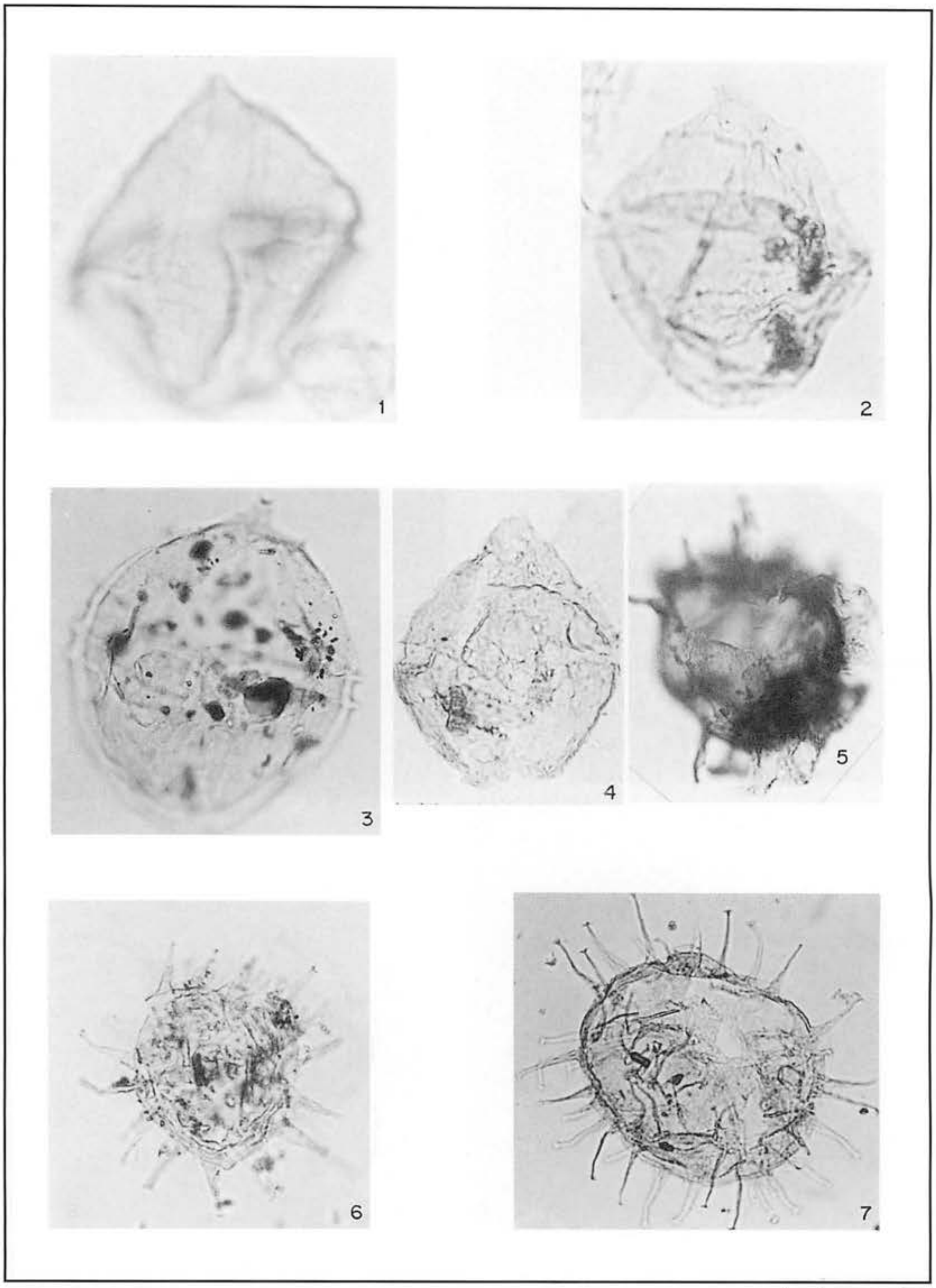


Plate 3. Figs. 1–4. *Cribroperidium* spp.
Fig. 1. Luconia province, Oligocene
Fig. 2. Balingian province, Early Miocene
Fig. 3. Luconia province, Early to early Middle Miocene
Fig. 4. Balingian province, Early Miocene
Fig. 5. *Danea* sp.
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Fig. 6. *Dapsilidinium pastielsii*
Luconia province, Late Pliocene
Fig. 7. *Exosphaeridium* sp.
Luconia province, late Middle-early Late Miocene

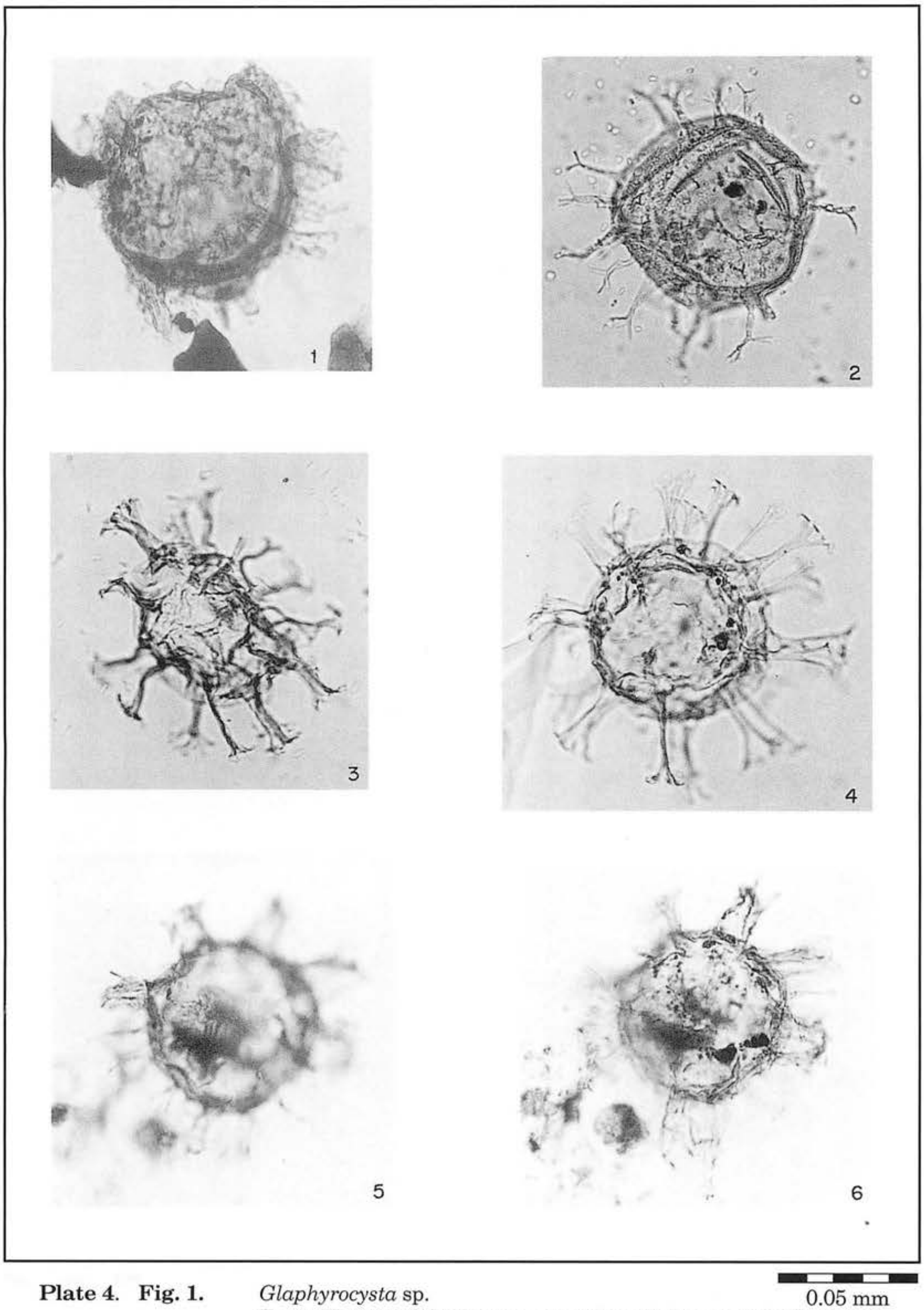


Plate 4. **Fig. 1.** *Glaphyrocysta* sp.
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Fig. 2. *Hafniasphaera* sp.
Luconia province, Late Pliocene
Figs. 3, 4. *Homotryblium plectilum*
Fig. 3. Sabah province, Miocene
Fig. 4. Luconia province, Late Oligocene Early Miocene
Figs. 5, 6. *Hystrichokolpoma rigaudiae*
Balingian province, Early Miocene

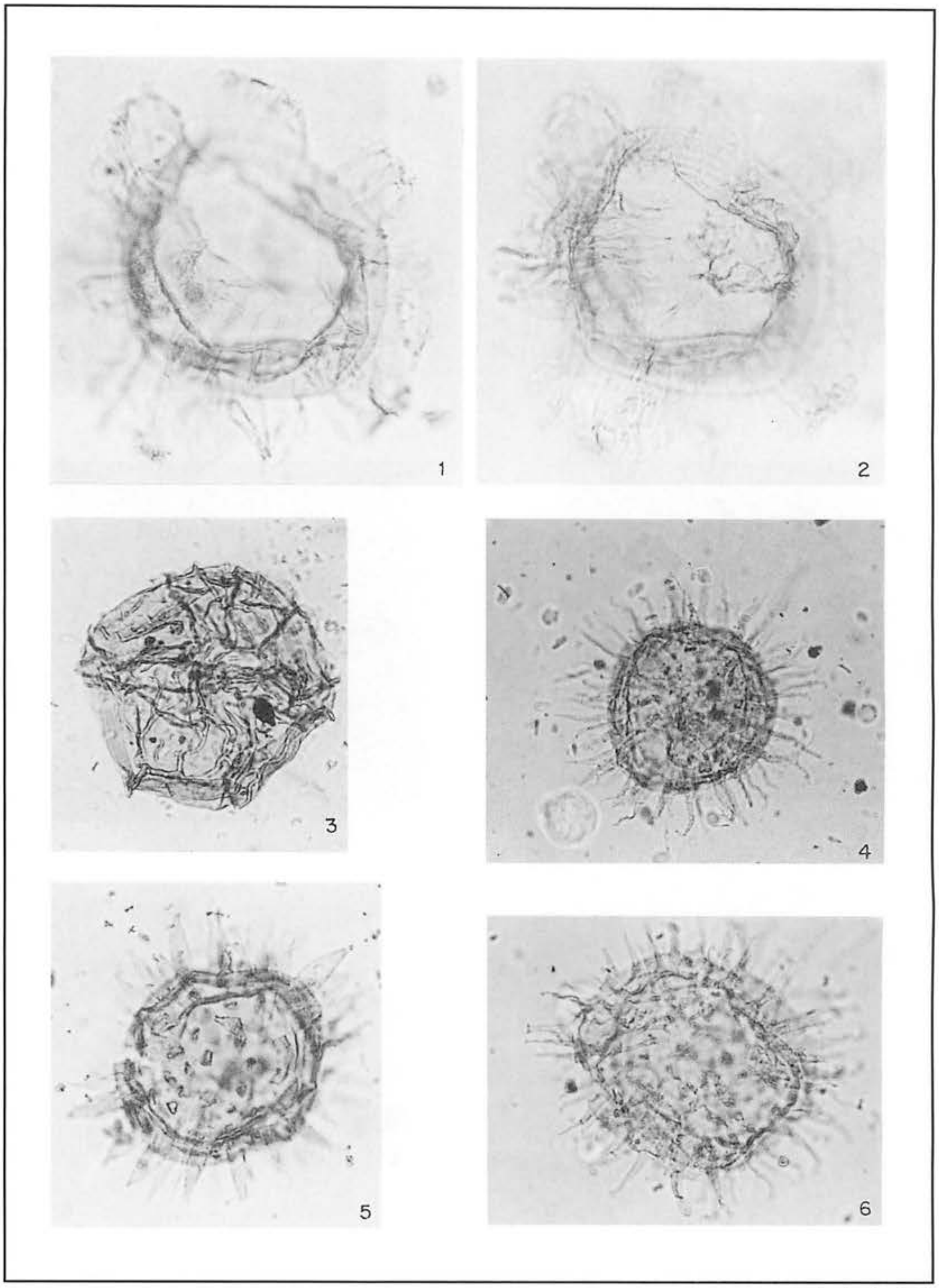
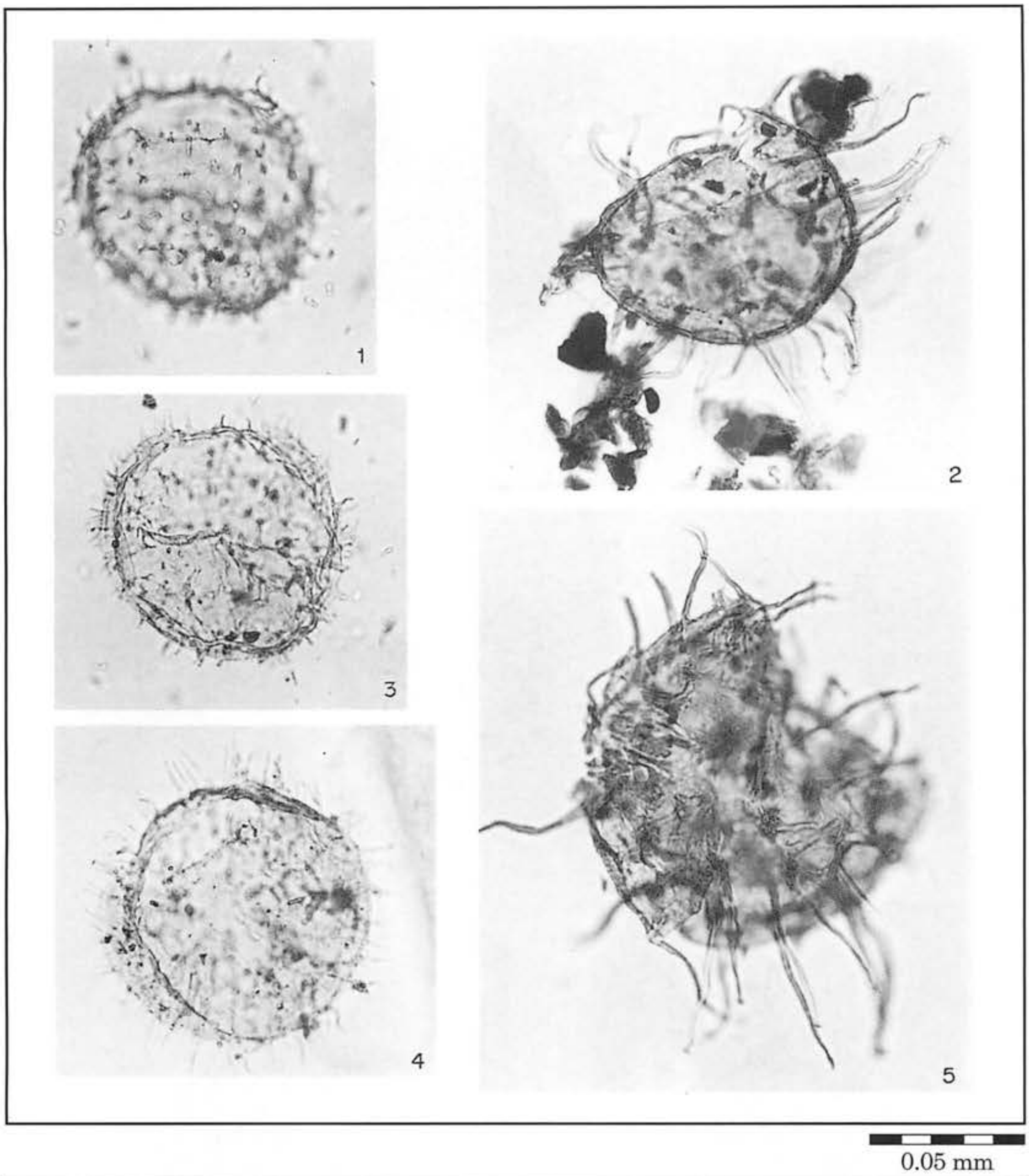


Plate 5. **Figs. 1, 2.** *Hystrichokolpoma* sp.
Balingian province, Middle Miocene
Fig. 3. *Impagidinium* cf. *patulum*
Luconia province, Late Miocene
Figs. 4, 5. *Lingulodinium machaerophorum*
Fig. 4. Luconia province, Late Miocene-Early Pliocene
Fig. 5. Balingian province, Middle-early Late Miocene
Fig. 6. *Lingulodinium ?pycnospinosum*
Balingian province, Middle-early Late Miocene



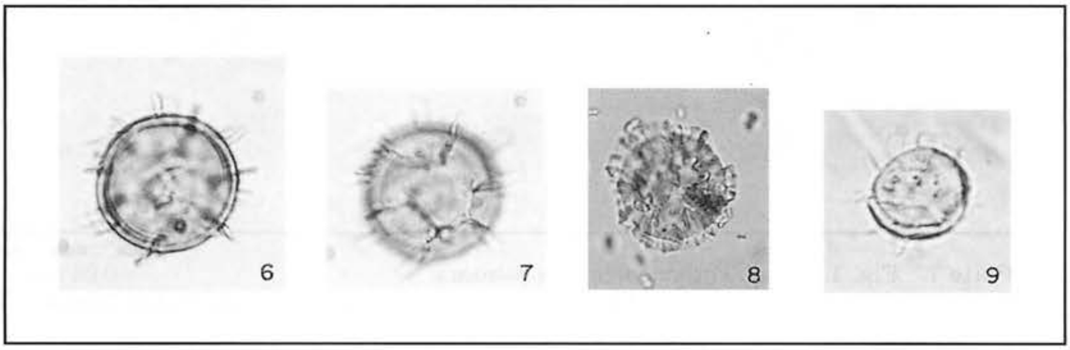
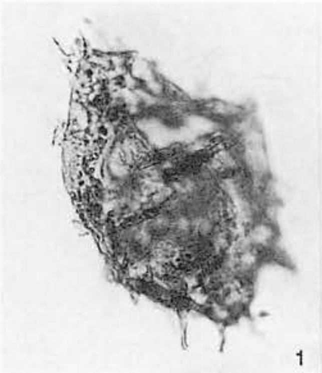
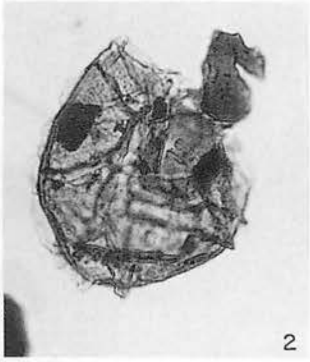
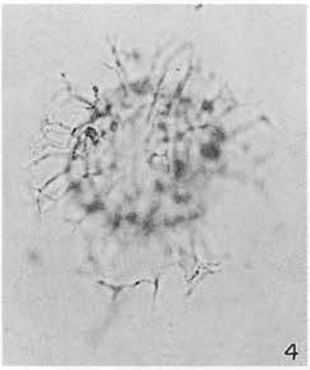
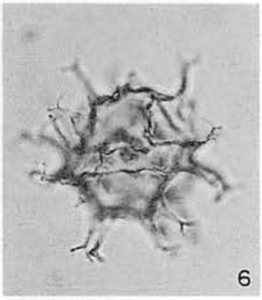


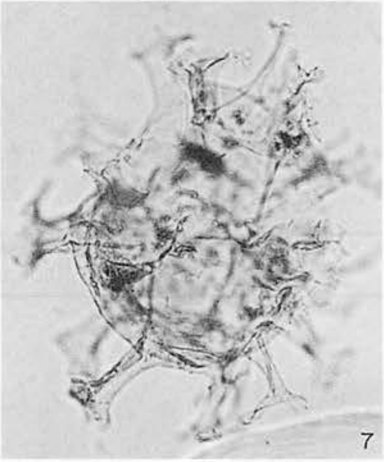
Plate 6. **Figs. 1, 3, 4.** *Operculodinium israelianum*
Figs. 1, 3. Balingian province, Early Miocene
Fig. 4. Sabah province, Late Miocene
Figs. 2, 5. *Operculodinium microtriainum*
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Figs. 6, 7. *Cymatiosphaera* cf. *nuda*
Balingian province, Early Pliocene
Fig. 8. *Cymatiosphaera undulata*
Luconia province, Early Pliocene
Fig. 9. *Micrhystridium* sp.
Luconia province, Late Miocene-Early Pliocene











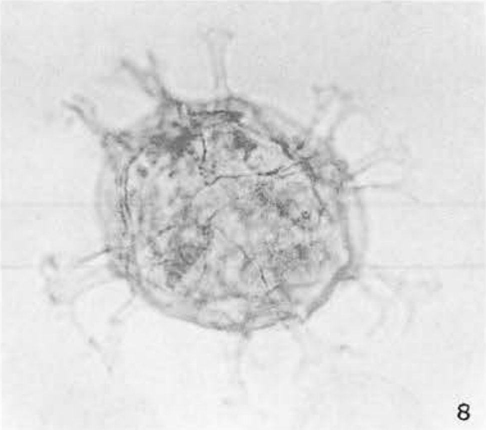


Plate 7. **Fig. 1.** cf. *Phthanoperidium comatum* 0.05 mm
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Fig. 2. *Phthanoperidium* sp.
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Fig. 3. *Cymatiosphaera* sp.
Sabah province, late Middle-early Late Miocene
Fig. 4. *Spiniferites mirabilis*
Sabah province, Late Miocene-Early Pliocene
Figs. 5, 6. *Spiniferites ramosus*
Fig. 5. Balingian province, Early Pliocene
Fig. 6. Balingian province, Early Miocene
Figs. 7, 8. *Spiniferites pseudofurcatus*
Fig. 7. Luconia province, Late Miocene-Early Pliocene
Fig. 8. Balingian province, Early Miocene

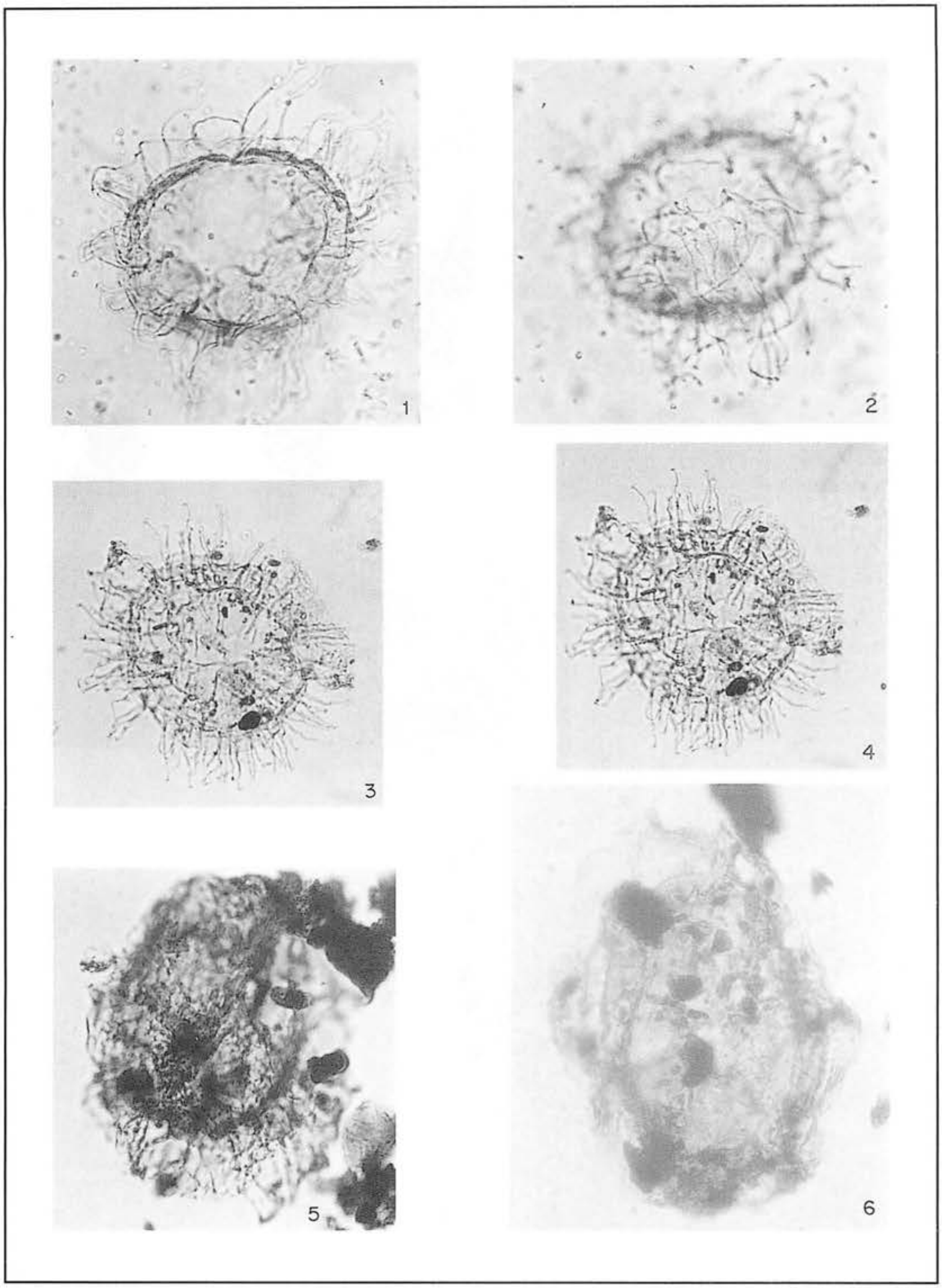


Plate 8. **Figs. 1-4.** *Systematophora placacantha*

0.05 mm

Figs. 1, 2. Balingian province, outcrop, Early Miocene
Figs. 3, 4. Balingian province, Early Miocene

Fig. 5. *Thalassiphora* cf. *patula*
Tatau Horst and Graben province, Late Paleocene-Middle Eocene

Fig. 6. *Thalassiphora pelagica*
Tatau Horst and Graben province, Late Paleocene-Middle Eocene

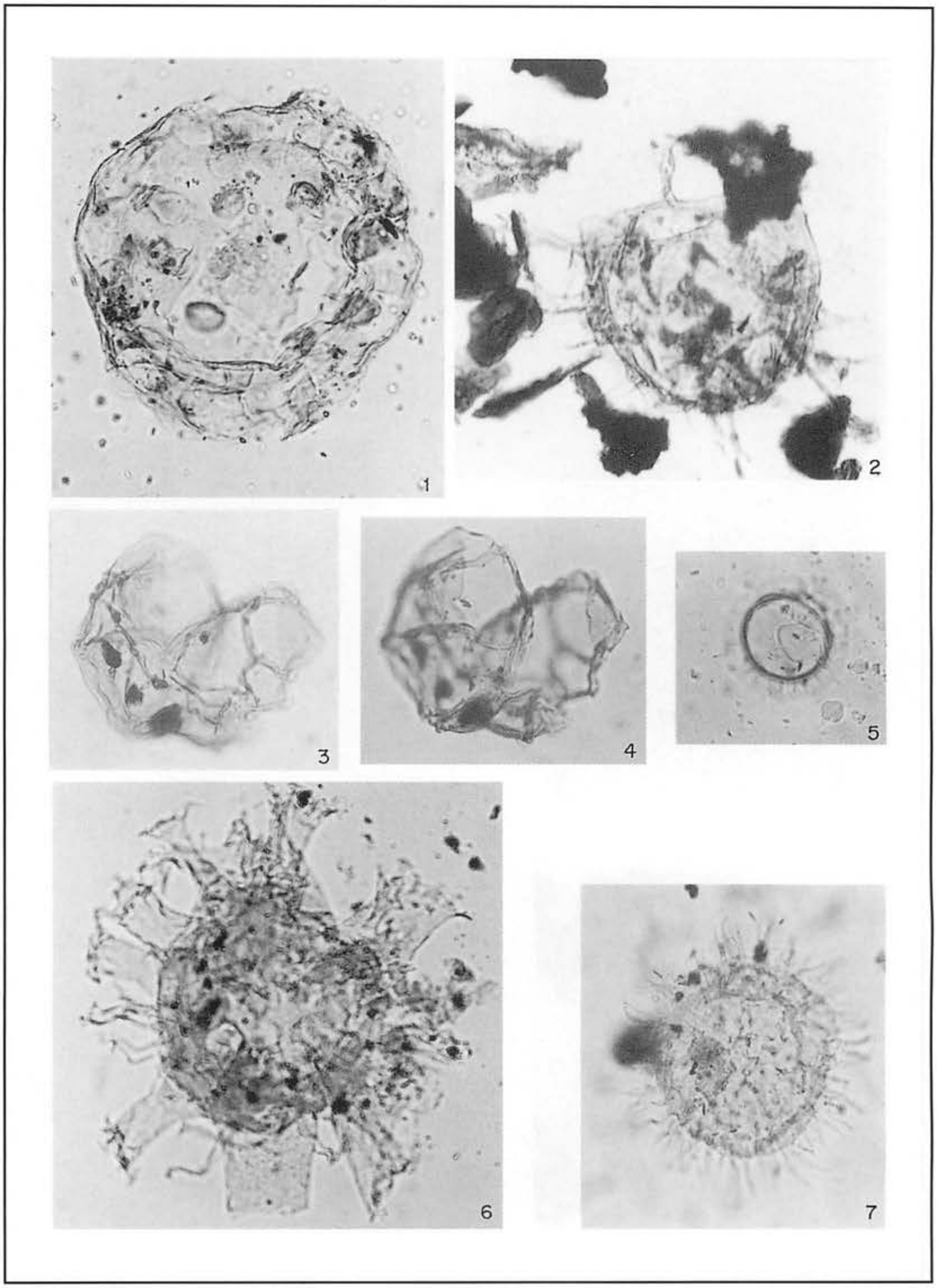


Plate 9. Fig. 1. *Tuberculodinium vancampoae*
Baram province, Early Pliocene
Fig. 2. *Cordosphaeridium inodes*
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Figs. 3, 4. *Impagidinium* sp.
Tatau Horst and Graben province, Late Paleocene-Middle Eocene
Fig. 5. *Pterospermella* sp.
Luconia province, Late Pliocene
Fig. 6. *Hystrichokolpoma* sp.
Baram province, Middle Miocene-Early Pliocene
Fig. 7. *Lingulodinium ?pycnospinosum*
Balingian province, Oligocene

- *Spiniferites mirabilis* (Rossignol, 1963) Sarjeant, 1970 (Plate 7, Fig. 4)
- *Spiniferites pseudofurcatus* (Klump, 1953) Sarjeant, 1970 (Plate 7, Figs. 7, 8)
- *Spiniferites ramosus* (Ehrenberg, 1838) Loeblich and Loeblich, 1966 (Plate 7, Figs. 5, 6)
- *Spiniferites* spp.
- *Systematophora placacantha* (Deflandre and Cookson, 1955) Davey *et al.*, 1969 (Plate 8, Figs. 1-4)
- *Thalassiphora* cf. *patula* (Plate 8, Fig. 5)
- *Thalassiphora pelagica* (Eisenack, 1954) Eisenack and Gocht, 1981 (Plate 8, Fig. 6)
- *Tuberculodinium vancampoae* (Rossignol, 1962) Wall, 1967 (Plate 9, Fig. 1)
- "round browns"

Acritarchs

- *Cymatiosphaera* spp. (Plate 7, Fig. 3)
- *Cymatiosphaera undulata* Hajos, 1966 (Plate 7, Fig. 8)
- *Cymatiosphaera* cf. *nuda* (Plate 6, Figs. 6, 7)
- *Micrhystridium* spp. (Plate 6, Fig. 9)
- *Pterospermella* spp. (Plate 9, Fig. 5)

Dinoflagellate cyst biostratigraphy

The dinoflagellate cyst record in NW Borneo comprises a number of long-ranging taxa which have been recorded from other areas (Fig. 7), these include a.o. *Lingulodinium machaerophorum, Systematophora placacantha, Tuberculodinium vancampoae, Spiniferites* spp., *Achomosphaera* spp., *Hystrichokolpoma* spp., *Lingulodinium ?pycnospinosum, Lingulodinium* spp., *Operculodinium* spp., *Adnatosphaeridium* spp. and *Homotryblium* spp. (AASP, 1986; Manum *et al.*, 1989; LPP, 1992).

Despite of the limiting factors in interpreting the Oligocene to Quaternary data set and the possible sample biasing effect (Fig. 4), the qualitative and quantitative distribution of dinoflagellate cysts suggests the presence of 7 informal successive assemblage groups (Figs. 3 and 7); these will be discussed from old to young.

(1) *Apectodinium hyperacanthum-Thalassiphora pelagica* Assemblage Group

- **Characteristics:** Assemblages from this group include a.o. *Apectodinium hyperacanthum, Thalassiphora pelagica, Thalassiphora* cf. *patula, Cordosphaeridium inodes, Cordosphaeridium gracile, Areosphaeridium multicornutum, Operculodinium microtriainum, cf. Phthanoperidium comatum, Phthanoperidium* sp., *Areoligera* spp., *Danea* spp., *Nematosphaeropsis* spp., *Impagidinium* sp. and/or *Glaphyrocysta* spp. (Figs. 3 and 7).
- **Occurrence:** So far, this unit has been identified in 8 samples from a holomarine inner neritic to bathyal interval in one well from the Tatau Horst and Graben province (Figs. 1, 5 and 6).
- **Age assessment:** Associated with this assemblage group are rare planktonic foraminifera, e.g. *Acarinina wilcoxensis* (Cushman and Ponton), *Morozovella velascoensis* (Cushman) (?= *Globorotalia caucasica* Glaessner) and *Acarinina bullbrooki* (Bolli), which suggests a Late Paleocene-Middle Eocene age (Stainforth *et al.*, 1975). This assessment is in agreement with the age interpretation based on sporomorphs. The assemblage group is definitely pre-*Brownlowia* zone, although it does not show the characteristics of the *Proxapertites* and *Retitriporites variabilis* assemblage zones. However, the presence of *Retitriporites variabilis* Muller, 1968 and *Spinozonocolpites baculatus* Muller, 1968 also suggests a Paleocene-Eocene age (Figs. 2 and 3).
- **Remarks:** The inferred age for this unit is well in line with the age obtained from the dinoflagellate cysts. *Apectodinium hyperacanthum* and *Cordosphaeridium inodes* indicate a Late Paleocene-Early Eocene age (Williams and Bujak, 1985; Wilson, 1988). The presence of *Cordosphaeridium gracile* would even suggest an exclusively Eocene age for this unit (Wilson, 1988).

(2) *Lingulodinium ?pycnospinosum* Assemblage Group

- **Characteristics:** This assemblage group is dominated by poorly diversified and preserved non-tabulate chorate dinoflagellate cysts assignable to *Lingulodinium ?pycnospinosum, Lingulodinium machaerophorum, Operculodinium* spp. and *Polysphaeridium* spp. Additional taxa include *Homotryblium plectilum, Hystrichokolpoma* spp. and *Systematophora placacantha*. Representatives of the *Cribroperidium-Apteodinium* complex are rare (Fig. 7).
- **Occurrence:** This assemblage group has been interpreted from 7 wells in the Balingian province and 1 well in the Luconia province (Fig. 4). However, only 13 samples have been investigated from this unit, which comprises predominantly lower coastal plain deposits (Fig. 5). Its presence has been confirmed in 1992 by spot observations in the Balingian province (Fig. 4).

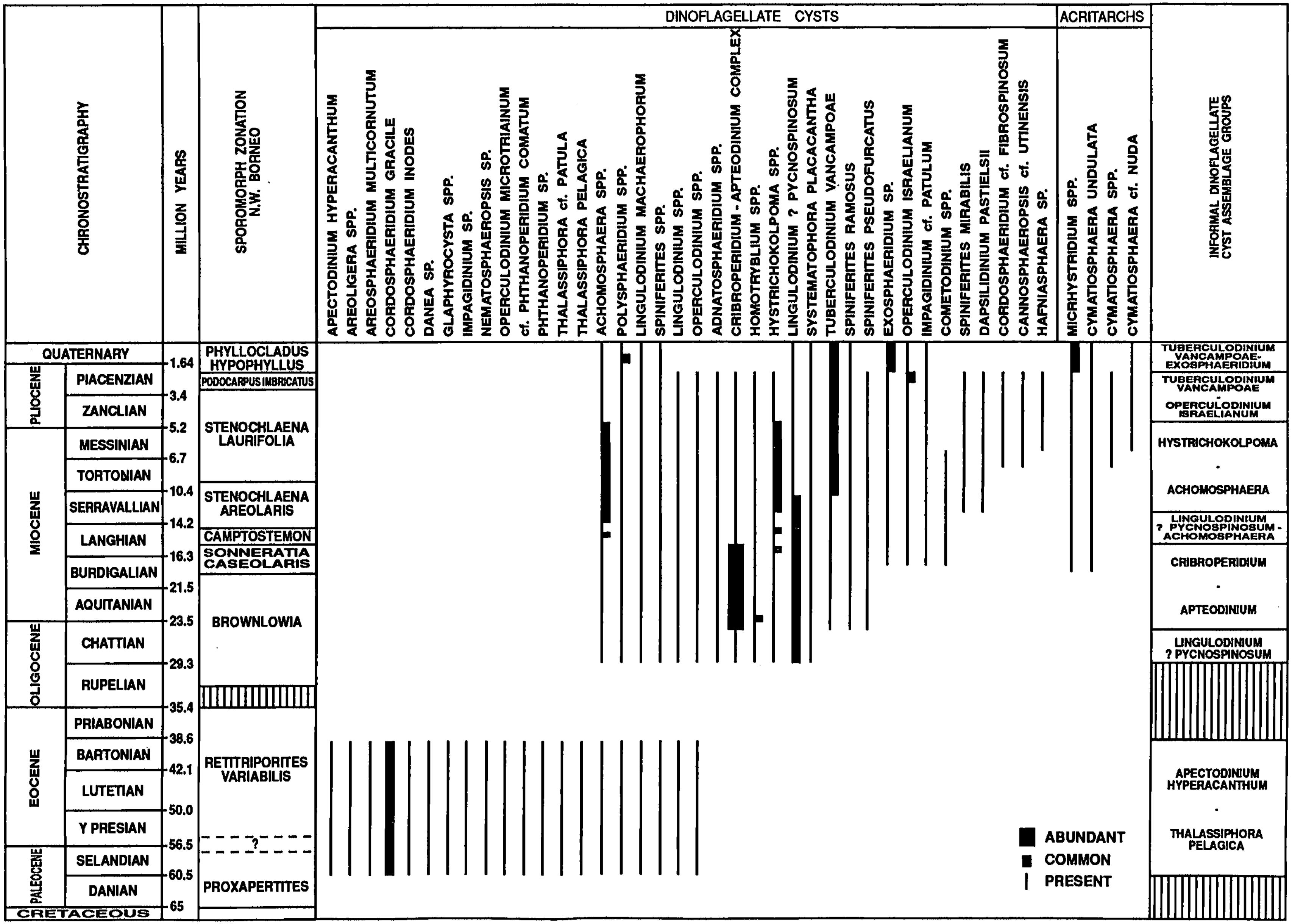


Figure 7. Schematic range chart of selected microplankton types in the Tertiary and Quaternary of NW Borneo.

- **Age assessment:** Based on pollen and spores, limited micropalaeontological and nannoplankton evidence an Oligocene age for this unit is adopted. The assemblage group has been encountered in the lower and middle parts of the *Brownlowia* Zone (Fig. 6). "NP 25 and older" calcareous zonal assessments could be attributed to some samples from this unit.
- **Remarks:** The validity of this unit as a biostratigraphical parameter is rather doubtful. So far, only very few samples from the thick Oligocene deposits were analyzed. No diagnostic Oligocene markers like *Chiropteridium* and *Deflandrea* have been encountered (LPP, 1992; Manum *et al.*, 1989). It may well be that this poorly diversified assemblage group is indicative of specific environments.

(3) *Cribroperidium-Apteodinium* Assemblage Group.

- **Characteristics:** This assemblage group is characterized by the optimum occurrence of the *Cribroperidium-Apteodinium* complex. Apart from the taxa also encountered in the *Lingulodinium ?pycnospinosum* assemblage group some other taxa show their first appearance in this unit, e.g. *Tuberculodinium vancampoae, Spiniferites pseudofurcatus* and *Spiniferites ramosus.* A few taxa have their FAD in the top part of this unit, e.g. *Impagidinium* cf. *patulum, Cometodinium* sp. and *Operculodinium israelianum.*
  Locally a marked increase of other taxa may occur at specific stratigraphical intervals, e.g. *Homotryblium* spp. (Luconia province), and *Hystrichokolpoma* spp. or *Lingulodinium ?pycnospinosum* (Balingian province).
- **Occurrence:** This assemblage group has been recorded from 11 wells in the Balingian province, 1 well in the Baram and 8 wells in the Luconia province (Figs. 4 and 5). This unit has been well established and has been encountered in predominantly lower coastal plain deposits with marine intercalations, and in holomarine inner neritic to bathyal environments.
- **Age assessment:** A latest Oligocene to early Middle Miocene age for this unit has been based on sporomorphs, limited micropalaeontological and calcareous nannoplankton evidence. The assemblage group is encountered in the upper part of the *Brownlowia* and the *Sonneratia caseolaris* sporomorph zones and in nannoplankton zones NN 3 to NN5.
- **Remarks:** The age assessment is well in line with the reported ranges from the dinoflagellate cyst content. The FAD of *Tuberculodinium vancampoae* occurs in the Late Oligocene (Williams and Bujak, 1985). Representatives of the *Cribroperidium-Apteodinium* complex strongly resembling those of Borneo are well represented in Burdigalian assemblages from Louisiana , USA (Lenoir and Hart, 1986). Bujak and Matsuoka (1986) report a LAD in the early Middle Miocene for *Cribroperidium tenuitabulatum* and *Cribroperidium granomembranaceum.* Matsuoka (1983b) reports a LAD of these taxa in the lower part of his "Older Assemblage" from Central Japan, which has an Early to early Middle Miocene age. Moreover, *Cribroperidium granomembranaceum* has an acme in the this unit. Manum *et al.* (1989) report an acme of *Cribroperidium tenuitabulatum* in the Early Miocene and a LAD of this taxon at the Early to Middle Miocene boundary in the Norwegian Sea. Although, representatives of the *Cribroperidium-Apteodinium* complex do not play an important role in the biostratigraphy of co-eval strata in the Tertiary of Europe, they do show a distinct decrease within the early Middle Miocene (Brinkhuis, Zevenboom, LPP, pers. comm).

(4) *Lingulodinium ?pycnospinosum-Achomosphaera* Assemblage Group

- **Characteristics:** Dinoflagellate cysts from this unit are relatively rare. However, they show a relative dominance of *Lingulodinium ?pycnospinosum, Lingulodinium* spp., *Operculodinium* spp. and/or *Achomosphaera* spp. Representatives of the *Cribroperidium-Apteodinium* complex are rare and irregularly present and show a distinct relative decrease.
- **Occurrence:** This assemblage group has been reported from all provinces (Fig. 4). It has been observed in a variety of depositional environments which range from lower coastal plain to bathyal (Fig. 5).
- **Age assessment:** The occurrence in the *Camptostemon* and *Stenochlaena areolaris* sporomorph zones indicate a Middle Miocene age for this unit.
- **Remarks:** No specific age assessment can be derived from the long-ranging taxa of this assemblage group. The overall poorness in microplankton may be due to unsuitable lithologies in the Middle Miocene interval.

(5) *Achomosphaera- Hystrichokolpoma* Assemblage Group

- **Characteristics:** This unit is characterized by a relative dominance of *Achomosphaera* spp., *Hystrichokolpoma* spp. *Spiniferites* spp. and *Tuberculodinium vancampoae. Lingulodinium ?pycnospinosum* shows a clear decrease in the lower part of this unit. Few taxa have a FAD in this assemblage group, e.g. *Dapsilidinium pastielsii* and *Spiniferites mirabilis*-*Cordosphaeridium* cf. *fribrospinosum*, *Hafniasphaera* sp., and *Cannosphaeropsis* cf. *utinensis* have their FAD in the upper part of this unit, whereas *Cometodinium* sp. has its LAD.

- **Occurrence:** This assemblage group has been encountered in the all geological provinces (Fig. 4), where it has been encountered in a variety of depositional environments (lower coastal plain to holomarine outer neritic/ bathyal, Fig. 5).
- **Age assessment:** A late Middle Miocene to early Pliocene age for this unit is inferred from its occurrence in the *Stenochlaena laurifolia* and *Stenochlaena areolaris* sporomorph zones.
- **Remarks:** No specific age assessment can be derived from the long-ranging taxa of this assemblage group. However, judging from the old data, this unit is well established.

(6) *Tuberculodinium vancampoae*-*Operculodinium israelianum* Assemblage Group

- **Characteristics:** This unit is characterized by a relative dominance of *Tuberculodinium vancampoae* and *Operculodinium israelianum*. Other taxa which are consistently present are e.g. *Impagidinium* cf. *patulum*. *Spiniferites ramosus*, and *Cymatiosphaera* spp. A considerable number of taxa have a LAD in this unit (Fig. 7). *Achomosphaera* spp. and *Hystrichokolpoma* spp. show a clear decrease in abundance.
- **Occurrence:** This assemblage group has been recorded in all geological provinces (Fig. 4), from a variety of depositional environments (Fig. 5).
- **Age assessment:** Its occurrence in the upper part of the *Stenochlaena laurifolia* and *Podocarpus imbricatus* sporomorph zones suggests an exclusively Pliocene age for this unit.
- **Remarks:** No specific age assessment can be derived from the long-ranging dinoflagellate taxa of this assemblage group.

(7) *Tuberculodinium vancampoae*-*Exosphaeridium* Assemblage Group

- **Characteristics:** This unit is characterized by a relative dominance of *Tuberculodinium vancampoae*, *Exosphaeridium* sp., *Operculodinium* spp., *Spiniferites* spp. and *Micrhystridium*. The assemblages generally exhibit a low diversity compared to the underlying assemblage groups.
Locally, *Polysphaeridium zoharyi* shows a clear predominance, whereas *Tuberculodinium vancampoae* is relatively rare compared to *Achomosphaera* and *Spiniferites*.
- **Occurrence:** So far, this assemblage group has been observed from 3 wells in the Luconia province and some wells in the Baram province (Fig. 4). It originates from a variety of depositional setting (Fig. 5). From the Sabah province only spot observations are available.
- **Age assessment:** Inferred from its occurrence in the *Phyllocladus hypophyllus* sporomorph zone, a latest Pliocene to Quaternary age has been adopted for this unit.
- **Remarks:** No specific age assessment can be derived from the long-ranging taxa of this assemblage group. However, the stratigraphical value of this unit needs further investigations, since only a few samples were investigated from this interval.

Problematic species

A number of dinoflagellate cyst taxa shows a stratigraphical range in NW Borneo which clearly conflicts with published information. These taxa include e.g. *Hafniasphaera* sp. whose LAD is reported in the Paleocene (Wilson and Clowes, 1980), *Cordosphaeridium* cf. *fibrospinosum*, whose LAD is within the Late Oligocene (Wilson, 1988) and *Cannosphaeropsis* cf. *utinensis* of which the reported age is Late Cretaceous (Williams and Bujak, 1985), with a world-wide re-occurrence in the Middle Miocene (Zevenboom, LPP, pers. comm.). Whether these taxa are reworked from older strata, have extended ranges or have been incorrectly identified remains an open question pending investigations of new material.

Comparison with other areas

Although the dinoflagellate record of NW Borneo yields a considerable number of taxa which have been recorded in other mid to high latitude areas, the successive assemblage groups cannot be easily compared with available zonal schemes from these other areas.

Comparison within SE Asia is strongly hampered by the very incomplete and scattered nature of the published information (Figs. 1 and 3), whereas the NW Borneo record does not show obvious similarities to the world wide zones of Williams (1977, in Williams and Bujak, 1985) or any other co-eval zonal scheme (Matsuoka, 1983b; AASP, 1986, Manum *et al.*, 1989; Brinkhuis, 1992). Main factors controlling these differences are latitude and local environmental settings.

Striking is the apparent absence in NW Borneo of marker taxa such as *Chiropteridium, Deflandrea, Selenopemphix, Xandradodinium, Multispinula, Hystrichosphaeropsis, Pentadinium,* and *Batiacasphaera,* which are reported to have stratigraphic value in other areas. Furthermore, *Sumatradinium hispidum, Tuberculodinium rossignoliae, Danea heterospinosa, Glaphyrocysta circularis, Glaphyrocysta dentata, Exosphaeridium reticulatum* and *Exosphaeridium brevispinosum* which were described from adjacent areas in SE Asia have not been observed yet in the NW Borneo record. However, it may well be that this apparent absence is only due to the preparation and analysis techniques used in the late 1960's and early 1970's. The presence of *Spiniferites mirabilis* and *Hystrichokolpoma rigaudiae,* albeit in low frequencies, in the Late Pleistocene to Holocene of the Philippine Sea (Matsuoka, 1981b), suggests that the apparent LAD of these taxa in the Late Pliocene of NW Borneo may also be caused by these acquisition techniques.

Environmental preferences of dinoflagellate cysts

The original 56 wells in the Oligocene to Quaternary interval which were investigated on their dinoflagellate content exhibit a large variety of depositional environments ranging from lower coastal plain, inner, middle, outer neritic (with or without fluvial influences) to bathyal settings (Figs. 5 and 6). The Late Paleocene-Middle Eocene section is interpreted to be deposited in holomarine middle neritic to bathyal environments. Assessments of these depositional environments have been based on benthonic foraminifera in combination with sedimentological and wireline log characteristics.

The comments on environmental preferences of dinoflagellate cyst taxa in NW Borneo record cannot be but very broad generalizations. To date no detailed integrated stratigraphical studies have been carried out to fully understand the relationship between dinoflagellate taxa and depositional environments. Nevertheless the environmental preferences which can be extracted from the existing data set are here discussed to demonstrate the potential of dinoflagellate cysts to assist in determining marine depositional environments. However, the validity of the observed relationships still needs to be tested.

As expected, well known low latitude (tropical to subtropical) taxa like *Tuberculodinium vancampoae* and *Operculodinium israelianum* with a restricted occurrence in the inner to outer neritic regimes (Edwards *et al.*, 1991; Harland, 1983, Wrenn and Kokinos, 1986) are well represented in the predominantly shallow marine deposits of NW Borneo. Other taxa known from restricted to shallow marine facies, like *Spiniferites, Areosphaeridium, ?Systematophora, Operculodinium* (inner to outer neritic: Wrenn and Kokinos, 1986, Brinkhuis, 1992), *Areoligera, Glaphyrocysta* (outer inner to inner outer neritic), *Homotryblium* (inner neritic and/or restricted (lagoonal) settings), representatives of the *Wetzeliella* and *Phthanoperidium* complexes (shallow marine, Brinkhuis, 1992), as well as taxa which occur from inner neritic to bathyal environments such as *Lingulodinium machaerophorum* and *Spiniferites mirabilis* (Wrenn and Kokinos,1986) are also present in NW Borneo. Taxa restricted to the outer neritic to bathyal realm which include *Impagidinium, Nematosphaeropsis* and *Cannosphaeropsis* (Matsuoka, 1981b; Wrenn and Kokinos, 1986, Brinkhuis, 1992) are very rare in NW Borneo.

The relationship between dinoflagellate cysts and depositional environment which are observed in other areas generally do not conflict with those within the predominantly shallow marine deposits of NW Borneo. The very restricted occurrence of *Impagidinium* and *Cannosphaeropsis* both in numbers and species suggests that deeper marine environments were either not extensively investigated or represented in the 56 wells studied (compare Matsuoka, 1981b). Based on the reported environmental preferences of associated types (e.g. *Tuberculodinium vancampoae* and *Spiniferites*), the relative abundance of *Hystrichokolpoma* and/or *Achomosphaera* may, in the local context, be indicative for inner to outer neritic environments (Fig. 7). However, spot observations in outer neritic to bathyal deposits of the Baram Delta demonstrate that such abundances occur in deeper marine environments as well.

The acme of the *Cribroperidium-Apteodinium* complex has been observed in predominantly lower coastal plain deposits of the Balingian and Luconia provinces, and in holomarine inner, and outer neritic to bathyal strata of the Baram Delta. In the Balingian province a clear relationship between this complex and depositional environments has been observed. In these predominantly lower coastal plain deposits the *Cribroperidium-Apteodinium* complex is a major component of the microplankton fraction and is generally associated with benthonic foraminifera indicative of fluviomarine inner neritic conditions; in the holomarine inner to outer neritic strata this complex is associated with an abundance of *Hystrichokolpoma.*

In the predominantly lower coastal plain deposits of the Balingian province an abundant representation of non-tabulate chorate cysts like *Lingulodinium ?pycnospinosum, Operculodinium* and *Lingulodinium* is generally associated with benthonic foraminiferal assemblages which indicate holomarine inner neritic environments. However, an abundant representation of *Lingulodinium ?pycnospinosum* has also been observed with benthonic foraminiferal assemblages indicative of lower coastal plain environments.

A dominance of *Homotryblium* has been observed from the predominantly lower coastal plain Late Oligocene deposits of the Luconia and Balingian provinces. In the Luconia province this abundance is associated with benthonic foraminiferal assemblages indicative for a holomarine inner neritic interval. The poor diversification of the microplankton fraction and the dominance of few species of *Homotryblium* suggests restricted (?lagoonal) conditions.

Polysphaeridium zoharyi, known from inner to outer neritic settings (Wrenn and Kokinos, 1986) shows a clear predominance in a Late Pliocene-Quaternary assemblage from the Sabah province. This dominance is associated with benthonic foraminifera indicative of holomarine inner to middle neritic settings.

Only in the Late Paleocene-Middle Miocene interval some questions remain (Figs. 2 and 3). Micropalaeontological control suggest a holomarine middle neritic to bathyal environment. Sporomorphs (common) and microplankton (abundant and diverse) agree with this interpretation, as does the presence of *Nematosphaeropsis, Impagidinium* and *Areosphaeridium.* However, *Areoligera* and *Glaphyrocysta* suggest a shallower inner neritic setting. Whether this apparent discrepancy is due to transportation or to other factors which may control the observed combination of taxa remains to be investigated.

DISCUSSION ON THE POTENTIAL OF DINOFLAGELLATE CYSTS IN THE TERTIARY AND QUATERNARY STRATIGRAPHY OF OFFSHORE NW BORNEO

Despite the limited data set from offshore NW Borneo it can be concluded that dinoflagellate cysts have potential to be used in the Tertiary and Quaternary stratigraphy of this area. In future they may assist in (inter) regional correlations within SE Asia and adjacent areas. In NW Borneo dinoflagellate cyst may have an impact on the understanding of chronostratigraphical relationships. Although sporomorphs can achieve a high degree of stratigraphical resolution (Poumot, 1989; Morley, 1991) the calibration of the SE Asian microfloral record to the Tertiary-Quaternary chrono-stratigraphical scale can only be achieved indirectly by calcareous nannoplankton and/or planktonic foraminifera. The latter groups have a global distribution, whereas the sporomorphs are restricted to the SE Asian tropical belt.

Paleocene-Eocene

Deposits of Paleocene-Eocene age have only been encountered sporadically in NW Borneo. Micropalaeontological control over this interval is extremely poor, whereas calcareous nannoplankton data is lacking. So far, these strata have been included into two sporomorph zones, viz. the *Proxapertites* (Late "Senonian"-Paleocene) and *Retitriporites variabilis* (Eocene) zones, which to date have only been recorded from SW Sarawak (Muller, 1968, Figs. 2 and 3). However, the zonal age assessments are based on rather weak evidence.

The Paleocene age for the *Proxapertites* zone is adopted from a single planktonic foraminifera dating (sample My 1411 from the marine Engkilili Fm) and the low percentages of *Discoidites borneensis* Muller, 1968 (=*Brownlowia*). Planktonic foraminifera identified include a.o. *Morozovella velascoensis* (Cushman) which would suggest a Late Paleocene age (Stainforth *et al.,* 1975). In addition, Muller (1968) uses the presence of *Proxapertites* Van der Hammen, 1956 in Maastrichtian strata of Columbia and Venezuela as an argument for including a Senonian age for the lower part of the *Proxapertites* zone. A review by Muller *et al.* (1987) presents an exclusively Paleocene age for *Spinozonocolpites baculatus* Muller, 1968 in northern South America, a taxon well represented in the *Proxapertites* Zone and previously considered to have a FAD in the Maastrichtian (Germeraad *et al.,* 1968). In view of this it may well be that the age of the *Proxapertites* zone is restricted to the Paleocene, and that the Senonian age interpretation can be discarded. This in line with the views of Morley (1988, pers. comm.) who suggests that the interpretation of the Cenomanian-Paleocene sporomorph succession in SW Sarawak is more complex due to a considerable amount of reworking of Early Cretaceous sporomorphs through out the interval. Although it is beyond the scope of the present paper to discuss the biostratigraphy of this area in great detail, the presence of *Dinogymnium* and *Odontochitina* in samples from the middle and upper parts of the *Proxapertites* Zone suggests that indeed reworking played an important role which has not been fully appreciated.

The *Retitriporites variabilis* Zone has been provisionally established and based on only 10 samples from a restricted (lacustrine) facies, and its probable Eocene age is based on its stratigraphical position above the *Proxapertites* Zone, and the absence of Oligocene and younger sporomorph taxa (Muller, 1968).

In addition to this, it should be emphasized that single specimens of the Late Paleocene planktonic foraminifera taxon *Morozovella velascoensis* (Cushman) are almost impossible to distinguish from the Eocene taxon *Globorotalia caucasica* Glaessner. They are generally distinguished on the basis of the associated planktonic foraminifera taxa (Stainforth *et al.*, 1975).

From this it is obvious that the Paleocene-Eocene stratigraphy from NW. Borneo is far from being completely solved. However, the presence of diverse dinoflagellate cyst assemblages (*Apectodinium hyperacanthum-Thalassiphora pelagica* Assemblage group) which taxa are known from co-eval strata in other areas demonstrate that the Paleocene-Eocene interval from NW Borneo can be subdivided more accurately by dinoflagellate cysts rather than by pollen and spores or planktonic foraminifera.

Oligocene

Strata included in the Oligocene represent very thick packages of predominantly lower coastal plain sediments, whereas in the Baram Delta holomarine outer neritic to bathyal deposits are encountered (Fig. 5). Micropaleontological and calcareous nannoplankton control over this interval is very incomplete and limited to a few spot observations from marine incursions. The Oligocene strata are included in the lower part of the *Brownlowia* sporomorph zone. However, the relation to the Oligocene stages is not fully understood. Age diagnostic sporomorphs in this interval are relatively rare and the assumed ranges are hardly verified by independent dating methods (Morley, 1978, 1991).

Although the dinoflagellate cysts from the Oligocene interval have not been investigated in great detail it may be obvious that microplankton is useful to highlight marine incursions in the predominantly lower coastal plain deposits of the *Brownlowia* zone and can be used in (intra) field and (inter) regional stratigraphical correlations.

Oligocene-Early Miocene boundary

The Oligocene-Miocene boundary in offshore NW Borneo has not been characterized palynologically (Germeraad *et al.*, 1968; James, 1984; Morley, 1991). This boundary is located in a sequence of predominantly lower coastal plain deposits where micropalaeontological and nannoplankton control is rare to absent (Fig. 5). From a palynological view this boundary falls within the *Brownlowia* sporomorph zone and the *Cribroperidium-Apteodinium* Assemblage Group.

The dinoflagellate data suggests that representatives of the *Cribroperidium-Apteodinium* complex may assist in a palynologically characterization of the Oligocene-Early Miocene boundary in this area. Most of the stratigraphical records of representatives of this complex provide an exclusively Early to early Middle Miocene range (Matsuoka, 1983b; Lenoir and Bujak, 1986; Bujak and Matsuoka, 1986; Manum *et al.*, 1989). Only the APLF (1986) reports an Oligocene age for *Cribroperidium tenuitabulatum*. In order to establish a palynological characterization of the Oligocene-Early Miocene boundary, detailed investigations within the *Cribroperidium-Apteodinium* Assemblage Group should be carried out and an attempt needs to be made to classify the individual taxa of the *Cribroperidium-Apteodinium* complex on a species level.

Early Miocene

A major part of the Early Miocene strata is developed in a predominantly lower coastal plain environment, where micropaleontological and nannoplankton control again is rare to absent (Fig. 5). Only from the late Burdigalian firm nannoplankton datings are available (NN4). In terms of palynological zones, the interval can be included in the upper part of the *Brownlowia*, the lower part of the *Sonneratia caseolaris* zones and the *Cribroperidium-Apteodinium* Assemblage Group. Preliminary investigations demonstrate that specific stratigraphical intervals can be recognized on dinoflagellate cysts.

Middle Miocene-Quaternary

Although nannoplankton, planktonic foraminifera and sporomorphs from this interval provide a framework for detailed stratigraphical correlations, the data presented suggest that dinoflagellate cysts can assist in refining stratigraphical correlations.

CONCLUSIONS

Dinoflagellate cysts are relatively rare compared to pollen and spores in the predominantly shallow marine Tertiary to Quaternary deposits of NW Borneo. However, they clearly demonstrate a potential for stratigraphical and environmental applications, which have not been tested to its full extend in palynological investigations in SE Asia.

The observed dinoflagellate succession in NW Borneo, which mainly is based on data collected in the late 1960's to early 1970's, enable the recognition of 7 informal assemblage groups, although the dinoflagellate record comprises a number of long-ranging taxa. The succession recognized does not closely compare to those reported from other low, mid and high latitude areas.

The data presented clearly demonstrate that the Oligocene, Middle Miocene, latest Pliocene-Quaternary have not been sufficiently investigated. Consequently, the assemblage groups recognized do not provide a representative picture of the dinoflagellate cyst development in these intervals.

Specific dinoflagellate cysts show a clear relationship to specific depositional environments, where they occur in relative high frequencies. Representatives of the *Cribroperidium-Apteodinium* complex generally are well represented in fluviomarine inner neritic settings. *Hystrichokolpoma* and non-tabulate chorate cysts like *Lingulodinium* spp., *Operculodinium* spp. and *Lingulodinium ?pycnospinosum* are generally abundant in holomarine inner neritic settings. *Polysphaeridium zoharyi* has been found in holomarine inner to middle neritic settings. However, these relationships are observed from a limited number of samples and their validity still needs to be tested.

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