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Pollen and diatom stratigraphy of a dendritic fluvial/lacustrine mire system at Tasik Bera, Malaysia: Preliminary results

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Abstract: The Tasik Bera mire system represents deposition of peat and peaty sediments within a dendritic fluvial drainage basin in the humid tropics. Peaty sediments have been accumulating for at least 4,500 years in the lowest part of the basin, but accumulation rates and hence the thickness and lateral extent of the mire underwent a rapid increase and expansion beginning at about 660 years BP. In this preliminary study, pollen and diatom stratigraphy of two cores is related to some physical and chemical characteristics of the organic rich sediments. The sediments are highly variable, both vertically and laterally, the variations principally controlled by the type of vegetation dominant. Vegetation in turn is related to the degree of wetness of the site. Three environments of deposition contribute peat with distinctive palynological and physical characteristics. The limnetic environment, dominated by algae and easily degraded aquatic macrophytes, contributes very fine hemic peaty sediment with high fine silt content and a large algal component. The littoral environment is dominated by sedges and the woody shrub *Pandanus*, both of which have a large sub-aqueous biomass, and are quite resistant to degradation. Sediment from this environment is woody, hemic to coarse hemic, with a moderate to high very fine silt content and a much smaller algal element. Forest swamps, which occupy most of the mire area, contribute woody, fibric to hemic peaty sediments with low to moderate mineral matter content in the form of clays and very fine silt. Succession from both limnetic to forest swamp, and the reverse, is recorded in cores from different sites. No part of the mire yet studied is approaching oligotrophic conditions.

INTRODUCTION

In this study we examine a dendritic fluvial mire in Peninsular Malaysia and present a detailed stratigraphy of carbonaceous sediments (average 43% organic matter) in two cores which record the transition from principally clastic to organic sedimentation. Background material for this study is principally drawn from a detailed ecological study undertaken between 1968 and 1974 by a multidisciplinary group under the auspices of the Malaysian and the Japanese National Councils of the International Biological Program. The results of that study were published as a Monograph edited by Furtado and Mori (1982) and some of the data presented herein was mined from that rich source. Measurements of primary and secondary productivity, a census of vegetation including dominant macrophytes and algae, and decomposition rates of plants are documented. In addition, organic rich sediments were studied in two borehole transects from the central and northern parts of the swamp, and a history of sedimentation and vegetation change constructed palynologically for the northern site (Morley, 1982a). Two radiocarbon dates were obtained, from depths of 3.9 m in "medium detritus mud" (660 ± 75 BP) and 8.6 m in basal silty sand (4,500 ± 80 BP). From stratigraphic evidence Morley (1982a) outlines a likely history of decreasing flow rates through the mid-Holocene Bera River system, rising water levels, and a late rapid increase in organic sedimentation and expansion of the swamp.

LOCATION

Tasik Bera (Lake Bera) is a fluvial/lacustrine mire system (swamps and marshes) of about 60 km^2 within a small (600 km^2) drainage basin in central Peninsular Malaysia, 110 km from the sea, at an elevation of 30 m (Fig. 1). The Tasik Bera deposit represents organic accumulation due to paludification of a dendritically drained alluvial basin (paludification occurs when peat deposition overflows beyond a basal depression onto mineral soil due to elevation of the water table). Although called a lake, only about 1% of the area of this topogenous wetland is open water, the rest being sedge and pandan marsh, and swamp forest (Fig. 2). The restricted drainage and high water table is believed to be the result either of an otherwise undocumented tectonic movement affecting the basin (Stauffer, 1968), or of damming by accumulating organic sediments accompanying the growth of dense *Pandanus* vegetation at a narrow defile at the northern extent of the present swamp (Morley, 1982a).

Direction of flow of Sungai Bera and the main channel through Tasik Bera is to the north, and is believed to have reversed from a southerly flow during the Pleistocene as a result of stream capture near the northern outlet by the Lower Pahang River, which drains east into the South China Sea. This expansion of the Pahang drainage led to extensive delta building and, along with Holocene sea level rise, consequent loss of gradient in the lower Pahang system. It now appears that the southwestern part of the drainage is being recaptured by the

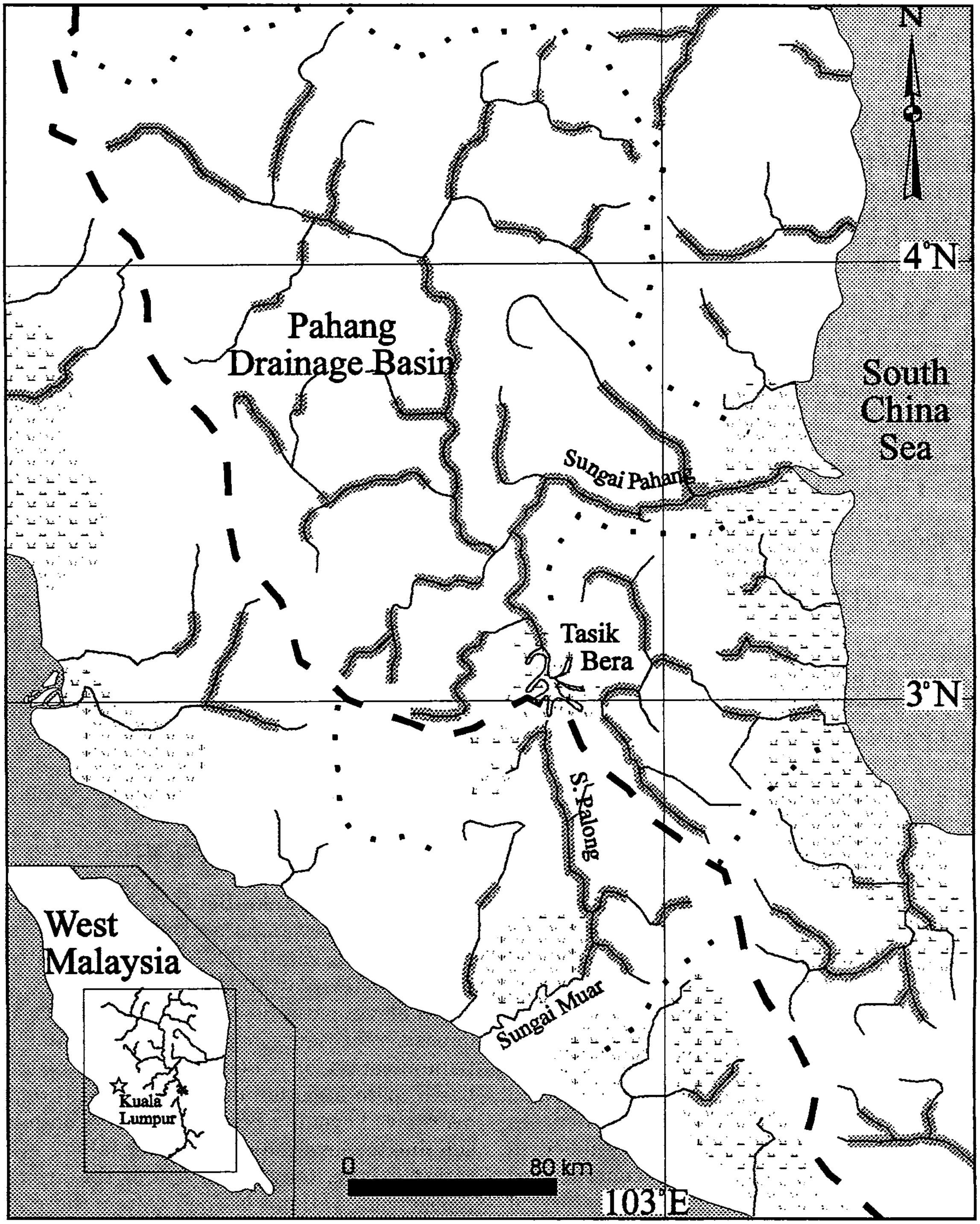

Figure 1. Drainage basins, flood prone river valleys and peatlands in Peninsular Malaysia (adapted from Dobby, 1960).

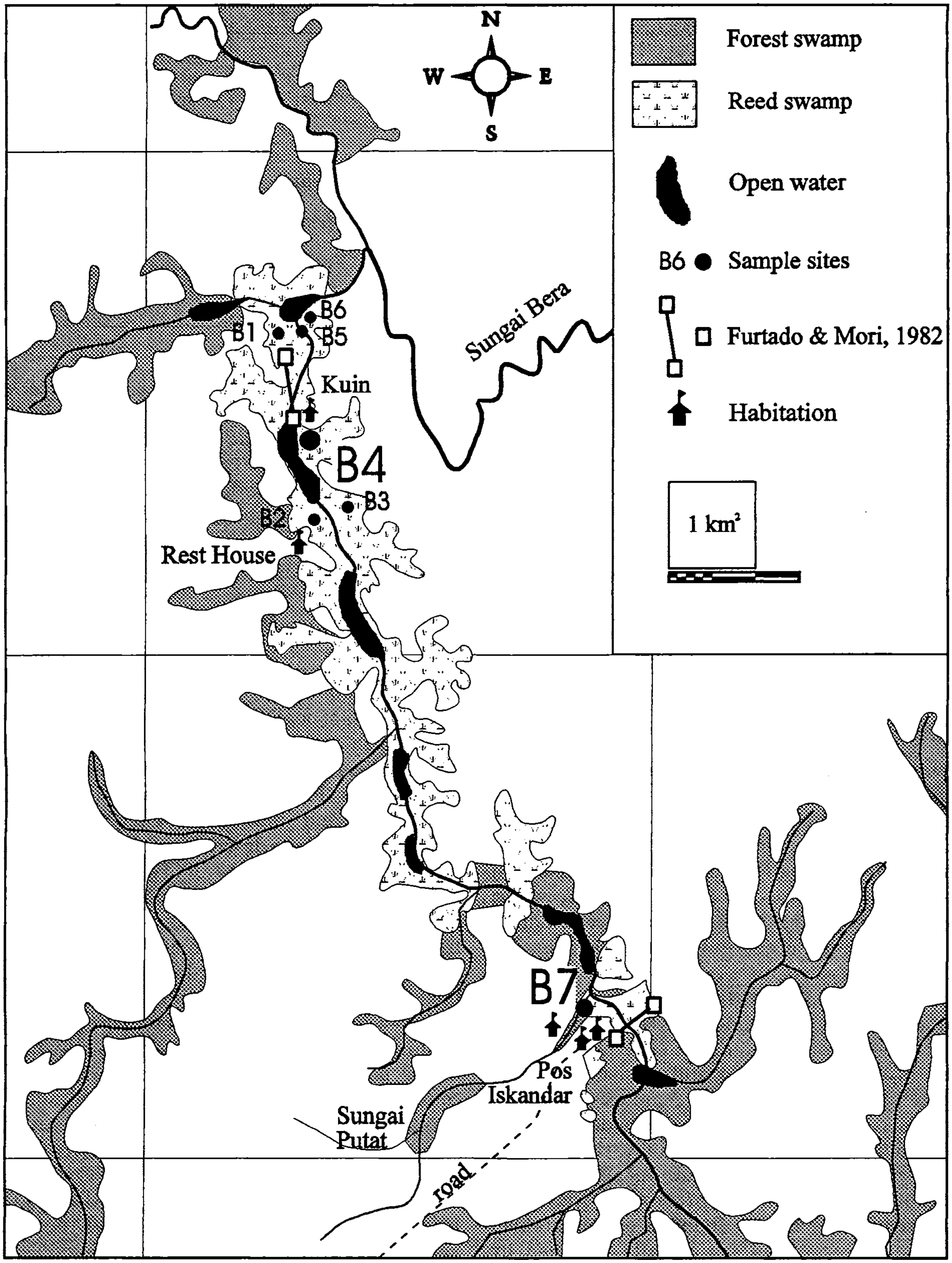

Figure 2. The north end of Tasik Bera. Cross sections and sample site locations from Furtado and Mori (1982) are indicated, as are sample sites, areas of open water, reed swamp and forest swamp.

Table 1. Sample sites at Tasik Bera.

Sample	Core depth (compacted)	H_2O depth	% Ash (mean)	pH (mean)	Base of core interval	Environment
B1	30 cm	50 cm		5.1	'peat'	*Pandanus* swamp
B2	30 cm	20 cm		4.6	'peat'	Open water/algal mat
B3	50 cm	35 cm	49	4.9	'peat'	*Lepironia / Pandanus*
B4	78 cm	25 cm	59	5.5	'peat'	Tree 'hammock'
B5	68 cm	20 cm	60	5.3	'peat'	*Eugenia* forest swamp
B6	25 cm	– 10 cm		5.5	'peat'	*Eugenia* forest swamp
B7	87 cm	50 cm	56	5.0	white clay	*Lepironia* reed swamp

southwesterly flowing S. Palong-S. Muar system (Dobby, 1960; Morley, 1982a). It is also reported that current flow in the lower S. Bera periodically reverses for short periods as a result of flooding in the upper S. Pahang drainage, possibly when combined with storm surge from the coast. This complex of events and circumstances — flooding, and disruption of drainage systems accompanying transgression of the profoundly eroded stable platform — created the potential for deposition of extensive marine and freshwater peats, and thus has implications for the onset of coal deposition (Anderson, 1964, 1983).

Environments of Deposition

Organic-rich sediments are accumulating as a topogenous peatland, the boundaries of which are controlled by the topography of the dendritic drainage system. Furtado and Mori (1982) distinguish 3 ecological environments based on vegetation, and the persistence of standing water; the open water (limnetic), the littoral or reed marsh, and the swamp forest environments (Fig. 2). Dominant vegetation is distinctive in each environment, but in all areas algae form a significant element. Limnetic environments, with an average standing water depth of 2 m, represent about 1% of the swamp area, and consists of patches of open water connected by a complex of winding channels. The pond fringes, and sides of some wider channels, are dominated by the floating aquatic plants *Utricularia flexuosa* and *U. aurea* (bladderworts), and *Cryptocoryne griffithii* dominates channel floors. Channels are maintained by human efforts, and periodically modified by floods. The littoral and sub-littoral surrounding the open water areas (average water depth 0.8 m) make up about 32% of the mire area, and are dominated by sedge marshes (principally *Lepironia articulata* reed marsh, with secondary *Eleocharis ochrostachys*), and *Pandanus* spp. (principally *P. helicopus*) swamps. The remaining 67% of the mire area is swamp forest, the most distinctive genera being the trees *Eugenia* spp. and *Tristania* spp. (Myrtaceae), *Santiria* spp. and *Dacryodes* spp., (Burseraceae) and *Campnosperma* spp. (Anacardiaceae), among others.

METHODS

Physical and Chemical Analyses

Samples of peat and associated clastic sediments were taken at 7 sites in the north of Tasik Bera between Pos Iskandar and the northern outlet at Sungai Bera (Fig. 2) in early May 1995 (i.e. end of the southwest monsoon season). Table 1 summarizes the site descriptions. Of these samples, intact cores from sites B4 and B7 were analysed for pollen and diatom content, and are discussed here in detail. Characteristics of the sediments recovered from the other sites are summarized in Table 2. At the time of sampling, water levels were not at flood, but at what may be considered 'normal high'. Samples consist of 3 cm diameter cores secured by pushing PVC pipe into the lake bottom by hand as far as possible and gently withdrawing it. The consistency of the peat, and in one case underlying clays, allowed the sample to remain intact, if somewhat compressed, in the pipe until extruded, described, and sealed in plastic bags. Cores B4 and B7 were extruded continuously in the lab, split longitudinally, and stored in split PVC pipe, lined and wrapped with aluminum foil. Samples were kept cool until subsampled for pH and sulphur content, and then stored frozen. Compression of the sediments, particularly the peaty and woody material, is inevitable with this sampling method

Table 2. Physical characteristics of Tasik Bera peats.

Sample	Depth in core	Z	Z est.*	pH	Sulphur	HTA %	H_2O %	
B1				5.10				bulk sample
B2				4.60				bulk sample
B3-6	0	35	35					
B3-5	10	45	62	5.41	0.27	53	86	hemic
B3-4	20	55	89	4.97	0.44	53	92	fibric
B3-3	30	65	116	4.85	0.36	35	92	coarse hemic
B3-2	40	75	143	4.81	0.36	47	89	hemic
B3-1	50	85	170	4.34	0.67	57	89	hemic
means				4.88	0.42	49	90	
B4-9	0	25	25	5.23	0.22	68	78	silty, hemic
B4-8	2	30	47	5.92	0.15	66	83	silty, hemic
B4-7	10	40	69	5.36	0.23	66	84	hemic
B4-6	20	50	91	5.34	0.31	56	87	hemic
B4-5	30	60	113	5.40	0.25	59	84	hemic
B4-4	40	70	134	5.16	0.19	52	86	fine hemic
B4-3	50	80	156	5.44	0.23	55	87	fine hemic
B4-2	60	90	178	5.41	0.24	58	84	hemic
B4-1	70	100	200	6.40	0.26	51	83	coarse hemic
means				5.52	0.23	59	84	
B5-7	10	30	30	5.33	0.13	72	73	clay
B5-6	20	40	55	5.12	0.29	53	88	clayey hemic
B5-5	30	50	80	5.10	0.27	54	89	clayey hemic
B5-4	40	60	105	5.21	0.21	61	85	clayey fine hemic
B5-3	50	70	130	5.81	0.24	58	88	clayey fine hemic
B5-2	60	80	155	5.10	0.27	60	87	clayey fine hemic
B5-1	70	90	180	5.40	0.22	60	82	wood
means				5.30	0.23	60	85	
B6				5.50				bulk sample
B7-9	0	50	50	5.19	0.16	68	85	silty, rooted
B7-8	5	55	55	6.28	0.22	38	80	hemic/coarse hemic
B7-7	15	65	83	5.28	0.4	49	92	fibric/coarse hemic
B7-6	25	75	105	5.39	0.37	65	90	coarse hemic
B7-5	35	85	128	5.43	0.27	60	85	coarse hemic
B7-4	45	95	150	5.30	0.31	24	90	fibric, layered
B7-3	55	105	173	4.43	0.31	25	87	silty hemic
B7-2	70	120	195	4.16	0.02	89	61	grey clay
B7-1	78	128	200	3.90	0.01	89	49	mottled white clay
means				5.04	0.23	56	80	

Z = Depth (cm) below water surface in compressed core.
Z* est. is an estimation of the depth of sample before compaction.

and difficult to quantify. At site B7, at which sampling extended from the surface to the base of the peat in clay, an estimate of the degree of compression of the core is made, and approximate uncompressed depths are included in the diagrams. However, all data is recorded according to uncorrected depths in the compressed cores (Table 2).

The organic-rich sediments collected at Tasik Bera were examined using methods commonly applied to studies of peat and coal. Definitions of peat vary as to allowable organic content, but in order to have some meaning in terms of precursors to economically viable coal deposits, a detrital mineral content of no more than 25%, dry weight, is generally accepted. Mineral matter content, henceforth called ash or HTA (high temperature ash) content, was determined by weight loss on ignition in a muffle furnace at 550°C. This study uses the University of South Carolina standard, by which peat is defined as Low (< 5 wt%), Medium (5–15 wt%) and High Ash (15–25 wt%). Above 25 wt% ash is not peat but carbonaceous or peaty sediment. In addition to ash, moisture content of wet peaty sediment, drained of superficial water, was measured by air drying at 50°C (wt% moisture lost), and is used in plots as an approximation of the density of the peat: the lower the moisture content, the denser the peat. In addition to the physical characteristics of the sediments, 1 cm subsamples were taken at 10 cm (compressed) intervals and tested for pH, and for total sulphur content (dry weight percent, dried at 50°C, crushed to 100 mesh), determined using a Leco® SC-132 Sulphur Analyzer.

Degree of humification of the organic constituents is based on relative proportions of large fibres or pieces of wood (will not pass a 2.0 mm sieve), medium sized (passes a 2.0 mm but not a 0.25 mm sieve), and fine constituents (pass a 0.25 mm sieve), as determined using a wet-sieving procedure modified from Staneck and Silc (1977). The more fibres the peat or peaty sediment contains, the less humified it is, in general. Subsamples of 2.7 and 3.8 cm (of 3 cm diameter core) were sieved in this fashion. The results of sieving of the organic matter were dried in a 50°C oven and then weighed. The results of sieving are shown graphically as percentages of total by dry weight in two cores, correlated with palynological analysis.

POLLEN AND DIATOM COUNTS

Pollen stratigraphy and counts of diatom abundance reflect fluctuations in the floral communities and hydrological conditions at sites B4 and B7 during deposition of the upper metre or so of sediment. Pollen and spore identification is based on published and unpublished work of Morley (1976, 1981, 1982a, 1982b), Anderson and Muller (1975), Haseldonckx (1977), Sowunmi (1972), van Geel (1976) and others. Samples were prepared from 3 cm diameter cores in increments of 2.7 or 3.8 cm. Whole sediment was sieved as described above, the fine organic fraction (< 0.25 cm) was then separated from mineral matter by flotation and acetolysed (Faegri and Iversen, 1989). No HF treatment was used, in order to preserve diatom frustules and phytoliths. Pollen diagrams (Figs. 3 and 6) represent percent of total pollen sum excluding *Pandanus* spp., for all identifiable taxa. *Pandanus* spectra represent percent of the total sum. Diatom stratigraphy is shown in Figures 4 and 8. As an aid in stratigraphic interpretation, selected pollen and spore sums are then compared to physical and chemical characteristics of the sediments, and diatom abundances, and presented in interpretive diagrams (Figs. 5 and 7).

Pollen and Spores

The most distinctive aspect of the pollen stratigraphy is the variation in the pollen of *Pandanus* spp., which make up from 35 to 95% of the total palynomorph count at B4, and from 4 to 75% at B7. *Pandanus helicopus* and other *Pandanus* species present at Tasik Bera are prolific pollen producers, and *Pandanus* pollen representation is expected to be greater than the representation of *Pandanus* spp. plants at the sites studied (Morley, 1982a). Nonetheless, changes in *Pandanus* pollen frequency provide a usable indicator of changing conditions in the swamp when plotted against other selected pollen and diatom sums. *Fusiformisporites* -type fungal spores were also included in the counts. This distinctive type of spore has proven to have utility in Paleogene palynostratigraphy (Elsik, 1968, 1970, 1980) and is assigned to (at least) modern tropical *Cookeina* sp. cup fungi by Elsik (1976) and tentatively associated with the forest swamp environment.

Diatoms

There are 7 main orders of algal phytoplankton represented in Tasik Bera, namely the Chlorophyta (very rich ~265 spp.), Bacillariophyta (diatoms) (rich ~61 spp.), Cyanophyta (poor), Rhodophyta, Pyrrhophyta and Euglenophyta (very poor), and Chrysophyta (rare). All environments are subject to seasonal fluctuations in phytoplankton densities which coincide with the monsoon rains (Table 3). Principal contributors to the seasonal peak are the Chlorophytes (green algae, particularly *Staurastrum* spp. ~22%, *Cosmarium* spp. ~12%, *Closterium* spp. ~10%, *Micrasterias* spp. ~10%) and

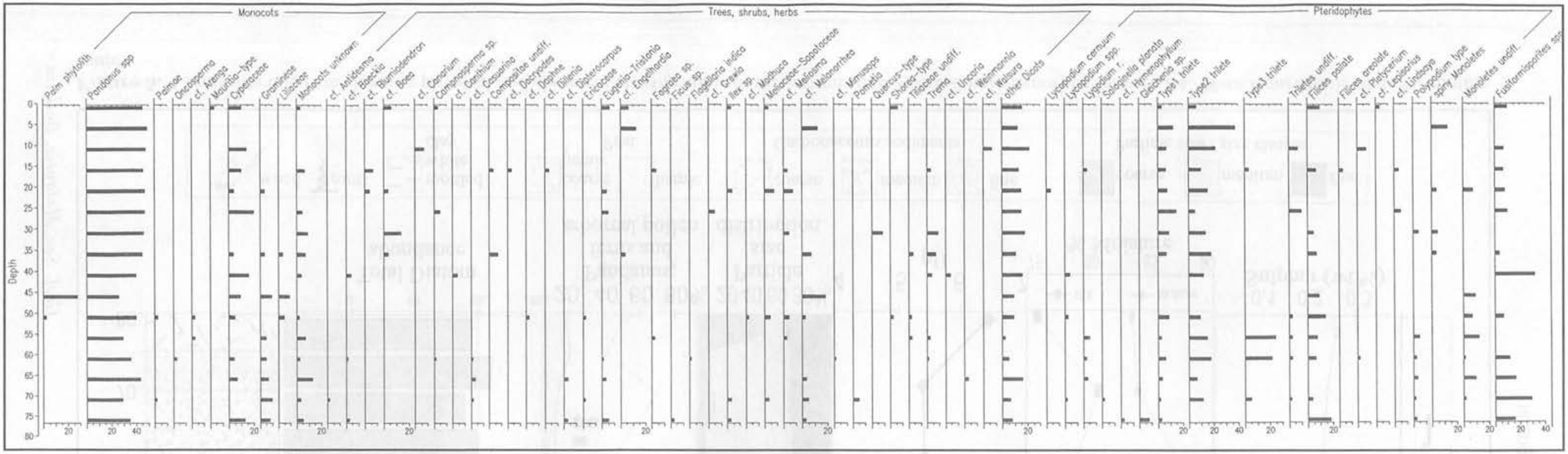

Figure 3. Pollen diagram of core B4. Bars represent percentages of total pollen sum less *Pandanus*.

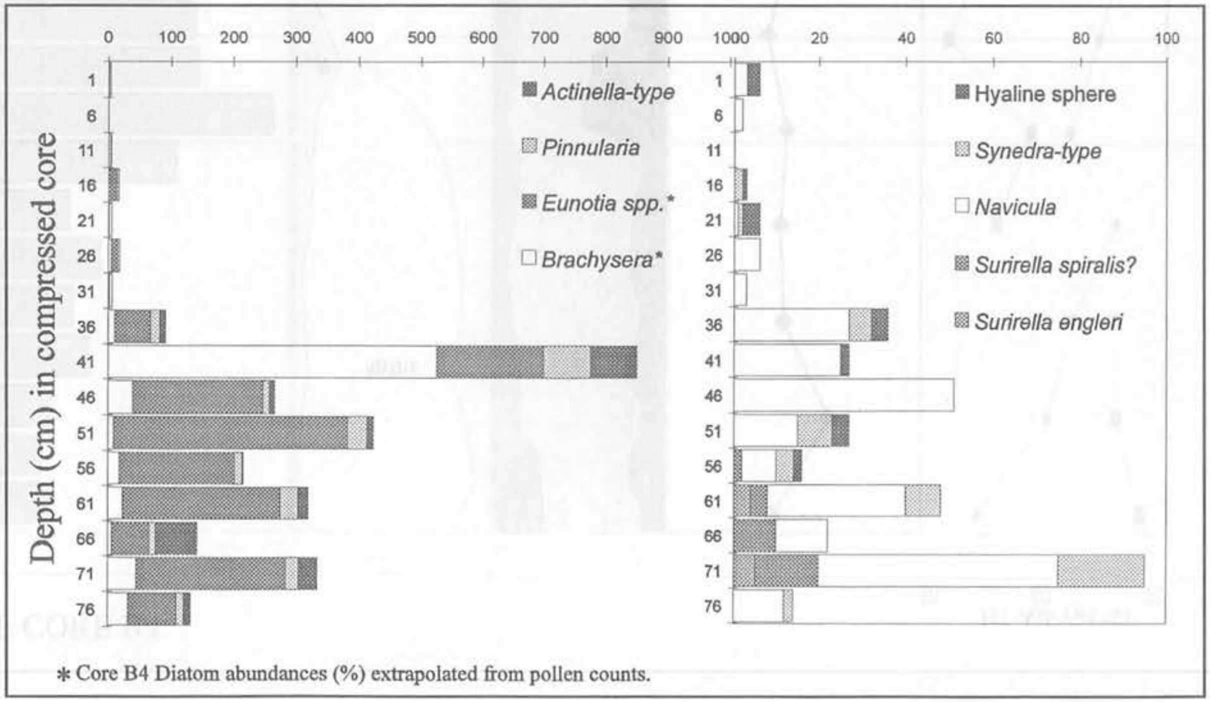

Figure 4. Diatom distributions (excepting *Frustulia*) in core B4.

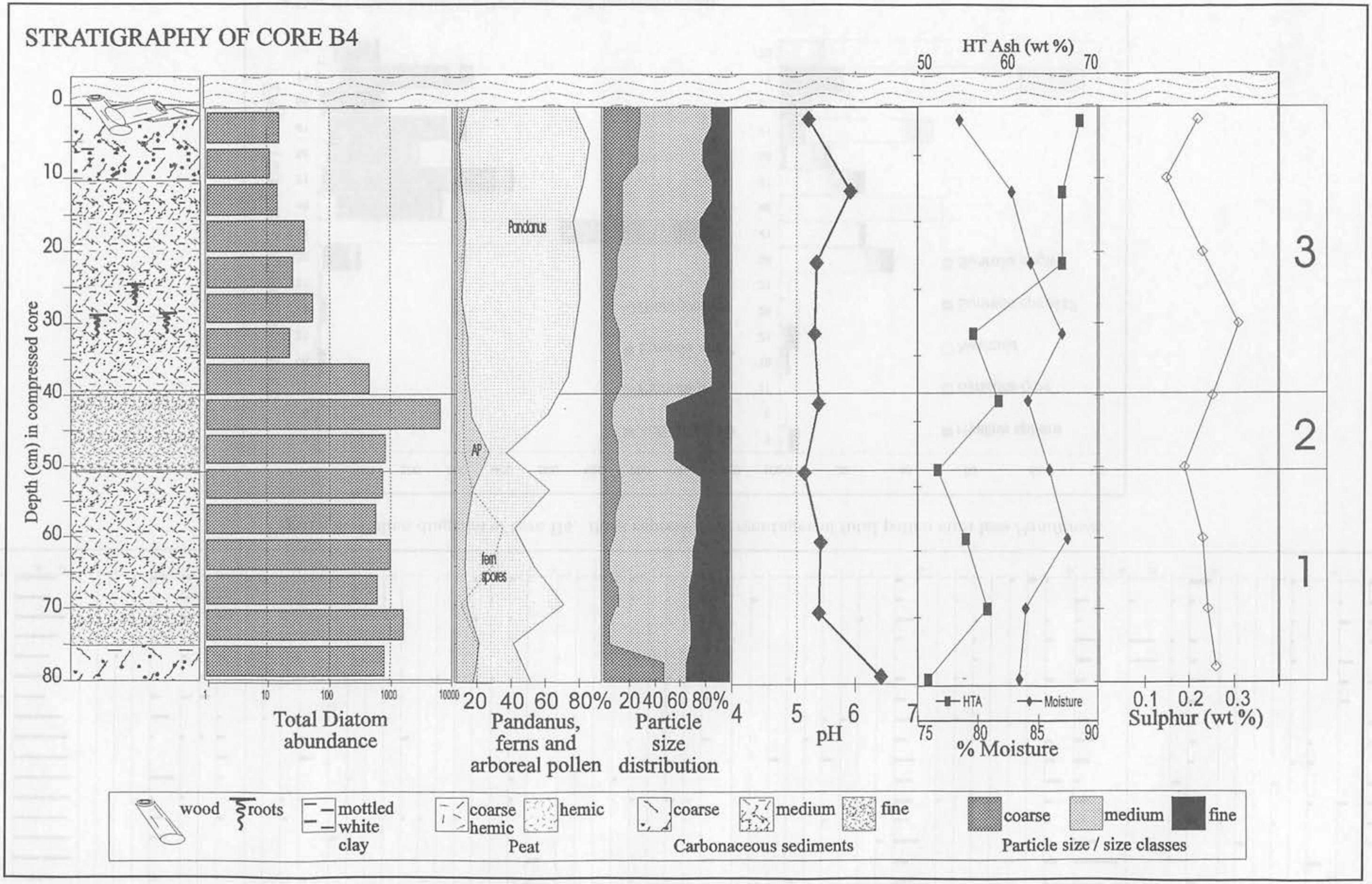

Figure 5. Composite diagram showing physical and chemical stratigraphic data, diatoms and selected palynomorphs for core B4. Note logarithmic scale for diatom counts.

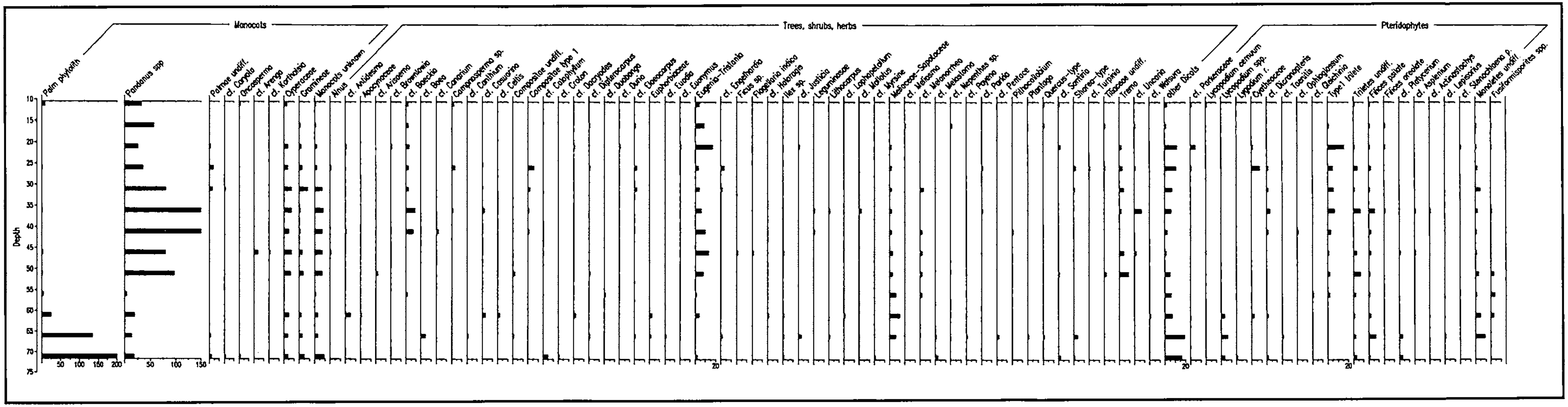

Figure 6. Pollen diagram of core B7. Bars represent percentages of total pollen sum less *Pandanus*.

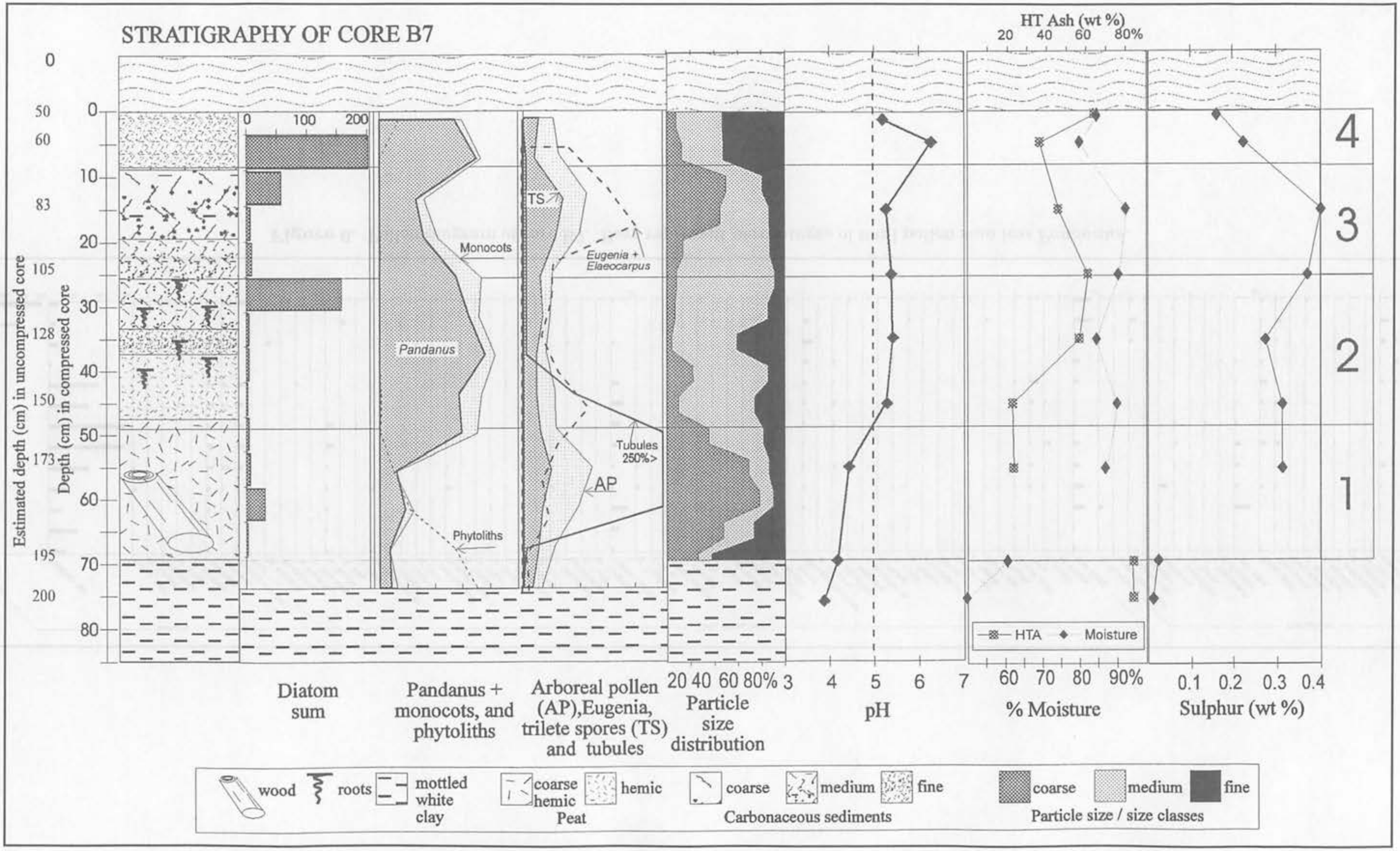

Figure 7. Composite diagram for core B7 showing physical and chemical stratigraphic data, diatom and pollen stratigraphy.

the Bacillariophytes (diatoms). The algal peak and richness is reflective of the rheotrophic nature of the mire, probably because of increases in nutrient flux brought on by flooding of the watershed, which leads to an increase in macrophyte productivity, and hence habitat for epiphyte algae (Table 4). Diatom abundance in the bottom sediments is thus seasonal and is related to turbidity. Diatoms tend to remain floating as long as conditions are favourable for photosynthesis, because they store food as lipids (sterols) which lend buoyancy. If turbidity increases, they tend to sink, particularly those with less complex (i.e. buoyant) frustule or colonial morphology (Scagel *et al.*, 1965). Thus there is an association of high algal deposition with high siltation in the limnetic sediments. Fungal elements in the sediments are likewise related to seasonal nutrient flux. Fungi, in the form of water molds, are common parasites on planktonic, epiphytic and benthic algae. These molds in turn may be attacked by hyperparasitic fungi. Populations of fungi are thus related to algal productivity in limnetic environments — algal blooms often terminate in outbreaks of phycomycetous fungi. Nutritional overload due to algal blooms (or pollution) result in high fungal populations but low species diversity. Under normal conditions, high diversity of algae will be accompanied by high fungal diversity (Sherwood-Pike, 1988).

Environmental interpretation based solely on counts of palynomorphs or diatoms must be

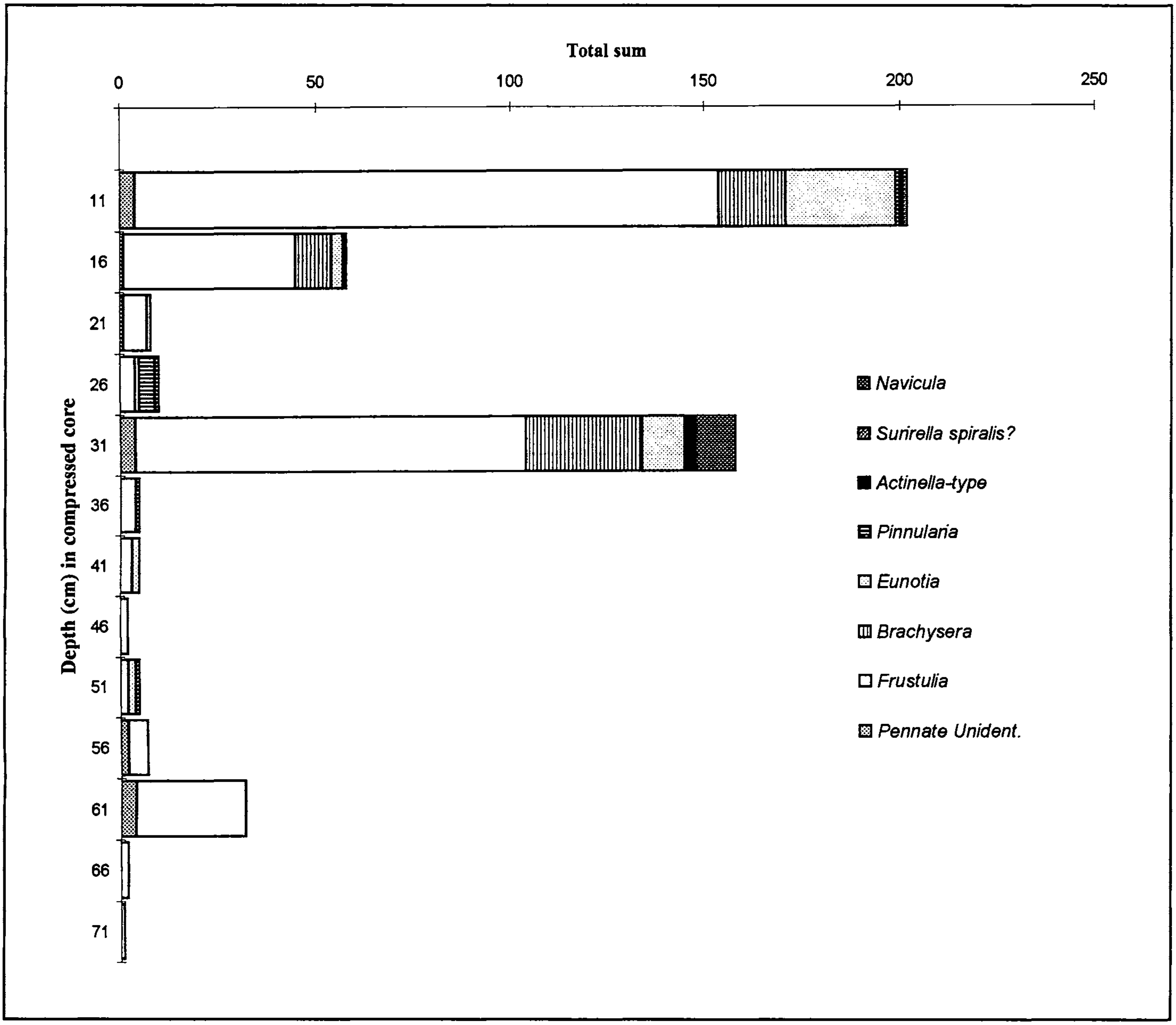

Figure 8. Diatom distributions in core B7.

Table 3. Seasonal variables affecting sedimentation rates at Tasik Bera.

Variable	Feb–Mar dry season	Apr–May SW monsoon	Jun–Aug dry season	Sept–Jan NE monsoon	Reference*
Water level	med.	med.	low	high	71
Precipitation	low	med	low (0 in 1971)	high	46–48
Litterfall		low	high	low	159
Fungal density	high	low	low	low	154, 228
Heterotrophic bacteria	high	low	high	low	151, 228
Chlorophytes	v. low	high diversity	v. low	high density and diversity	214, 221
Bacillariophytes (diatoms)	low	high density and diversity	high diversity	high density and diversity	214
Cyanophytes	high density	high density and diversity	low	low density	210, 214
Epiphyte/benthic algae	high	low	high	low	238
Degradation	fast	slow	fast	slow	158–170

Note: * page references are to Furtado and Mori, 1982. Observations were made near Pos Iskandar.
In addition, the standing crop of the important aquatic macrophytes *Utricularia flexuosa* (a submerged plant) and *Lepironia articulata*, a sedge, was found to fluctuate directly with water levels, peaking during the NE monsoon, and decreasing due to drying conditions.

Table 4. Epiphyte algal associations (Chlorophytes mainly excluded).

Habitat: attached to...	Dominant Algae	
Reed swamp: *Lepironia articulata* sedge	Bacillariophyta:	*Eunotia flexuosa, E. robusta* (Eunotiaceae); *Anamoeneis serians* vars., *Frustulia rhomboides, Pinnularia abaujensis* (Naviculaceae).
	Cyanophyta:	*Stigonema panniforme, Hapalosiphon stuhlmanni* (Stigonemataceae).
Open water margins: *Utricularia* spp. (bladderworts)	Bacillariophyta:	*Eunotia curvata* vars., *E. hexaglyphis, E. nageli, E. pectinalis, E. robusta* (Eunotiaceae); *Anamoeneis serians* vars., *Frustulia rhomboides, F. rhomboides* var. *saxonica* (Naviculaceae); *Surirella engleri, S. spiralis (psuedospiralis?)* (Surirellaceae).
	Cyanophyta:	*Fisherella reptans* (?); *Oscillatoria* sp. (Oscillatoriaceae).
Channels: *Cryptocoryne g.*	Bacillariophyta:	No known associations.
	Rhodophyta:	*Batrachospermum* spp. (Batrachospermaceae).
	Chlorophyta:	*Schizoclamys gelatinosa* (Tetrasporaceae).

Source: Furtado and Mori, 1982.

approached with the greatest caution. The pitfalls are well known (Faegri and Iversen, 1989) and problems are magnified in tropical studies, as the ecology of many of the plants is poorly understood, and the proportion of unknowns is higher than in temperate regions. In this study, diatoms have proven helpful principally in distinguishing marginal limnetic and *Lepironia* reed marsh deposits (Table 4). The algal community epiphyte on *Utricularia* is dominated by *Frustulia*, *Eunotia* and *Surirella* spp. In the *Lepironia* reed marsh diagnostic epiphyte diatoms include *Pinnularia abaujensis* and *Eunotia flexuosa* (Watanabe *et al.*, 1982). Channel deposits are more problematic: benthic Chlorophytes and Rhodophytes dominate the floors of active channels, and pollen analysis in sediments associated with flowing water must accommodate the potential for reworking, transport and removal of palynomorphs (For forest swamp species, pollen transport is assumed to be minimal and the sediment record local). Diatoms were identified to the genus or species level and counted along with palynomorphs. The pennate diatoms *Frustulia* spp. (principally *Frustulia rhomboides*), *Eunotia* spp., *Actinella*-type, *Synedra* spp., *Brachysera* sp., *Pinnularia*-type, *Navicula* spp., *Surirella spiralis* or *psuedospiralis*, and *Surirella engleri* were counted, along with a sum for 'other' genera. Only intact (> 95%) frustules were counted, as fragments are considered more likely to have been transported from outside the depositional site. Some diatom species are more robust than others and thus will be favoured by this approach; most samples were dominated by the relatively durable *Frustulia* spp. and *Eunotia* spp., and the more delicate genera such as *Actinella*-type and *Synedra* spp. may be somewhat underrepresented in the counts. Also counted were sponge spicules (both smooth and covered with blunt spines or bacculae) and spherical phytoliths (variable from 5 to 20 µm in diameter, and with blunt spines, probably palm phytoliths). A count of at least 150 palynomorphs was made for most samples, and of at least 150 diatoms of the dominant species, where applicable. In samples containing very large numbers of diatoms, the count was stopped at 150 of the dominant species, and the number of *Pandanus* grains recorded along with the diatom count. The pollen count was then continued, and diatom totals were adjusted to the final numbers of *Pandanus* recorded. The validity of this proportional estimation was tested by full counts on two samples; the estimates were found to vary up to 24% from the true count in the more numerous genera, and by almost 30% in the rarer diatoms. Variation was both positive and negative, thus error tends to be reduced when sums are plotted; nonetheless, errors of up to 24% may be present in the extrapolated diatom sums. True counts of diatoms are used for specific stratigraphic interpretation. Numerical abundance of diatoms and number of species respond similarly to changes in environmental conditions, diversity and density being greatest in wetter environments, according to Lim and Furtado (1982), Mizuno and Lim (1982).

RESULTS AND INTERPRETATION: SITE B4

Site B4 is near the northern outlet of Tasik Bera at the margin of a small 'hammock' or island of stunted trees (*Eugenia* spp.) and dense shrubs and vines, surrounded by extensive *Pandanus* swamp south of the Kuin promontory (Fig. 2). None of the sediment that makes up this core is peat, as it contains 51–68% mineral matter by weight (Table 2). The site is located close to the main channel of Sungai Bera, near the south end of a cross section mapped by Lim *et al.* (1982), in 25 cm of water over a bottom of coarse woody debris blanketed by epiphyte/benthic algae.

Pollen Diagram B4 (Fig. 3)

In general, pollen is sparse in these sediments, with the exception of *Pandanus* spp., the distribution of which is discussed in the following section. Among other monocots, the Gramineae are present in small numbers, principally in the lower third of the core. Cyperaceae pollen is slightly more abundant and is distributed uniformly throughout the core. Pteridophyte spores are relatively common and dominate the lower third of the core. Although most fern spore identifications are inadequate for environmental interpretations, absolute abundance and diversity is higher near the base and may, along with more abundant Gramineae pollen, suggest open conditions and luxuriant herbaceous growth. For example, *Gleichinia* spp. are present in the basal samples, and in lowland Malaysia are associated with open ground and forest margins (Holttum, 1966). However, *Lycopodium* spp. clubmosses, which were strongly associated with Gramineae in the Sebangau River peatland of Kalimantan (Morley, 1981) are virtually absent from the Tasik Bera samples. *Lygodium* spp., also present in the lower part of the core (66 to 56 cm) may be swamp or dry land taxa.

Arboreal pollen includes *Eugenia / Tristania* spp. (Myrtaceae), present at the base and in the upper third of the core, and a pollen identified as cf. *Melanorrhea* (see Anderson and Muller, 1975), of the Anacardiaceae type, which is present throughout the core but most common near the base. Also present throughout are Meliaceae/Sapotaceae (undifferentiated). All are associated with forest swamps and river margins. Dry land taxa include *Trema* (Ulmaceae) and *Boea* (Gesneraceae), both present in the upper third, and cf. *Meliosma* (Sabiaceae) found throughout the central section.

Stratigraphy of core B4 (Fig. 5)

The physical stratigraphy of core B4 is fairly uniform throughout most of its depth, although with a distinctly more humified layer from 40–50 cm (compressed). There is no obvious relation between sulphur content, which is low throughout, and other physical factors. Greatest variability is in diatom abundance and diversity, although variations in the proportion of *Pandanus* pollen also aid in the delineation of three successive phases of deposition, summarized as follows and in Figure 5.

Phase 1: (78–53 cm)

The bottom 3 cm of the recovered core is coarse hemic peaty sediment with ash content of about 50% and near neutral pH of 6.4. From 74 to 53 cm the more humified carbonaceous sediment is higher in ash and more acidic (~5.2). Total sulphur content is consistently low. *Pandanus* pollen frequency fluctuates through the interval, averaging about 50% of total palynomorphs. Total fern spores are high (up to 30%) and all other pollen is sparse. Diatoms are abundant and diverse (note that the diatom scale in Figure 5 is logarithmic). Figure 4 shows proportions (actual counts or projections) of non-*Frustulia* diatoms throughout the core. In this lower section there is a gradual decrease, then disappearance of *Surirella* spp., which are epiphyte on *Utricularia*, and thus associated with the open water and marginal limnetic environments (Table 4). *Eunotia* spp, diverse and abundant throughout the section, suggest the same environment. Fungal hyphae, fruiting bodies, and *Fusiformisporites* sp. fungal spores are abundant in the lower three samples from this interval.

Phase 2: (53–40 cm)

The lower part of this short interval of fine hemic sediment (53–47 cm) is distinguished from the underlying sediments by slightly lower mineral matter content (52%), low *Pandanus* and high Arboreal pollen content, and a high in the fungal spore *Fusiformisporites* sp. This is followed (47–40 cm) by an increase in *Pandanus* and a very large diatom spike. *Frustulia* dominates, *Brachysera* sp. is very abundant, and *Pinnularia* are numerous, while *Eunotia* spp. are somewhat reduced from the lower interval. This assemblage, combined with the high degree of humification, suggests drying conditions and the onset of *Pandanus* domination.

Phase 3: (40–0 cm)

Throughout this upper interval *Panadanus* pollen is abundant (500 to 1800% of total pollen sum with *Pandanus* excluded), and other pollen is very sparse. Mineral matter content steadily increases and diatom abundance drops abruptly to near zero.

Core B4 documents terrestrialization. Sediments from this site near the main channel record the terrestrialization of an originally open water site, accompanying the development of dense *Panadanus* vegetation. At the bottom of the core *Pandanus* frequency is relatively low (about 50% of total), arboreal pollen represents 20%, and diatoms are abundant, dominated by *Frustulia*. Thus the record likely starts in a marginal limnetic or marginal channel setting in proximity to mixed forest swamp. Algal density and diversity in the present mire is highest marginal to open channels with flowing water, bordered by *Utricularia* and other aquatics (note that *Nymphaea* spp. are rare in the modern Bera mire). The narrow, highly humified second interval reflects a period when the surface likely experienced frequent or regular cycles of wet and drier conditions. The unusual distribution of diatom species, including the disappearance of *Surirella* and increase in *Pinnularia* and *Brachysera*, presaging the transition to *Pandanus* domination, suggests drying conditions. This may have resulted from partial damming and eventual diversion of an active channel, accompanied by an increase in the trapping and deposition of fine clastics. *Pandanus* dominates the monotonous third stage of deposition up to the top 5 cm. Mineral matter at first drops, then increases to its highest level and pH drops (as do ash and pH at the top of core B7) under the influence of reduced flow of surface waters. Diatoms are reduced drastically, first in diversity, then in abundance. The present vegetation is dominated by small trees, shrubs and vines, although dense Pandanus vegetation is present only 2 or 3 metres away.

RESULTS AND INTERPRETATION: SITE B7

Site B7 is located in an embayment 500 m north of the promontory at Pos Iskandar near the approximate north-south centre of the Bera mire, close to the banks of the Sungai Putat where that tributary stream joins the Sungai Bera (Fig. 2). This is the only site at which basal sediment was encountered. The sample site is in 50 cm water depth in *Lepironia articulata* reed marsh beside one of the many shallow channels which meander through the open reed marsh areas, well away from the deep main channel of Sungai Bera. The corer penetrated to a total depth of 200 cm: 50 cm water, 135 cm of peat and carbonaceous sediments, and 15 cm of mottled white clay. Thickness of the peaty sediment was compressed to 72 cm by coring. Changing depositional conditions and vegetation are somewhat less distinct in the diatom record, and least so in the chemical stratigraphy. Sulphur content shows some variability, and is highest in the fibric and woody sediments. Table 2 and the composite Figure 7 summarize the physical, chemical and palynostratigraphy of the core

Pollen Diagram B7 (Fig. 6)

In the basal 20 cm of the compressed core, from 71 cm to around 50 cm, *Pandanus* spp. pollen is virtually absent. Above 50 cm, *Pandanus* is much more variable than at site B4, as discussed in the next section. Cyperaceae pollen is present throughout, although more prominent in the upper part of the core. Pollen of Gramineae is present at background levels throughout. Pteridophyte spores are present in moderate abundance throughout the core, but species distribution is quite variable — one could only wish for more positive identifications and environmental data. Spores are dominated by mostly indeterminate triletes. Spores of *Cyathea*-type show a distinct spike at the 26 cm level. Three or 4 species of these tree ferns are known from different environments in Peninsular lowland forests. Parkeraceae-type (acquatic fern) spores occur only above the 20 cm level. *Lycopodium* spp. spores are present only at the base of the core.

Among prominent trees and shrubs, the swamp taxa *Eugenia/Tristania* (Myrtaceae), *Campnosperma* (Anacardiaceae) and rare *Elaeocarpus* (Elaeocarpaceae) are present in the upper third of the core. *Eugenia* is particularly abundant at 2 levels — 46 to 36 cm, and 21 to 16 cm (see below). In contrast, Meliaceae/Sapotaciae (undifferentiated) are much more prominent in earlier sediments, at around 60 cm in the compressed core, and are absent in the upper 16 cm. cf. *Melanorrhea* is present in low abundance throughout the central section. Of dry land taxa, *Trema* (Ulmaceae) is absent at base and top, and variable through the central section. *Baeckia* (Myrtaceae), also absent at the base, shows an abrupt spike at 41 cm and is then present in reduced numbers to the top.

Stratigraphy of core B7 (Fig. 7)

Four stratigraphic units or phases of deposition are distinguished, based on *Pandanus* and selected palynomorphs in conjunction with diatom distribution and degree of humification (particle size).

Phase 1: (72–48 cm)

The basal sediment recovered, from 85 cm to 72 cm depth, is grey-mottled, sticky white clay with abundant fine rootlets, a 1 cm diameter root penetrating to a depth of 5 cm, and an organic matter content of 11% by weight. Mottles are vermicular, sub-vertical and 1–2 mm diameter. Diatoms are virtually absent in the clay, but palm phytoliths are abundant. *Pandanus*, arboreal pollen and trilete spores are sparse and about equally represented. The transition to overlying peaty sediment is abrupt. The pH of interstitial water is low (~4) and total S is very low (< 0.02 wt%). From 72 to 48 cm is fibric, woody, relatively unhumified peat with large pieces of wood, a very small fine fraction, and about 25% mineral matter content. Included is a 15 cm x 5 cm piece of wood, oriented sub-vertically, slightly root-penetrated, and enclosed within distinctly bedded coarse wood, leaf and bark debris. The coarsest peat has low pH (< 4.5). Sulphur content is moderately high (> 0.3 wt%) for such unhumified peat. Palm phytolith abundance decreases rapidly to near zero, and arboreal pollen increases, to a peak which coincides with the most fibric peat. At this same level there is a large peak in abundance of a distinctive but as yet unidentified phyteral which appears to be a rootlet with nodular thickenings. *Pandanus* pollen and most diatoms are at low levels throughout the lower part of this section, but *Pandanus* increases rapidly in frequency to very high levels at the top of the section as fibre content decreases. There is a small spike in the diatom *Frustulia rhomboides* at around 60 cm.

Phase 2: (48–28 cm)

Medium (hemic) peaty sediment with ash content of 50–60% and abundant roots. pH rises to around 5.3 throughout, and total sulphur remains moderately high. Pollen throughout the entire section is dominated by *Pandanus*, with a corresponding small increase in other monocot pollen types (Cyperaceae, occasional Palmae and Gramineae). *Eugenia/Tristania* pollen also increases in abundance in the interval 48 to 40 cm. Diatom abundance is very low until the top of the section, where a significant spike in *Frustulia rhomboides*, and to a lesser extent, *Brachysera* sp. and *Eunotia* spp. occurs.

Phase 3: (28–6 cm)

From 28 to 18 cm is coarse hemic peaty sediment with slightly lower ash content of about 50%, highest total sulphur in the core (0.4 wt%), and pH just above 5. As was seen lower in the core, an increase in the proportion of fibric material coincides with a decrease in the proportion of *Pandanus* pollen and monocots and an increase in both arboreal pollen (led by *Eugenia / Tristania*) and trilete fern spores. Likewise *Frustulia, Brachysera* and *Eunotia* diatoms increase in abundance.

Phase 4: (6–0 cm)

At 6 cm there is a transition from coarse to fine hemic peaty sediment (38% ash) accompanied by an increase in *Pandanus* (although other monocot pollen decreases), and decreases in arboreal pollen and trilete fern spores. Total sulphur drops by almost 50% through this transition from coarse to fine hemic sediment, and pH rises above 6. Diatoms peak in both abundance and diversity, dominated by *Frustulia* and *Eunotia* spp. Sediment closest to the water interface is a silty, fine hemic carbonaceous sediment with 68% ash. The pore waters are slightly more acidic (pH ~5.2) and total sulphur is low. Diatoms are abundant and pollen is sparse. Palm phytoliths reappear.

Core B7 documents flooding of forest and onset of paludification at a site higher in the drainage basin than the northern sites B1 to B6. The massive rooted clays at the base of the core were deposited in quiet water, possibly by flocculation as they have the lowest pH of all sediment sampled, and contain virtually no diatoms. The transition to the deposition of coarse hemic peat containing wood and leaves, but few roots (the only true peat encountered) suggests deposition of allochthonous organic material over a deeply weathered clay soil in which humic acids were not buffered by floodwaters. The deposition of this probably hypautocthanous woody peat is followed by more open conditions dominated by *Pandanus* and Cyperaceae, increasing wetness and more clastic input — true *Pandanus* marsh. Next, the reduction in *Pandanus* and increase in arboreal pollen associated with forest swamp (*Eugenia, Elaeocarpus*) and with disturbed conditions (*Baeckia, Trema, Compositae*), as well as the increased abundance of diatoms suggest permanently flooded forest swamp. The sequence ends in *Utricularia* floating vegetation and *Lepironia* reed marsh (present vegetation) with abundant epiphyte diatoms suggesting permanent standing water of near neutral pH in which fine hemic peaty sediments are deposited. There is a significant increase in ash content in the top 3 cm of sediment, which likely reflects increased flooding, and human influence, in the form of rubber and oil palm plantations encroaching on the Bera watershed in recent years.

The bottom of the sample interval at B4 resembles the third section of B7. It seems reasonable to view the two cores as representing a continuum of organic sedimentation, from the base of B7 in humid forest on mineral soil (clay) to the top of B4 in a permanently flooded swamp in transition between *Pandanus* and true forest swamp rooted in peat.

DISCUSSION

This preliminary study suggests that most of the late Holocene sediments deposited in the Tasik Bera basin are carbonaceous silts and muds containing 30–72% organic matter, and occasional high- to medium-ash peats. The composition and degree of humification of the organics reflects the relative persistence of standing water, as well as the pH of the environment. These peaty sediments overly clays, silts and silty sands of a dense dendritic fluvial channel system. A radiocarbon age of 660 ± 75 years BP was obtained at a depth of 4 m in core TB5 (Morley, 1982), an accumulation rate of 6 mm/yr of mostly medium- to high-ash peat. This contrasts sharply with the 1.2 mm/yr rate of accumulation of mostly carbonaceous sediment ("grey silt with detritus mud") between 8.6 m depth (4,500 ± 80 years BP) and 4 m depth in the same core [Although Morley (1982a) notes evidence of a possible hiatus in deposition at about 5 m depth which makes the lower accumulation rate less certain]. The rapid elevation of the swamp surface after 660 BP at TB5 suggests an equally rapid lateral expansion of swamp conditions into the tributary network to create the present dendritic mire system. Thus it is likely that the shape of the modern Bera mire is a relatively young phenomenon, possibly about 650 years old, and that areas of permanent standing water and hence of peat accumulation may have expanded rapidly once a certain threshold of paludification was reached. This rapid growth and expansion of the mire system has implications for processes active at the early stages of economic coal formation. The exclusion of mineral matter from a mire requires either a physical or geochemical barrier, and the elevated water table that accompanies paludification can create such a barrier.

Site B7, in the middle reaches of the basin, represents an early stage in the establishment of an environment in which true peat can accumulate. The shallowness (~145 cm) of peaty sediments at the site reflects topographic effects and suggests that organic matter has not been accumulating here for very long. The peaty sediments are fibric, rooted and frequently woody, and algal input is minimal until near the top of the core, where organics are highly degraded and silt content is also high. Nonetheless, the lowest ash peats are found in the early forest swamp deposits. Site B4, along with Site TB5 of Furtado and Lim (Fig. 2), as interpreted by Morley (1982a), represents a more advanced stage, in the lower reaches of the basin, at which swamp conditions have been established for some time and peat and carbonaceous sediments have accumulated to a depth of about 4.5 m over silt and sandy silt. Deep water sediments with a large algal component are overlain by less humified woody (*Pandanus*) remains.

The degree of humification was found to be much more variable in the shallow B7 core than in the more 'mature' B4 site, the base of which is topographically lower, but the bulk of the B7 organics are not highly humified. In studies of domed tropical peats, basal topography has shown to have little effect on drainage and water table (Cohen and Stack, 1996). A perched water table which closely follows the peat surface during at least part of the year is a common feature of many raised or domed deposits. In everwet conditions such as found in coastal Panama (Phillips and Bustin, 1996) the central parts of domed deposits can be almost continually submerged despite their elevated position and independent of basal topography. This occurs because organic sediments drain much more slowly than inorganic soils. In the Bera mire, degradation rates were found to differ markedly between dominant vegetation of the forest swamp, littoral and limnetic environments (Sato, 1982, in Furtado and Mori, 1982), an element which likely overrides variations caused by any but the most severe water table fluctuations.

Pandanus vegetation is of special interest in the development of the Tasik Bera mire. Both *Pandanus* and *Lepironia*, which share dominance of the littoral environment, display high resistance to degradation when deposited in water (Sato, 1982), and *Pandanus* once occupied a much larger proportion of the mire area than at present (Morley, 1982a). Morley proposed that the expansion of the Tasik Bera peat deposit may be a result of damming of the northern outlet due to the proliferation of *Pandanus* vegetation before 660 BP, and the accumulation of *Pandanus* detritus. *Pandanus* thickets develop a massive interlocking root system which both stabilizes and encroaches upon channels in the mire, and periodic violent floods uproot and transport large blocks of root mass and substrate into the channels.

CONCLUSIONS

Drainage basins, which are the source areas for the clastics carried by fluvial systems, can also be sites of deposition of organic sediments. The Tasik Bera mire system represents deposition of peat and peaty sediments within a dense dendritic drainage basin. As such, it serves as an analogue for the earliest stages of coal deposition in low-relief topogenous coal swamps. The basin is composed of low-lying and frequently flooded valleys separated by steep, dissected hills which generally attain less than 30 m elevation above the valley floors. Peaty sediments have been accumulating for at least 4,500 years in the lowest part of the basin, but accumulation rates and hence the thickness and lateral extent of the mire underwent a rapid increase and expansion beginning at about 660 years BP. Characteristics of the sediments are highly variable, both vertically and laterally, the variations principally controlled by the type of vegetation dominant at any given time. Vegetation in turn is related to the degree of wetness of the site, and three distinct environments of deposition contribute peat with different physical characteristics. The limnetic environment, dominated by algae and easily degraded aquatic macrophytes, contributes very fine hemic peaty sediment with high fine silt content and a large algal component. The littoral environment is dominated by sedges and the woody shrub *Pandanus*, both of which have a large sub-aqueous biomass, and are quite resistant to degradation. Sediment from this environment is woody, hemic to coarse hemic, with a moderate to high very fine silt content and a much smaller algal element. Forest swamps, which occupy most of the mire area, contribute woody, fibric to hemic peaty sediments with low to moderate mineral matter content in the form of clays and very fine silt.

In the short cores studied in this preliminary investigation, succession from both limnetic to forest swamp, and the reverse, is seen in this rheotrophic wetland. No part of the mire yet studied is approaching oligotrophic conditions.

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