

Quaternary Changes in Sea-Level in the South China Sea

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Abstract: The extensive shelf areas of the South China Sea provide an excellent area for the study of the Quaternary cycles of eustatic sea-level changes. As water depths do not exceed 200 meters and are less than 100 meters over large areas, relatively minor fluctuations of sea-level result in major lateral shifts in sedimentary facies.

Evidence from punch cores off the east coast of West Malaysia documents the Quaternary cycles of eustatic changes in sea-level and their extent. Lithologic changes combined with foraminiferal and spore-pollen data indicate shallowing of extensive areas of the South China Sea from middle neritic depths (50–100 meters) to mangrove swamps, fresh water marshes and coal swamps or even lateritised surfaces, and *vice versa*.

The youngest eustatic drop of sea-level occurred 11,000 ± years ago, coeval with the Latest Wisconsinian/Würm event. Two, or possibly three, older Pleistocene events of sea-level drop are observed.

INTRODUCTION

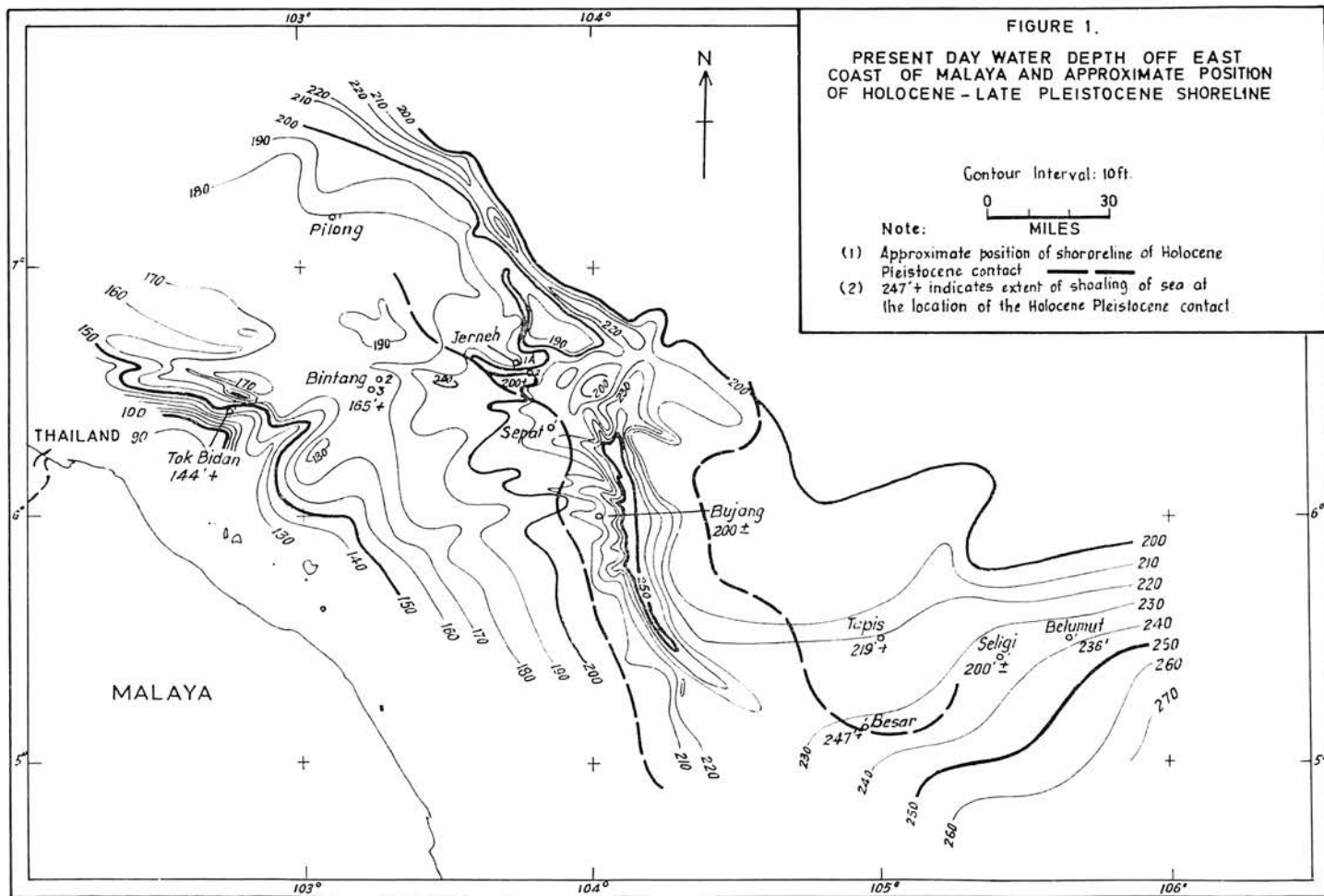
Quaternary eustatic sea-level fluctuations provide significant evidence of the intimately interrelated nature of worldwide cycles of tectonic changes of oceanic basins and continental shields. Not only did the oceanic basins periodically spill over the continents and withdraw from the continental shelves but stupendous tectonic changes took place in the oceanic basins and on the continents themselves.

Evidences of Quaternary eustatic rise and fall of sea-level are recorded in the numerous drowned mangrove swamps, raised beaches and prograding stream patterns on the continental shelves (Fisk and McFarlan, 1955, Haile, 1970, Hammer *et al.*, 1967, Scrivenor, 1949, Suggate, 1968, Tjia, 1970, Walker, 1956, Ward, 1971, etc.). Indications of climatic deterioration and warming are imprinted in the advancing and retreating fronts of ground moraines in temperate belts and, in the lowering and receding snowlines in the mountains of the tropical and subtropical belts (Stauffer, 1968, Wadia, 1949). Waves of migration of Siwalik (Indian) and Sinian mammals in Java, and change of plant associations have been related to the cycles of Quaternary climatic fluctuations (Puri, 1946, Van Bemmelen, 1949, Vishnu-Mettre *et al.*, 1963, Wilson and Webster, 1942). Lately, changes in the coiling direction of planktonic foraminifera have been utilised to read the Quaternary climatic fluctuations in deeper marine sediments (Beard, 1969, Bolli *et al.*, 1968, Emiliani, 1966, Emiliani and Milliman, 1966).

Sunda Shelf is of course one of the classic regions illustrating spectacular Quaternary tectonic changes. Molengraff recognized in the bathymetric contour of the submerged Sunda Shelf evidence of two large Quaternary river systems. According to his interpretations the Northern Sunda River had its head-waters in West Kalimantan and Sumatra, and debouched into the South China Sea near the Natuna Islands. And the East Sunda River debouched into the Bali Sea at the south end of the Makassar Straits with its headwaters in Java and South Kalimantan (in Tjia, 1970).

With the advent of offshore petroleum exploration we can now add one more line of evidence of eustatic changes of sea-level in the Sunda region based on convincing determinative data from Quaternary core samples. Punch cores and sea-floor cores

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taken by Esso from several locations off the East Coast of West Malaysia provide lithological, foraminiferal and spore-pollen evidence of cycles of appreciable shallowing, or even of subaerial emergence of areas, now 100 miles or more offshore (Figs. 1-4, pls. 1-4). Lithologic evidence indicates either a lateritised surface in some locations or profuse lateritic wash in others. Foraminiferal data likewise reveal that water depths of 200 feet or more in some locations were converted to brackish lagoons, mangrove swamps, and coal marsh; in other locations water depths of the order 250 feet shoaled to bays scarcely more than 30-50 feet deep. Clays and claystones from locations with a present day water depth of 200 feet are virtually devoid of spore-pollen, although they contain abundant foraminifera. Sediments from the same locations at the Holocene-Pleistocene interface as well as from older Pleistocene regressive surfaces contain abundant mangrove swamp spore-pollen but are barren of foraminifera. The present day sandy East Coast of West Malaysia has a mere smattering of the mangrove vegetation, the protected West Coast being their real stronghold. Therefore, the abundance of mangrove spore-pollen at the Quaternary regression surfaces in cores from the East Coast offshore reveals their entirely different configuration at the time of the Quaternary eustatic drops of sea-level.

LITHOLOGIC EVIDENCE

General Lithology

Lithology of eight punch cores ranging in age from Holocene to Late Pleistocene have been plotted in Figure 2. Lithology of two sea-floor cores of Holocene to older Pleistocene are indicated in Figure 4.

The sediments above the Holocene-Pleistocene interface are invariably unconsolidated clays of a greenish or yellowish green color, deposited in a water depth of 144-247 feet (measured depths of sea bottom).

Below the Holocene-Pleistocene contact the clays are generally more consolidated, being either claystone or clay, decidedly less plastic than their Holocene counterparts. Only two punch cores Sepat No. 1 and Pilog No. 1 proved an exception to this rule where the section started with a clay/claystone (without any unconsolidated portion at all). As the punch cores were taken by driving pipes perforated at the top into the sea bottom, it is assumed that there was no recovery of the Holocene clays in these two instances (personal discussion with Mr. R.T. Johnson). A higher degree of consolidation of the clays has been noted below the Holocene-Pleistocene contact for offshore Louisiana area also (Fisk and McClelland, 1959).

The clays and claystones associated with the Latest Pleistocene and older Pleistocene regression surfaces consistently have a greyish hue in contrast with the greenish tint of the deeper marine clays (Plate 1). Apparently a higher content of clastic organic debris in the clays and claystones deposited in a shoaled basin accounts for their greyish hue.

Lateritisation

In three locations, Tok Bidon No. 1, Bintang No. 1 and Tapis No. 1 lateritised surfaces were encountered at the Holocene-Pleistocene interface. The lateritisation is in the form of color banding in red, brown and green or mottling in these colors (Figures 2, 3 and Plate 1). In the other four locations there is profuse lateritic wash at the same shoaled interval. Only in one location, Seligi No. 1, neither a lateritised surface

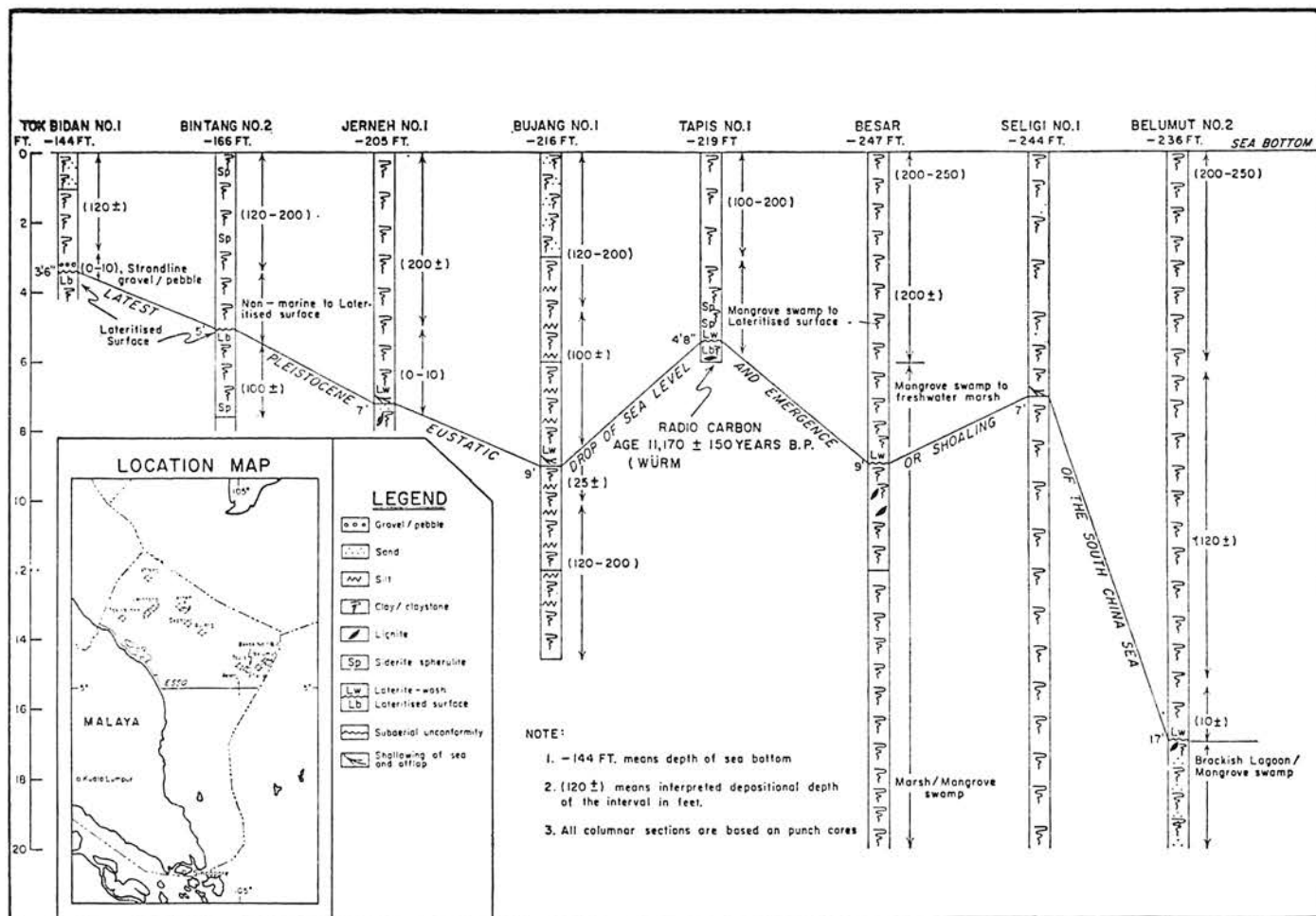


Fig. 2. Pleistocene eustatic drop of sealevel in east coast offshore, West Malaysia.

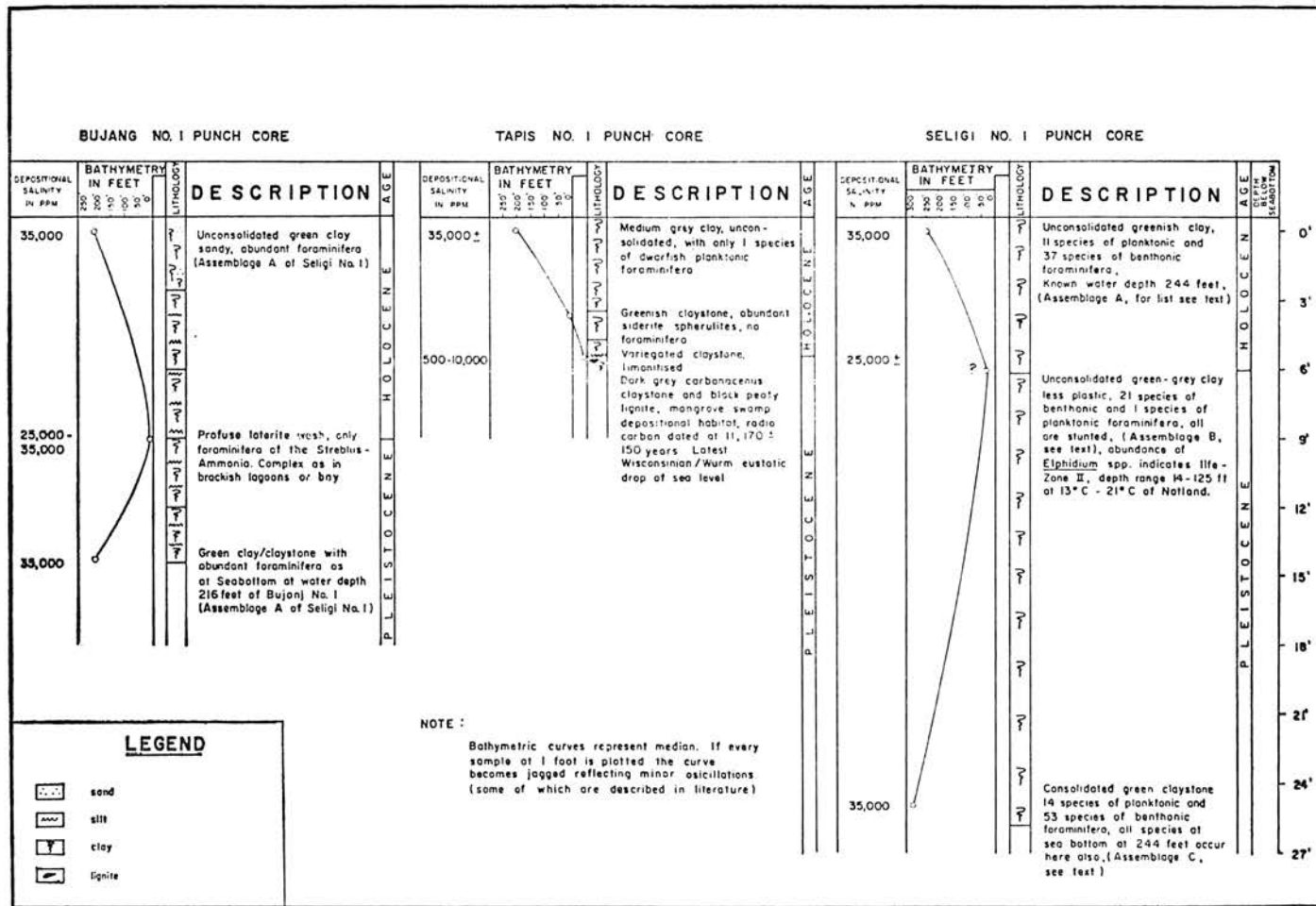


Fig. 3. Holocene-Quaternary eustatic sea-level drop in east coast offshore, West Malaysia.

nor laterite-wash was encountered, although considerable shoaling did take place there at the Holocene-Pleistocene contact.

A correlation between the proximity to land and abundance of clastic lateritic grains may be inferred because cores from Tok Bidan, closest to the coastline, have the highest concentration of clastic laterite.

Besides lateritisation and laterite-wash, sideritic spherulites sometime occur associated with the shoaled regressional surfaces. But as these spherulites get washed into deeper water, sideritic spherulites by themselves do not seem to have a definite palaeobathymetric significance.

Two additional lateritised or near-lateritised surfaces are recognisable in the older Pleistocene of Jerneh. The upper one of these, at a depth of 130 feet below sea bottom at Jerneh, corresponds well with lateritisation at a depth 95 feet below sea bottom at Besar (Figure 4).

The lowest lateritised surface, at the level 300–305 feet below sea bottom at Jerneh, is featured by mottling of claystones in red and greenish gray, by an abundance of sideritic spherulites and by the occurrence of charred wood. Apparently this surface was not reached in the Besar sea-floor core.

FORAMINIFERAL EVIDENCE

Punch cores provide an unique opportunity for studying and recording Recent foraminiferal assemblages. Along the east coast of West Malaysia foraminiferal assemblages have been recovered from the sea floor at depths of 144 feet to 247 feet. These associations provide excellent control for interpretation of comparable depth range assemblages in the Holocene and Pleistocene. Palaeobathymetric interpretations of water depths from 10 feet to 140 feet are based on published data. Particular use has been made of life-zones of Recent foraminifera of Southern California (Natland, 1933), of Shell's observations on the distribution of planktonic foraminifera in offshore Borneo (1963), of Todd and Bronnimann's observations of Mangrove Swamp I and II assemblages (1957) and of Biswas' data on the Indian coasts (1961).

Foraminiferal lists in Tables 1 through 4 include only the more commonly found species. These assemblages provide control for palaeobathymetric interpretations as follows:

- | | |
|------------------------|---|
| Table 1, Assemblage A, | Seligi No. 1, Recent assemblage on sea floor at 244 feet. |
| Table 2, Assemblage B, | Seligi No. 1, very Late Pleistocene, 6 feet below sea floor (Holocene-Pleistocene shoaling). Interpreted palaeobathymetry is 30 to 50 feet. |
| Table 3, Assemblage C, | Seligi No. 1, Late Pleistocene, 25 feet below sea floor. Interpreted palaeobathymetry is 300 feet. |
| Table 4, Assemblage D, | Jerneh No. 2, Early Pleistocene, 338 feet below sea floor. Interpreted palaeobathymetry is 200 to 250 feet. |

Interpretation of environment and palaeobathymetry, when foraminifera are absent due to shoaling which has converted the basin into mangrove swamps or fresh water marshes, is based on plant tissues and spore-pollen of mangrove and fresh water plants.

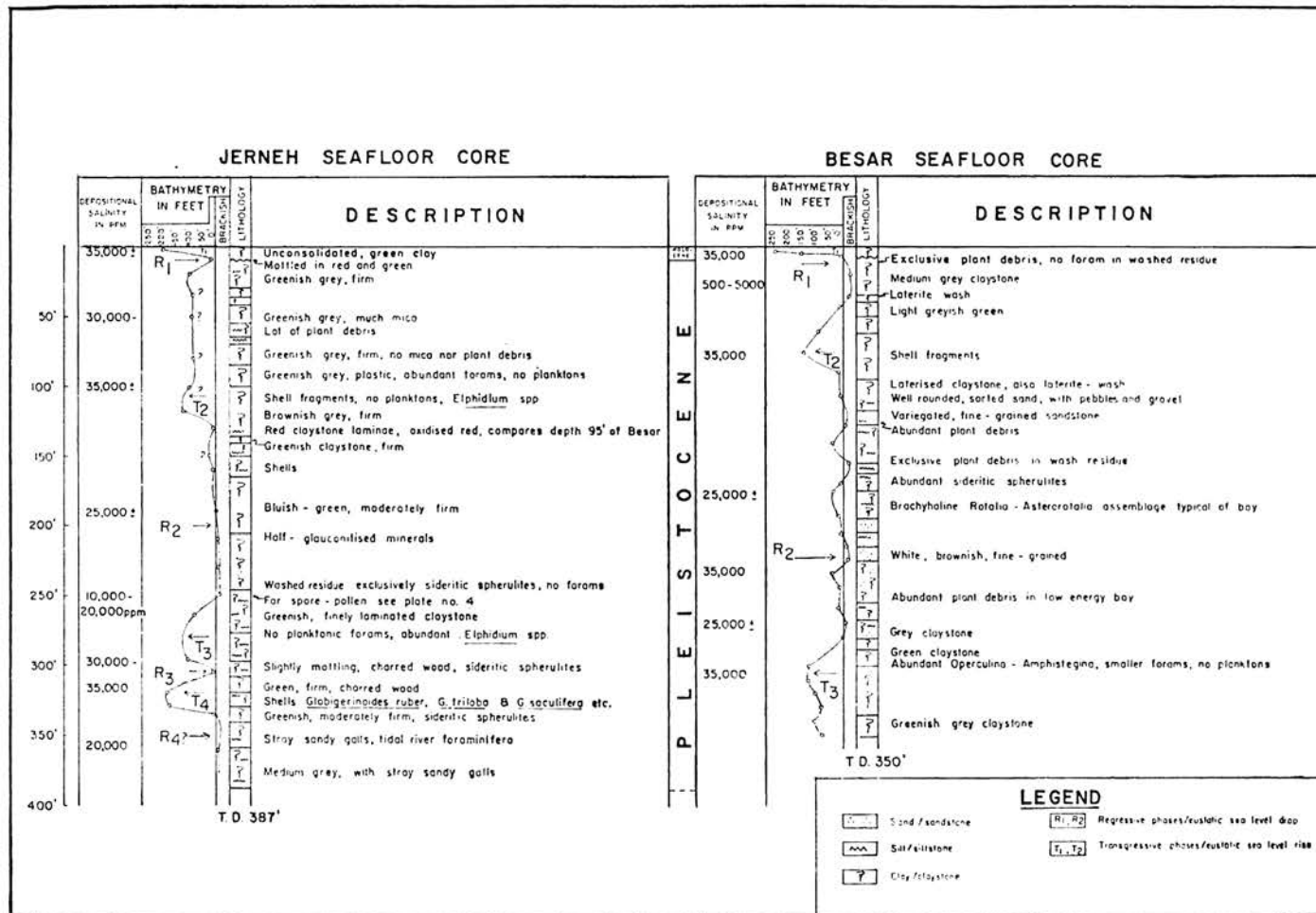


Fig. 4. Quaternary cycles of eustatic sea-level drop in offshore, West Malaysia.

Table 1. Foraminiferal Assemblage A, Recent, Seligi No. 1, Water Depth 244 feet.

<i>Planktonic Species:</i>	
<i>Orbulina universa</i> d'Orb.	rare
<i>Globorotalia menardii</i> (d'Orb.)	common
<i>Globoquadrina dutertrei</i> (d'Orb.)	common
<i>Globigerinoides triloba</i> Reuss	fairly common
<i>Globigerinoides sacculifera</i> (Brady)	fairly common
<i>Globigerinoides conglobatus</i> (d'Orb.)	rare
<i>Globigerina conglomerata</i> Schwager	very rare
<i>Globigerinella siphonifera</i> (d'Orb.)	rare
<i>Pulleniatina obliquiloculata</i> (Parker and Jones)	very rare
<i>Benthonic Species:</i>	
<i>Textularia pseudogrammen</i> Chapman and Parr	
<i>T. sagittula</i> DeFrance	
<i>T. agglutinans</i> d'Orb.	
<i>T. trochus</i> d'Orb. of Brady (<i>T. sp. nov.</i> of Barker)	
<i>T. cf. conica</i> d'Orb.	
<i>Bigenerina nodosaria</i> d'Orb.	
<i>Liebusella soldanii</i> (Jones and Parker)	
<i>Triloculina tricarinata</i> d'Orb.	
<i>T. sp. indet.</i>	
<i>Quinqueloculina seminulum</i> (Linnaeus)	
<i>Q. pseudoreticulata</i> Parr	
<i>Q. cf. reticulata</i> d'Orb.	
<i>Spiroloculina depressa</i> d'Orb.?	
<i>Cribrulinoides disparilis</i> (d'Orb.) var. <i>curta</i> Cushman	
<i>Elphidium advena</i> (Cushman)	
<i>Lagena laevis</i> (Montagu)	
<i>Rectoglandulina torrida</i> (Cushman) of Millett (p. 509-510, 1970)	
<i>Oolina globosa</i> (Montagu)	
<i>Bulimina marginata</i> d'Orb.	
<i>Reussella simplex</i> Cushman	
" <i>Eponides repandus</i> (Fichtel and Moll)" (right- and left-coiling)	
<i>E. berthelotianus</i> (d'Orb.), seemingly grading to <i>E. procera</i> Brady	
<i>Cibicides praecintus</i> (Karrer) (right- and left-coiling)	
<i>C. refulgens</i> Montfort	
<i>C. cf. subhaidingerii</i> Parr	
<i>C. lobatulus</i> (Walker and Jacob)	
<i>Cancris indicus</i> (Cushman) (right- and left-coiling)	
<i>Gavelinopsis cf. lobatulus</i> (Parr)	
<i>Anomalina colligera</i> Chapman and Parr	
<i>Epistominella sp.</i>	
<i>Streblus gaimardii</i> (d'Orb.)	
<i>S. schroeterianus</i> (Parker and Jones)	
<i>Rotalia annectens</i> Parker and Jones	
<i>Rolshausenia rolshauseni</i> (Cushman and Bermudez)	

Table 2. Foraminiferal Assemblage B, Latest Pleistocene, Seligi No. 1, Interpreted Water Depth 30-50 feet.

<i>Planktonic Species:</i>	
<i>Globigerinoides triloba</i> Reuss (very rare and stunted)	
<i>Benthonic Species:</i>	
<i>Bigenerina nodosaria</i> d'Orb.	
<i>Quinqueloculina vulgaris</i> d'Orb.	
<i>Q. seminulum</i> (Linnaeus)	
<i>Q. bradyana</i> Cushman	
<i>Florilus scaphum</i> (Fichtel and Moll)	
<i>Elphidium advena</i> (Cushman)	
<i>E. macellum</i> (Fichtel and Moll)	
<i>E. cf. lessoni</i> (d'Orb.)	
<i>Lagena striata</i> d'Orb.	
<i>L. costata</i> Williamson of Millett (p. 110, 1970)	

(Table 2 continued)

Nodosaria cf. *simplex* Silvestri
Loxostomum porrectum Brady
Bolivina aff. *abbreviata* Heron-Allen and Earland
Asterorotalia trispinosa (Thalmann)
Streblus gaimardii (d'Orb.)
Rotalia annectens Parker and Jones
Rolshausenia rolshauseni (Cushman and Bermudez)
Cibicides cf. *subhaidingerii* Parr
Anomalina colligera Chapmann and Parr

Table 3. Foraminiferal Assemblage C, Late Pleistocene, Seligi No. 1, Interpreted Water Depth 300 feet.

<i>Planktonic Species:</i>	
<i>Orbulina universa</i> d'Orb.	rather rare
<i>Globorotalia menardii</i> (d'Orb.)	very common
<i>Globoquadrina dutertrei</i> (d'Orb.)	common
<i>Globigerinoides ruber</i> (d'Orb.)	common
<i>Globigerinoides triloba</i> Reuss	common
<i>Globigerinoides sacculifera</i> (Brady)	common
<i>Globigerinoides conglobatus</i> (d'Orb.)	fairly common
<i>Globigerina bulloides</i> d'Orb.	common
<i>Globigerina falconensis</i> Blow	scarce
<i>Globigerinella siphonifera</i> (d'Orb.)	rare
<i>Hastigerina</i> cf. <i>murrayi</i> Thomson	rare
<i>Pulleniatina obliquiloculata</i> (Parker and Jones)	rare
<i>Sphaeroidina bulloides</i> d'Orb.	very rare
<i>Benthonic Species:</i>	
<i>Textularia pseudogrammen</i> Chapmann and Parr	
<i>T. sagittula</i> De France	
<i>T. agglutinans</i> d'Orb.	
<i>T. spp.</i>	
<i>Spiroplectammina</i> sp. indet.	
<i>Bigenerina nodosaria</i> d'Orb.	
<i>Liebusella soldanii</i> (Jones and Parker)	
<i>Reophax</i> aff. <i>scorpus</i> Montfort	
<i>Pyrgo vespertilio</i> (Schlumberger)	
<i>P.</i> aff. <i>globula</i> (Bornemann)	
<i>Dentostomina agglutinans</i> (d'Orb.)	
<i>Aldesonia soldanii</i> d'Orb. var. ("young Miliolidae" of Barker)	
<i>Quinqueloculina seminulum</i> (Linnaeus)	
<i>Q. pseudoreticulata</i> Parr	
<i>Q. reticulata</i> d'Orb.	
<i>Q.</i> cf. <i>granulocostata</i> Germeraad	
<i>Q. spp.</i> (ornate)	
<i>Spiroloculina depressa</i> d'Orb.? (Brady, pl. 9, fig. 7, in Barker)	
<i>S. rotunda</i> d'Orb.? (Brady, pl. 9, figs. 15-16, in Barker)	
<i>Flintina bradyana</i> Cushman (also cf. <i>Triloculina costifera</i> Terquem and <i>T. fichteliana</i> d'Orb.)	
<i>Cribrolinoides disparilis</i> (d'Orb.) var. <i>curta</i> Cushman	
<i>Elphidium advena</i> (Cushman)	
<i>Lagena striata</i> d'Orb.	
<i>L. laevis</i> Montagu	
<i>Lagena gracilis</i> Williamson	
<i>L.</i> cf. <i>costata</i> Williamson	
<i>Fissurina laevigata</i> var. <i>acuta</i> Reuss	
<i>Rectoglandulina torrida</i> Cushman	
<i>Dentalina</i> cf. <i>intorta</i> (Dervieux)	
<i>Loxostomum porrectum</i> (Brady)	
<i>L. karreianum</i> (Brady)	
<i>Bolivina</i> aff. <i>abbreviata</i> Heron-Allen and Earland	
<i>Bulimina marginata</i> d'Orb.	
<i>Virgulina squamosa</i> d'Orb.	
<i>Reussella simplex</i> (Cushman)	

(Table 3 continued)

- Bifarina elongata* Millett
Uvigerina canariensis d'Orb.
Geminospira cf. *simaensis* Makiyama and Nakagawa, (*Bulimina convoluta* Williamson of Millett, p. 279, 1970)
Siphoninoides cf. *echinata* (Brady)
 "Eponides repandus (Fichtel and Moll)"
E. berthelotianus d'Orb. seemingly grading to *E. procera* Brady
Poroepionides lateralis (Terquem)
Cibicides praecinctus (Karrer)
C. refulgens Montfort
C. cf. *subhaidingerii* Parr
C. lobatulus Walker and Jacob
Canceris indicus (Cushman) right- and left-coiling
Gaevelinopsis cf. *lobatulus* (Parr)
Anomalina colligera Chapman and Parr
Epistominella sp.
Streblus gaimardii (d'Orb.)
S. schroeterianus (Parker and Jones)
Rolshausenia rolshauseni (Cushman and Bermudez)
Operculina ammonoides (Goronovius)? (Brady, pl. 112, figs. 3-9, non figs. 11-13 in Barker)

Table 4. Foraminiferal Assemblage D, older Pleistocene, Jerneh No. 2, Interpreted Water Depth 200-250 feet, level 338 feet below sea bottom.

Planktonic Species:

- | | |
|---|-------------|
| <i>Orbulina universa</i> d'Orb. | rare |
| <i>Globoquadrina dutertrei</i> (d'Orb.) | scarce |
| <i>Globigerinoides ruber</i> (d'Orb.) | common |
| <i>Globigerinoides sacculifera</i> (Brady) | rather rare |
| <i>Globigerinoides conglobatus</i> (d'Orb.) | rare |
| <i>Globigerinoides triloba</i> Reuss | rare |
| <i>Globigerinella siphonifera</i> (d'Orb.) | scarce |
| <i>Hastigerinella</i> cf. <i>murrayi</i> Thompson | scarce |

Note: No *Globorotalia menardii* (d'Orb.) in spite of depth being appropriate; cooling?

Benthonic Species:

- Textularia agglutinans* d'Orb.
T. conica d'Orb.
T. pseudogramen Chapman and Parr
T. sagittula De France
Spiroplectammina sp. indet.
Bigenerina nodosaria d'Orb.
Liebusella soldanni (Jones and Parker)
Pyrgo aff. *globula* (Bornemann)
 "Aldesonita semistriata d'Orb." (Pl. 3, fig. 12, Barker)
Quinqueloculina seminulum (Linnae)
Q. pseudoreticulata Parr
Q. reticulata d'Orb.
Q. lamarckiana d'Orb.
Spiroloculina communis Cushman and Todd
S. depressa d'Orb.
Triloculna tricarinata d'Orb.
T. kerimbatica (Heron-Allen and Earland)
Flintina bradyana Cushman
Ammomassilina alveoliformis Millett
Dentostomina agglutinans (d'Orb.) (pl. 8, figs. 6-7, Barker)
Haueriana fragilissima (Brady)
H. orientalis Cushman
H. sp. (pl. 7, figs. 21-22, Barker)
Peneroplis sp. (abraded)
Nonionella turgida (Williamson) (? *N. subturgidum* Cushman)
Elphidium advena (Cushman)
E. craticulatum (Fichtel and Moll)

(Table 4 continued)

E. crispum (Linnaeus)
E. indicum Cushman
Lagena crenata Parker and Jones
L. laevis (Montagu)
Nodosaria catesbyi d'Orb.
 "Nodosaria aequalis Reuss" (pl. 11, fig. 3, Millett)
Stilostomella antillea (Cushman) (pl. 76, figs. 9-10, Barker)
Fissurina seguenziana (Fornasini)?
Robulus sp.
Rectoglandulina torrida (Cushman)
Loxostomum limbatum (Brady)
L. sp. nov. (pl. 53, figs. 14-15).
Bolivina aff. *abbreviata* Heron-Allen and Earland
Bifarina cf. *porrecta* Brady (pl. 4, fig. 3, p. 91, Millett)
Trifarina bradyi Cushman
Reussella simplex (Cushman)
Siphonina sp.
Eponides berthelotianus (d'Orb.)
Poroeponides lateralis (Terquem)
 "Eponides repandus Fichtel and Moll"
Cibicides lobatulus (Walker and Jacob)
C. refulgens Montfort
Cibicides spp. indet.
Anomalina colligera Chapman and Parr
Planorbulinella larvata (Parker and Jones)
Cancris indicus (Cushman) right- and left-coiling
Streblus schroeterianus (Parker and Jones)
Rotalia annectens Parker and Jones
Rolshausenia rolshauseni Cushman and Bermudez
Epistominella sp.
Tinoporovus spengleri (Gmelin)
Operculina gaimardi d'Orb.
O. ammonoides (Goronovius)?
Amphistegina lessoni d'Orb.

The faunal lists presented in Table Nos. 1-4 are not a complete check list of foraminifera but represent only the more common species. Recent sea bottom samples from other locations of comparable depths have also been found to contain *Clavulina multicamerata* Chapman, *Spiroloculina communis* Cushman and Todd, *Ammomassilina alveoliformis* (Millett), *Siphotextularia concava* (Karrer), *Haueriana* spp. *Peneroplis* sp., *Lagena hispida* Reuss, *Entosolenia* sp., *Planorbulinella larvata* (Parker and Jones), *Loxostomum* sp. indet. (pl. 53, Figures 14, 15, Barker, 1960), *Buliminoides williamsonius* (Brady), *Cassidulina crassa* d'Orb., *Hoeglundina elegans* (d'Orb.), *Rosalina* sp. indet.

Studies by various workers on planktonic foraminiferal assemblages have shown that coiling direction of these floating species is controlled climatic (i.e. temperature) changes. A dominance of sinistral forms indicates cold water while a dominance of dextrally coiled forms is associated with relatively warm water environment. Differences in coiling direction are present in benthonic foraminifera of the South China Sea, but as sea floor temperatures are more uniform the ratio of sinistral to dextral specimens is usually about equal. No change in the coiling directions of planktonic foraminifera from the Quaternary of the South China Sea was noticed.

Contrary to the observations of Bolli (1966, p. 456), where depositional depths were adequate, *Globorotalia truncatulinoides* does occur in adjoining areas of the South China Sea in the Early-Middle Pleistocene successions.

SPORE-POLLEN EVIDENCE

Depositional Salinity Indications of Spore-Pollen

On the basis of plant associations Corner (1951) has divided the coastal region of West Malaysia from the seaward end to inland into the following ecological regimes:

1. *Rhizophora* mangrove swamp.
2. *Nipa* palm tidal swamp.
3. *Pandanus-Barringtonia* transitional swamp.
4. *Dipterocarpus* forests and swamp.

Studies of the writer in the mangrove swamps and fresh water marshes of the Bengal Delta indicate that:

1. *Rhizophoraceae* dominated mangrove swamps are characterised by anastomosing tidal estuaries extending from muddy deltaic shorelines to 30 miles or more inland, with tidal salinities ranging from 20,000–30,000 ppm total solutes and containing Mangrove Swamp I foraminiferal assemblage of Todd and Bronnimann (1957).
2. *Nipa-Avicennia* tidal swamp has tidal salinities of the order of 5,000–20,000 ppm. Mangrove Swamp II *Miliammina-Haplophragmoides-Trochammina* complex of arenaceous foraminiferal assemblage is typical of this regime.
3. *Pandanus-Barringtonia* swamps have weak tidal influence with salinities ranging from 500–5000 ppm and are either devoid of common foraminifera or contain extremely small "microforaminifera" usually washed through sieves in routine micropaleontologic work.
4. Fresh water marshes with soil and substrate salinities of 500 ppm or less of total solutes are totally devoid of even "microforaminifera".

These criteria of plant associations and tidal salinities are equally applicable to the punch cores from West Malaysian offshore because the same species of plants and foraminifera extend from the subtropical Bengal Delta to the mangrove swamps of Malaysia. It is true that spore-pollen from fresh water marsh habitats can and do get washed into the mangrove swamp habitat, and the mangrove swamp elements in their turn to the delta-front bays. But when they do so, such spore-pollen assemblages are associated respectively with Mangrove II and Mangrove I/bay foraminifera so that taking both spore-pollen and foraminiferal evidence together the true habitat of sedimentation can be established beyond question.

Punch Core Data

Several Recent samples from a water depth of 144–247 feet and more were processed for spore-pollen. These were found to be either barren or to contain insignificant quantities of spore-pollen. The same samples of course contain abundant foraminifera, including a sizeable fraction of planktonic foraminifera in waters deeper than 200 feet.

In contrast the sample of peaty lignites (with no obvious fibrous structure) associated with the Holocene-Pleistocene regression surface of Tapis contain an admixture of spore-pollen of a fresh water marsh as well as of mangrove swamp habitat (Plate 2). The fresh water element is constituted of such forms as: *Gleichenia linearis* (Burm.), *Polypodiaceae*, *Lygodium* sp., *Cannaceae*, *Ilex* cf. *cymosa*, *Eugenia* spp., *Mimosaceae* and *Barringtonia*. The mangrove swamp elements are represented by abundant pollen of various genera of the *Rhizophoraceae*.

The carbonaceous claystones from 5 feet 6 inches to 7 feet in the Jerneh No. 1 punch core contain not only an admixture of fresh water marsh and mangrove swamp spore-pollen assemblages (Plate 3) but also strongly brackish lagoonal/bay foraminifera. The depositional salinity of the level apparently ranged between 20,000–30,000 ppm.

Spore-pollen assemblages from the older Pleistocene regressional sequence at 252 feet below sea bottom of Jerneh (Figure 4, Plate 4) contain an admixture of fresh water marsh, *Pandanus-Barringtonia* transitional swamp, *Nipa* palm tidal swamp as well as *Rhizophora* (-*Sonneratia*) mangrove swamp assemblages. The tidal salinity of the assemblage fluctuated within the range 10,000–20,000 ppm.

Spore-pollen and Sea-level Drop

The present day water depth at Tapis and Jerneh are 219 feet and 205 feet respectively. The existence of mangrove swamps at a depth 4 feet 8 inches to 6 feet below sea bottom at Tapis, and of brackish lagoons at a depth 5 feet 6 inches to 7 feet below sea bottom at Jerneh, indicated by spore-pollen data, provide an independent line of evidence of an eustatic drop of sea-level at the Holocene-Pleistocene interface.

The occurrence of plant debris with no foraminifera 17 feet below the sea bottom at Belulut No. 2 is another instance of vegetational indication of sea-level drop in the Latest Pleistocene epoch (spore-pollen from this level was not studied).

Likewise, mangrove swamp deposition at 252 feet below sea bottom of Jerneh indicated by spore-pollen is evidence for an older Pleistocene cycle of sea-level drop in the South China Sea.

Floral Contrast of Tropics and Subtropics

There is little contrast in the foraminiferal assemblages from comparable water depths of the tropics and the subtropics. This raises the question of biologic and palaeobiologic contrast between tropical and subtropical regimes.

The distinction lies more in the distribution and adaptation of plant life in these belts rather than those of marine animals. Because, water temperature contrasts are less for one thing. As water temperature drops with depth in the tropical seas, an ecologic continuity with the marine habitats of the subtropical seas is achieved at comparatively shallow water depths. Therefore, virtually the same marine animals are found in the tropical and subtropical seas.

One major distinction lies in the great diversity (500 species) as well as profusion of ferns in the tropics and their paucity at comparable altitudes in the subtropics (Holtum, 1954). Punch cores testify to a comparable variety and abundance of ferns in West Malaysia throughout the Quaternary. Studies of the Recent and Pleistocene flora of the Bengal Delta by the writer confirm the paucity of ferns throughout the Quaternary at low altitudes in the subtropical belt (unpublished data).

A second contrasting feature of plant distribution in the tropics lies in the occurrence of several flowering plant genera throughout the Quaternary in West Malaysia, that are also known from the northern temperate belt, but are missing from the intervening subtropics. The occurrence of pollen of *Podocarpus*, *Ilex* spp., *Quercus* spp., all temperate genera, throughout the Quaternary in West Malaysia in punch cores brings out this interesting fact. *Podocarpus polystachyus*, *Ilex cymosa* and *Quercus*

conocarpa flourish and flower at sea-level in West Malaysia at the present day. None of these genera are known in their natural habitat in the plains of India; even if they are cultivated as cultured specimens, they never bloom there. Nor are their pollen known in the Quaternary successions of the Bengal Basin, although surprisingly the pollen of these genera can be identified from the Eocene fresh water marshes of Bengal (Biswas, 1962). Similar instances of the occurrence of north temperate flowering plants and ferns in the Recent flora of the Sunda region have been recorded by Steenis (1934) and Holttum (1954).

There are two obvious aspects of climatic differences between the tropics and subtropics.

1. Tropical Malaysia and the Sunda region are humid throughout the year with rainfall every month. In the Indian Plains there is a 4–6 month dry spell with the winter break, which is specially detrimental to the existence of ferns except for the most sturdy and adaptive ones.
2. B.O.A.C. (1967, p. 61–63) “Welcome Aboard” temperature chart lists average variations from January through December as 40°–64° F in London, 59°–96° F in Delhi and 80°–82° F in Singapore. The question may be raised why should we not use the average temperature variation of Calcutta, 67°–86° F, from the same chart instead of that of Delhi? The reason is that the Quaternary cycles of deterioration of temperature are believed by the writer to be the cut-off phase of an annihilation of many plant genera and species from the subtropical plains. According to Emiliani (1966b) the order of sea water temperature reduction during the Quaternary eustatic drop of sea-level in the Caribbean was 6° C. As the order of drop of atmospheric temperatures corresponding 6° C drop of sea water temperature, would be nearly double, the average minimum temperature of Calcutta during the cycles of Quaternary chilling more nearly approached that of the present day in the neighbourhood of Delhi. It is worth pondering if the intermigration of the montane flora of Malaysian (Steenis, 1934–35) and of the temperate belts might have had taken place during these same cycles of Quaternary climatic deterioration.

Whether this pattern of variation of humidity and temperature can explain the adaptation of *Podocarpus*, *Ilex*, *Quercus* and similar genera in the tropical Sunda Land as well as northern tropical belts (also in the cooler Lower Himalayas) and account for their failure in the subtropical plains of India is hard to verify. The writer cannot think of alternative explanations. The absence of the Himalayas, the occurrence of the Tethys Sea in the Eocene where the Himalayas are now located, and of occurrence of another Eocene sea along the Arakan Yomas certainly suggest a much more equable climate for the plains of India in the Eocene. The abundance of fern spores, and the occurrence of *Ilex*, *Podocarpaceae* and *Fagaceae* in the Eocene sediments of India obviously indicate a greater similarity between the climate of India at that time and that now prevailing in West Malaysia.

It is interesting to observe that many species of flowering plants that bloom in India only in summer flower the year round in Malaysia, e.g., *Delonix regia*, *Lageros-troemia flos-reginae*, *Mangifera indica*, *Artocarpus indica* etc. Although blooms are not subject to fossilisation, the seasons of flowering and their relation to prevailing wind directions may have a bearing on the past and present pattern of dispersal of spore and pollen grains.

EXTENT OF SEA-LEVEL CHANGE

Estimation of the extent of sea-level drop is easier and more reliable for the Holocene-Pleistocene interface as there is control from eight locations (Figure 2).

For six locations where withdrawal of the sea was total with a subaerial exposure of the depositional basin, the magnitude of withdrawal can be confidently estimated:

Tok Bidan No. 1	144+ feet
Bintang No. 2	165+ feet
Jerneh No. 1	205 feet
Tapis No. 1	219 feet
Besar	247 feet
Belumut No. 2	236 feet

For locations where the drop of sea-level was not total but a shoaled sea remained the extent of shallowing is interpretative:

Bujang No. 1	200± feet
Seligi No. 1	200± feet

The control available from Besar and Jerneh suggests that the magnitude of drop of sea-level in the older Pleistocene cycles varied from about 150–200 feet (Figure 4).

AGE OF FLUCTUATION OF SEA-LEVEL

Holocene-Latest Pleistocene

Only one absolute age measurement is available from the punch cores. Lignites from the level 4 feet 8 inches from Tapis No. 1, associated with the latest cycle of Quaternary sea-level drop, was radiocarbon dated at $11,170 \pm 150$ years B.P. (Figures 2 and 3).

There is considerable discussion in literature regarding the absolute age of the Holocene-Pleistocene boundary (Morrison, 1969). The more or less complete consensus in Europe places the contact at 11,000 years.

Difference of opinion still exists regarding the choice of the boundary, and the age of the Holocene in the United States, especially in the Gulf Coast. There the boundary is still placed by many at 18,000–20,000 years. It is significant that Wilson and Webster recognized a sharp dwindling of the Conifer pollen of *Picea* (spruce) in the type region of Wisconsin in bog sections (1942). This event has since been age-dated at 11,000 years by the radiocarbon method. It is likely that the Holocene-Pleistocene boundary will eventually be placed at the same level in the Gulf Coast (Morrison, 1969). The colleagues of the writer have pointed out that lately the Holocene-Pleistocene contact in the Gulf of Mexico region has been raised considerably higher, to possibly as high as 7000 years B.P.

Therefore, it seems reasonable to assume that the latest Quaternary drop of sea-level recognized in punch cores from the eight locations of offshore Malaysia (Figure 2) truly corresponds to the Holocene-Pleistocene contact, coeval with the Würm event of Europe and possibly the Latest Wisconsinian of the United States.

Pleistocene

Control on Pleistocene eustatic drop of sea-level exists only in the sea-floor cores at Jerneh and Besar (Figure 4).

Four marine regressive events and three events of sea-level rise can be recognized down to 387 feet below sea bottom in Jerneh. Due to the briefness of the interval of separation of third (R_3) and fourth (R_4) regressive events it is difficult to be sure if they are the same event with a sudden rise of sea-level in between or if they are indeed separate events related to independent cycles of eustatic drops of sea-level. In view of the substantial magnitude of the sea-level rise (T_4) in between R_3 and R_4 it is tempting to assume R_3 and R_4 to be distinct and separate events. In the absence of continuous core control extending to the base of the Pleistocene, it is not possible to establish the relations of R_3 and R_4 satisfactorily, as we do not know if additional events of eustatic drop of sea-level are represented lower down in the Pleistocene.

Two regressive and two transgressive marine events can be identified at Besar. As the control does not extend lower down T_3 (Figure 4), it is not possible to be certain about the spatial spread of events R_3 and R_4 at Jerneh.

Although there is a general correspondence of the events of sea-level rise and drop between Jerneh and Besar successions, it is noticeable that neither the extent of sea-level rise and fall nor the rates of subsidence and sedimentation in the two areas are uniform.

QUATERNARY CONFIGURATION OF THE WESTERN PART OF THE SOUTH CHINA SEA

The approximate positions of shore lines at the Latest Pleistocene eustatic drop of sea-level have been superimposed on the present day bathymetric contour map of the South China Sea (Figure 1). As extensive areas of the western part of the South China Sea have water depths of 250 feet or less at the present day, it is obvious that a shoaling of the order of 200 feet or more caused its substantial shrinkage approaching some 300,000 square miles (Figure 5). Perhaps much of the western part of the modern South China Sea became fresh water marshes and mangrove swamps except for a relatively narrow arm of the sea along the center of the basin. A striking confirmation of such an inference exists in the manner of distribution of spore-pollen of mangrove swamp plants in the Quaternary successions of the East Coast offshore punch cores.

Watson has observed that 98.5% of the modern mangrove forests of West Malaysia is restricted to its west coast where the shoreline is protected (1928, p. 5, 10). In contrast the sandy shoreline of the open East Coast of West Malaysia contains a mere 1.5% mangrove forests near old river mouths. Such a pattern of distribution of the mangrove forests readily explains the paucity of mangrove pollen in the Holocene punch core sediments of the East Coast offshore. Yet there is an overwhelming abundance of mangrove pollen in the East Coast offshore sediments associated with the Holocene-Latest Pleistocene eustatic drop of sea-level as well as with older Pleistocene regressional events. Obviously, with the eustatic drops of sea-level the configuration of the western part of the South China Sea changed enough to transform its open coast line to protected bays, estuaries and inlets teeming with mangroves. The frequent occurrence of micas and lateritic clastics in locations like Jerneh and Bujang indicate that river mouths discharging such clastics lay close by.

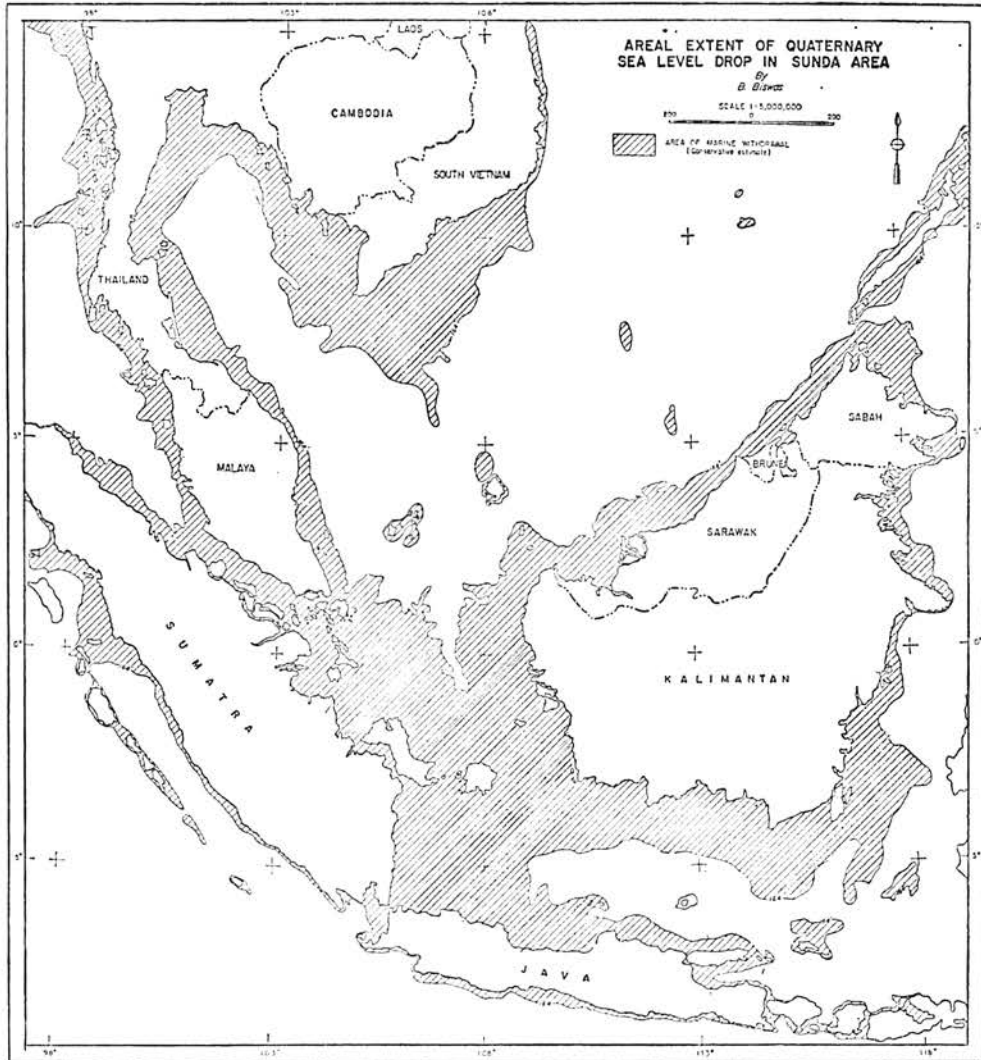


Fig. 5. Areal extent of Quaternary sea-level drop in Sunda Area.

The elongate depression that can be identified in the present day bathymetric contour map of the South China Sea (Fig. 1) either existed as such or in a modified form throughout the Quaternary Period. During cycles of rise of sea-level the Quaternary South China Sea looked very much like its modern counterpart. It must have been a different sight altogether during the cycles of eustatic drop of sea-level. Brackish lagoons and bays existed at the center of the basin bordered by widespread mangrove swamps and forests, obviously one of the largest mangrove colonies, ever known in the history of the world. Fresh water marshes fringing these mangrove swamps must have

provided enough continuity for the phases of intermigration of Quaternary mammals between West Malaysia, Sumatra, Java and Borneo as well as adjacent offshore regions, the Great Sunda of authors, the land that emerged and faded time and again before the eyes of the prehistoric man and the Java ape man!

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BISWAS: PLATE 1

- 1: Sliced punch core of claystone from Tapis No. 1; top left hand corner is top of core (sea bottom) and bottom right hand corner is base of core; top of core contains middle neritic foraminifera; devoid of foraminifera from 4 feet at the Pleistocene-Holocene interface; lateritized at 4 feet 5 inches; abundant mangrove swamp and fresh water marsh spore-pollen between 5 feet 6 inches—6 feet from peaty lignite; as fibrous plant structures are not recognizable lignite seems to be a more appropriate term; X 1/8.
- 2: Sliced punch core of claystone 5 feet 6 inches below sea bottom in Bintang No. 2 showing mottling and color banding in red, brown and green, and lateritization at the Pleistocene-Holocene interface; X 3/10.
- 3: Sliced punch core of claystone 5 feet below sea bottom at Bintang No. 3 showing color banding in greyish green, brown and red, and lateritization at the Pleistocene Holocene interface; X 3/10.
- 4: As above, lateritized bedding plane of claystone; X 1/4 approximately.
- 5: Green clay 1 foot below sea bottom in Bujang No. 1; Holocene with fairly abundant planktonic foraminifera similar to those from sea bottom in Seligi No. 1 (see text); shell hash on the lamination plane; X 1/4 approximately.
- 6: Green clay from sea bottom to 1 foot down from Seligi No. 1; fairly abundant planktonic foraminifera (water depth 244 feet, for list see text); X 3/10.
- 7: Fern *Lygodium flexuosum*; mature spores of this species develop coarse tubercles although immature ones are smooth; spores of *Lygodium scandens* illustrated in Plate 4 are from a related species; X 3/5.

(Cost of colour plate paid by Esso Exploration Inc.)

PLATE I



1



6



2



3



4



5



7

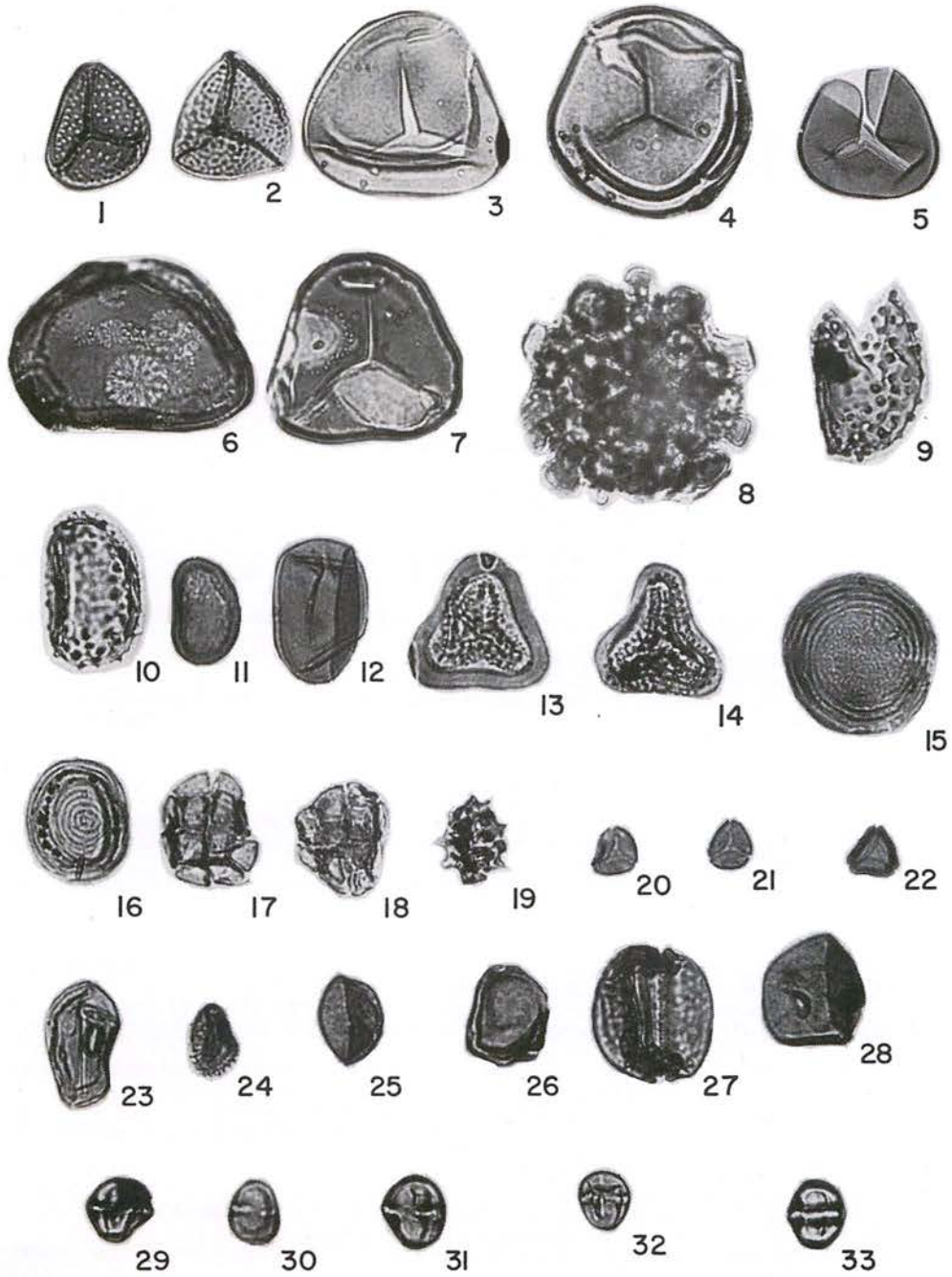
BISWAS: PLATE 2

All spore-pollen illustrated in this plate are from Late Pleistocene peaty lignite at 5 feet 8 inches below sea bottom of Tapis No. 1, recovered from punch core. 1-22 are of spore-pollen of characteristically freshwater plants. 23-28 are pollen of plants living in a transitional habitat between freshwater marsh and mangrove swamp. 29-33 are pollen of viviparous mangroves that can exist only in brackish swamps with regular tidal salinity flush.

In all descriptions l.d. means long diameter.

- 1-2: Spores of *Lycopodiaceae*; l.d. 34 and 32 microns respectively.
 3-5: Spores of *Microlepia* (?) spp., l.d. 53, 55 and 63 microns respectively; haplotypic apparatus short; the genus is widespread in Asia, with six species native in Malaysia.
 6-7: Trilete spores showing fungal decay apparently under aerobic conditions; 61 and 51 microns respectively.
 8: *Lygodium* (?) sp.; l.d. 63 microns; six species of *Lygodium* are native in Malaysia.
 9-10: Spores of *Polypodiaceae* with exospore membrane; l.d. 42 and 40 microns; *Polypodiaceae* are very prolific and diverse in Malaysia.
 11-12: Spores of *Polypodiaceae*; l.d. 27 and 36 microns.
 13-14: Spores of *Cyatheaceae*; l.d. 36 microns both; sixteen species of tree ferns are native in Malaysia; some flourish in hilly areas, others in lowland forests but always near streams.
 15-16: *Classopollis* sp.; l.d. 40 and 32 microns; natural affinity with pollen of *Cannaceae* and *Araaceae*.
 17-18: Pollen of *Mimosaceae*; l.d. of massulae 32 and 32 microns; at least twenty five species of *Mimosaceae* tree are native in Malaysia; 3 species of creepers are introduced.
 19: Pollen of *Compositae*; l.d. 23 microns.
 20-22: Pollen of *Eugenia* spp.; l.d. 13, 13 and 15 microns; *Eugenia* is the foremost tree genus in terms of abundance in Malaysia; 31 species are native.
 23: *Cocos* sp., cf., *C. nucifera*; l.d. 33 microns.
 24: *Ilex* sp., l.d. 19 microns.
 25: Pollen of *Palmae*; l.d. 23 microns; precise identification of genus and species is likely to be very helpful in ecologic interpretations.
 26: *Quercus* sp.; l.d. 23 microns; 25 species native in Malaysia.
 27: *Barringtonia* sp., l.d. 36 microns; ten species are native in Malaysia; *B. sumatrana* occurs on banks of tidal rivers and creeks; known from Eocene-Recent of Bengal Basin, Biswas (1961) generically.
 28: Pollen of *Gramineae*; l.d. 27 microns.
 29-33: Pollen of *Rhizophoraceae*; l.d. 17, 17, 19, 16, 19 microns respectively; eight species in four genera *Rhizophora*, *Bruguiera*, *Ceriops* and *Kandelia* are native in Malaysia.

PLATE 2

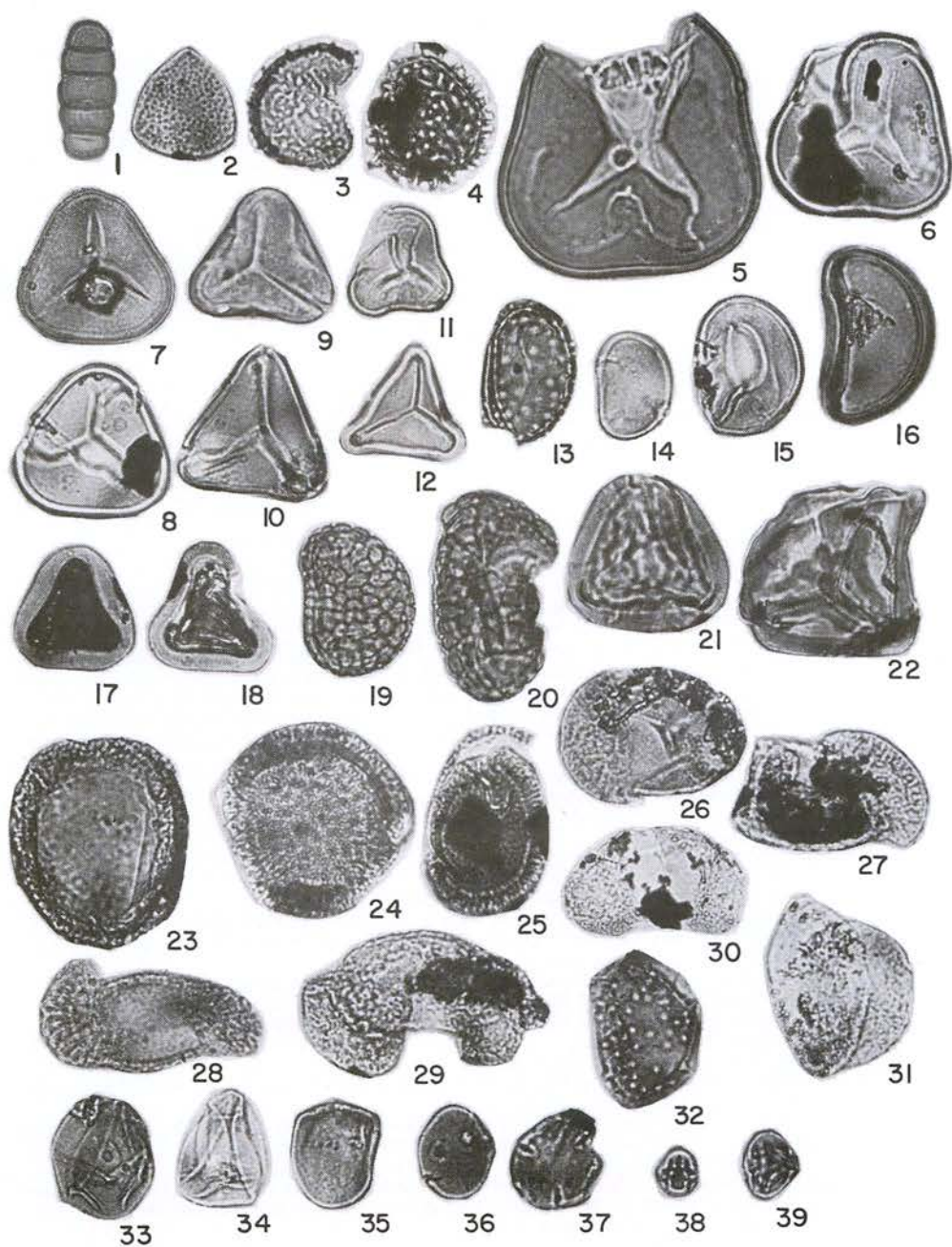


BISWAS: PLATE 3

All spore-pollen illustrated in this plate are from the Late Pleistocene carbonaceous claystone (of shoaled brackish lagoonal/bay habitat) at 5 feet 6 inches below sea bottom of Jerneh No. 1, recovered from punch core. 1-22 are spore-pollen of fresh water plants. 23-31 are Conifer pollen with air sacs enabling them to float to relatively long distances somewhat comparable to planktonic foraminifera. 32-39 are pollen of brackish water *Palmae*, *Gramineae*, *Cyperaceae* and *Rhizophoraceae*.

- 1: Uniseptate fungal spore; l.d. 40 microns.
- 2: Spore of *Lycopodiaceae*; l.d. 31 microns; faint trilete scar distinguishes it from otherwise similar looking pollen of *Calamus*.
- 3-4: Spore of *Selaginellaceae*; l.d. 36 microns both.
- 5-7: Spores of *Microlepidia* (?) spp; l.d. 59, 52 and 42 microns.
- 8-10: Spores of *Gleichenia* spp.; l.d. 44, 39, and 44 microns; figure 9 is a Recent spore of *Gleichenia linearis*, hence other two grains belong to the same species; of eight species of *Gleichenia* native in Malaya, three are common in low lands.
- 11-12: Spores of *Gleichenia* spp.; l.d. 32 and 36 microns.
- 13: Spore of *Polypodiaceae* with exospore membrane; l.d. 40 microns.
- 14-16: Spores of *Polypodiaceae*; l.d. 32, 40 and 51 microns respectively.
- 17-18: Spore of *Cyatheaceae* (?); l.d. 36 microns both: opacity of the apical portion flanged by transparent annular band possibly due to oxidation of the former in the process of stream transport.
- 19: Spore of *Davalia* sp.; l.d. 44 microns.
- 20: Spore of *Nephrolepis* (?) sp.; l.d. 59 microns; of the eight species of *Nephrolepis* known from Malaya four are ubiquitous.
- 21: Spore of *Cibotium* (?) sp.; l.d. 46 microns.
- 22: Spore of *Dicksoniaceae*; l.d. 59 microns.
- 23: Conifer pollen *Dacrydium* sp.; l.d. 59 microns; four species of *Dacrydium* are native in Malaya.
- 24-25: Monosaccate Conifer pollen, possibly *Dacrydium* spp.; l.d. 57 and 49 microns.
- 26-28: Bisaccate Conifer pollen, *Podocarpus* spp.; l.d. central body 40, 32 and 44 microns.
- 29: Bisaccate Conifer pollen, *Podocarpus* (?) sp.; l.d. central body 53 microns, bladder l.d. 35 microns.
- 30: *Podocarpus* sp., aff. *P. polystachyus*; l.d. central body 55 microns bladder coarser l.d. 35 microns; four species of *Podocarpus* are native in Malaysia, all of Southern Hemisphere affinities.
- 31: Bisaccate Conifer pollen; one wing broken; l.d. central body 40 microns.
- 32: Palm pollen, possibly *Nipa* sp.; l.d. 38 microns; pollen of modern *Nipa fruticans* (acetolysed) is bigger, about 56 microns according to Erdtman (1952).
- 33-34: *Gramineae* pollen; l.d. 36 and 34 microns.
- 35: *Cyperaceae* pollen; l.d. 32 microns.
- 36: *Sonneratia* sp.; l.d. 28 microns; characteristically salt-tolerant species (non *S. acida*).
- 37: *Brownlowia* sp.; l.d. 26 microns; characteristically salt-tolerant.
- 38-39: Pollen of *Rhizophoraceae*; l.d. 15 and 19 microns; confined to mangrove swamps with regular tidal salinity influx.

PLATE 3



BISWAS: PLATE 4

All spore-pollen illustrated in this plate are from Pleistocene claystones (of shoaled brackish swamp habitat) at 252.5 feet below sea bottom of Jerneh, recovered from sea-floor cores. 38-44 are pollen of plants confined to mangrove swamps with regular tidal salinity influx. 32-36 are possibly pollen of plants of a similar habitat. 16-18, 21 and possibly 22-24 are pollen of plants of brackish swamps with a mild tidal salinity influence. 1-15 and 19-20 are spore-pollen of plants characteristic freshwater marshes.

1-2: Fungal spores, l.d. 71 and 84 microns.

3: Spore of *Lycopodiaceae*; l.d. 31 microns.

4-5: Spores of *Microlepia* (?) sp.; l.d. 67 and 59 microns.

6: *Gleichenia lineris*; l.d. 36 microns.

7-8: *Lygodium scandens*; l.d. 86 and 80 microns.

9-10: Spores of *Polypodiaceae*; l.d. 44 and 42 microns.

11: *Podocarpus* sp.; l.d. central body 4 μ microns, bladders 40 microns.

12: *Pinus* (?) sp.; transverse diameter of central body and bladder both 40 microns; bladder ornamentation not discernably coarser, hence believed to be *Pinus*; no *Pinus* wild in Malaya; only *P. merkusii* known from *Burma, Sumatra, Java, Borneo*.

13: *Podocarpus* sp.; l.d. central body 50 microns, bladders 46 microns across.

14-15: Pollen of *Nipa* (?); l.d. 42 and 36 microns; alternative family affinity with *Araceae*.

16-17: Pollen of *Palmae*, monosulcate, possibly *Nipa* sp.; l.d. 31 and 32 microns.

18: Pollen of *Calamus*; l.d. 30 microns.

19-20: *Classopollis* sp.; l.d. 38 and 39 microns.

21: Pollen tetrad of *Pandanus*; l.d. single grain 23 microns; screw-pine or *Rassau* of Malaysia.

22-24: *Gramineae* pollen; l.d. 44, 36 and 34 microns.

25-30: Polar, oblique and equatorial compressions of *Ilex* sp.; l.d. 23, 19, 21, 21, 23 and 23 microns; four species of *Ilex* are native in Malaysia of which *I. cymosa* is the marsh species.

31: *Quercus* sp.; l.d. 25 microns.

32-36: Pollen of *Meliaceae* (?); l.d. 30, 25, 30, 25 and 27 microns; pollen of mangrove representative *Carapa obovata* from Sunderban of the Bengal Delta are tetraporate, hence it can be eliminated.

37: Unidentified pollen tetrad; l.d. single grains 44.

38: *Barringtonia* sp.; l.d. 43 microns.

39-43: *Sonneratia caseolaris* with polar "caps"; l.d. 32, 34, 36, 32 and 37 microns; typically salt water.

44: *Sonneratia* sp. without polar "cap"; l.d. 30 microns.

PLATE 4

