Geol. Soc. Malaysia, Bulletin 39, July 1996; pp. 157-184

Integrated biostratigraphic zonation for the Malay Basin

AZMI MOHD YAKZAN[1], AWALLUDIN HARUN[1], BAHARI MD NASIB[1] AND ROBERT J. MORLEY[2]

[1]P.R.S.S. (Petronas Research and Scientifiic Services Sdn. Bhd.)
Hulu Kelang, Selangor, Malaysia

[2]PALYNOVA, Littleport
Cambridge, U.K.

Abstract: This study presents an integrated biostratigraphic scheme for the Malay Basin based on the examination of 6 wells by P.R.S.S., and the review of data from ten wells, which were previously studied by service companies. For each of the wells reviewed, foraminiferal, nannofossil and quantitative palynological data was available. This paper demonstrates that through the integration of data from all three biostratigraphic disciplines, and through taking careful account of lithologies, it is possible to make accurate correlations within the Malay Basin which would not be possible using data from a single discipline.

All stratigraphic units in the Malay Basin contain abundant palynomorphs, whereas foraminifera and nannofossils predominantly occur in brief marine transgressive intervals. Palynology thus forms the primary tool for correlation, the succession being divided into 16 palynomorph assemblage zones and subzones (termed 'PR' zones). Nine foraminiferal acme zones (termed 'TR' zones), reflecting transgressive intervals, can be characterised on the basis of their foraminiferal content, and association with calcareous nannofossils and palynological zones. Nannofossils occur predominantly in the more distal sections of the transgressive intervals, and are important in placing the whole sequence of biostratigraphic events into a chronostratigraphic framework by reference to the standard scheme of low latitude nannofossil zones.

The chronostratigraphic significance of the scheme of seismic groups established by EPMI and widely used in subsurface studies within the Malay Basin has been appraised by reference to the biostratigraphic scheme. It is concluded that, provided a few adjustments are made to seismic picks in some wells, the seismic markers used to differentiate the seismic groups reflect time planes, and that therefore the seismic groups, which mostly have a distinct lithological expression, may be considered as time-rock units. Each seismic group has been characterised on the basis of biostratigraphic data.

By reference to a cumulative maximum time-thickness curve, ages have been applied to the palynomorph assemblage zone and seismic group boundaries.

Two distinct unconformities are observed in the upper part of the succession; one, dated at about 10.0–10.5 Ma, and termed the *Middle Miocene Unconformity*, probably relates to a pronounced period of low sea level, whereas the second, dated at 7.8 Ma in the upper Miocene (here termed the *Upper Miocene Unconformity*), relates to a phase of tectonic inversion.

INTRODUCTION

Various attempts have been made by the petroleum industry to use biostratigraphy to determine stratigraphic relationships in the paralic Malay Basin; most of these have been unsuccessful. This is due, in part, to the limited representation of marine facies in the basin, with the result that marine microfossils, such as foraminifera, calcareous nannofossils and dinocysts, are rarely present to their full stratigraphic range, and in part to the limited understanding of the stratigraphic significance of terrestrially derived miospores and freshwater algae, which are abundantly represented throughout the Malay Basin succession.

This paper presents a summary of a detailed biostratigraphic scheme for the basin, based on the study of six well sections by P.R.S.S. (Petronas Research and Scientific Services), and the review of biostratigraphic data from 12 other wells, which were previously studied by service companies. For each of the wells reviewed, foraminiferal, nannofossil and quantitative palynological data were available. This study demonstrates that through the integration of data from all three biostratigraphic disciplines, and through taking careful account of lithologies, it is possible to make accurate correlations within the Malay Basin in a manner which is not possible from a single discipline alone.

Presented at GSM Petroleum Geology Conference '95

Since all stratigraphic units in the Malay Basin contain abundant palynomorphs, but only limited intervals yield foraminifera and nannofossils, palynology forms the primary tool for correlation. Foraminifera and nannofossils are also important in that they permit the differentiation of marine transgressive events (marine flooding surfaces), the stratigraphic position of which can be determined by reference to their position relative to the scheme of palynological zones. Nannofossils are also valuable in providing dates to the marine transgressive events, which permit the sequence of palynological zones to be placed into a chronostratigraphic framework.

LITHOLOGICAL SUCCESSION

The Malay Basin is a northwest-southeast trending, elongate tectonic feature believed to have been formed during the latest Eocene or early Oligocene (EPMI, unpublished). The basin contains well in excess of 10,000 m of sediments, and is bounded to the southwest by the Tenggol Arch, and to the northeast by the Khorat Swell (Fig. 1). To the northwest, the Malay Basin is connected to the Pattani Trough, a similar pull-apart basin with a north-south lineament, and at its southern end, it is connected to the east-west aligned Penyu and West Natuna Basins.

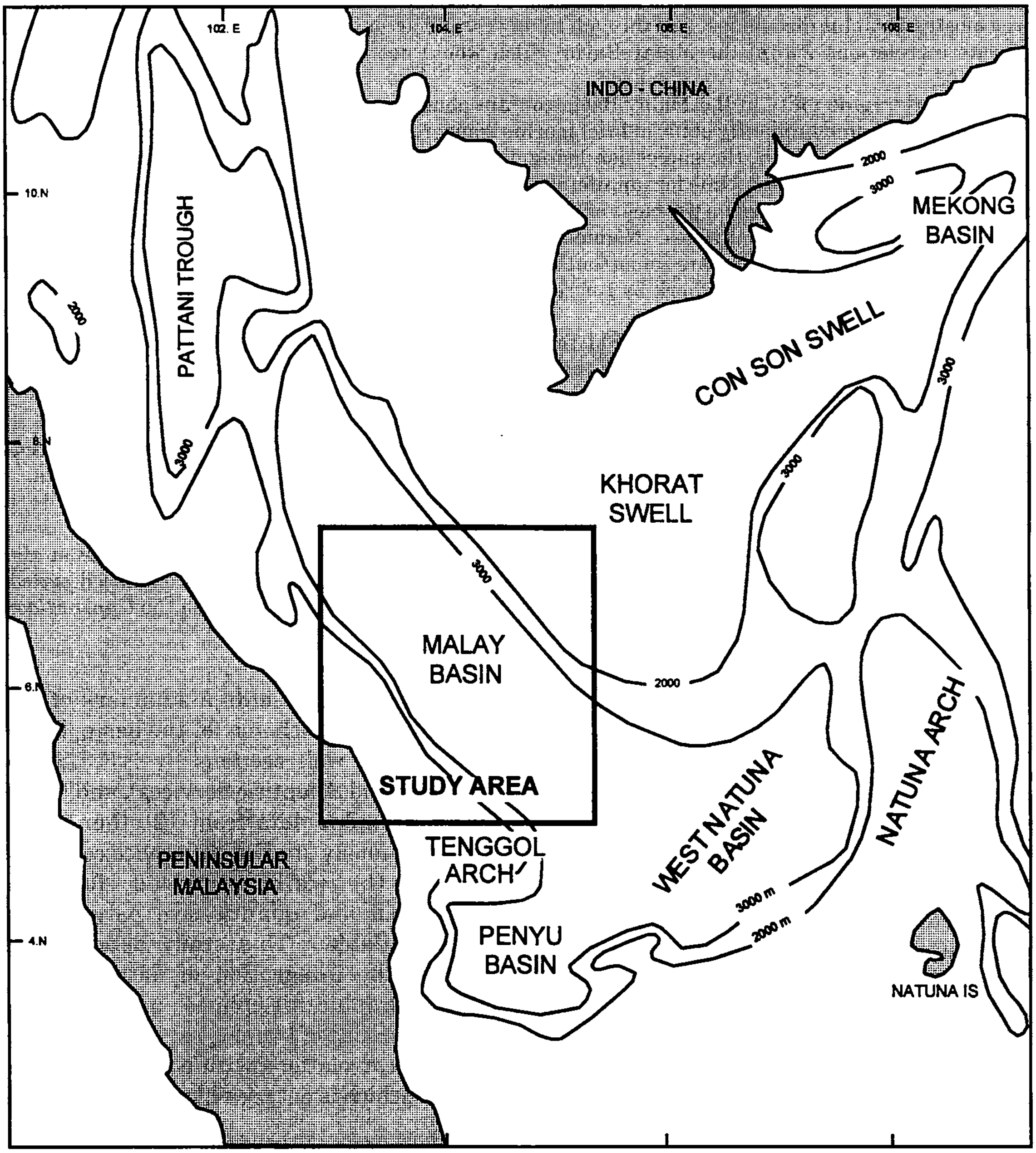

Figure 1. Malay Basin, geographical and tectonic setting.

The initial phase of sediment accumulation involved the deposition of lacustrine and fluvial sediments during the Oligocene 'rift' phase of basin development (Fig. 2). Subsequently during the early Miocene 'regional subsidence' phase, paralic sediments, consisting mainly of coastal plain sands, muds and coals, and interbedded transgressive marine muds, were deposited throughout the basin. In the middle, and initial part of the late Miocene 'compressional' phase, subsidence waned in the southern part of the basin, but continued apace in the middle and northern areas. Tectonic inversion occurred in the middle part of the late Miocene, relating to the collision of the Australian and Sunda Plates, and resulted in a widespread unconformity, which extends also into the adjacent Natuna Basin (e.g. Ginger *et al.*, 1993), following which marine sediments accumulated uniformly across the region.

The repetitive nature of sand and shale sequence and coal seam makes the task of establishing lithostratigraphic subdivisions for the basin difficult, and currently, lithostratigraphic terminology remains unsatisfactory (Fig. 2). During the initial phase of exploration, a lithostratigraphic scheme for the southern Malay Basin area was informally adopted (see Nazri Ramli, 1988), and subsequently, a formal lithostratigraphic scheme was proposed (Armitage and Viotti, 1978), using the Pulai-1 well as a type locality. However, the latter scheme has never received general acceptance since firstly, it uses some of the same formational names as the earlier Conoco scheme, but for different stratigraphic units (e.g. Tapis Formation); secondly, many of the age interpretations are suspect, and some are based on taxa which, to the authors' knowledge, have never been recorded in the Malay Basin; thirdly, some of the formational units are difficult to apply regionally; and fourthly, the Pulai-1 well records an incomplete lithostratigraphic column for the basin, the upper section being missing as a result of erosion.

Bearing in mind of the difficulties to define the formations in the classical sense, ESSO Production Malaysia Inc. geologists introduced a new scheme based on seismic reflectors. Altogether, eleven 'seismic groups' came into usage, termed Groups A–M (but with 'C' and 'G' missing); however, definitions of the groups remain unpublished. The reflectors chosen to define group boundaries principally coincide with the tops of widespread shales, hence the seismic groups also have a lithological response. Some of these groups coincide with formational units, with the result that often a combination of formally defined and informal lithostratigraphic units, and seismic groups, have been used together (e.g. Nik Ramli, 1988). An attempt was made subsequently to subdivide these using a regionally based cycle concept, in the manner successfully applied in Sarawak, and in 1988, a scheme of eight such cycles was introduced for the southern Malay Basin based on the recognition of marine transgressive, and regional shales, with boundaries being supported by seismic and biostratigraphic data (Nazri Ramli, 1988).

In this study, reference is made to the scheme of seismic groups originally proposed by EPMI, since the tops of these seismic groups represent the only stratigraphic units which are available for all of the wells included in this study. In support of making this choice, with the exception of a few wells, for which seismic interpretation is believed to be spurious, biostratigraphic data invariably demonstrates that the seismic group boundaries reflect time planes, and that the groups may be considered as seismically defined time-rock units. In a majority of sections, it is also possible to define the groups on lithological criteria. The time-synchroneity of the seismic reflectors demonstrated here is in contradiction to numerous (unpublished) suggestions that many seismic group boundaries are diachronous.

PREVIOUS BIOSTRATIGRAPHIC SCHEMES FOR THE MALAY BASIN AND ADJACENT AREAS

Three biostratigraphic zonation schemes have previously been used in the Malay Basin, although an indication of the criteria on which these zones are based have been published for only one of these (Morley, 1978). This scheme has been modified many times in different unpublished service company reports; based on the present day knowledge of the ranges of the palynomorphs used for this zonation, the zones which can be widely applied are illustrated in Figure 3. Note, however, that in the Malay Basin, the *Podocarpus imbricatus* and *Phyllocladus* zone cannot be applied, and the *Dacrydium* zone can be effectively used only to the north of the Malay Basin, in the Gulf of Thailand. In some areas of Southeast Asia, it is possible to differentiate the Oligocene on the basis of the occurrence of *Meyeripollis naharkotensis* (e.g. Rahardjo *et al.*, 1994 for Java), but this is difficult within the Malay Basin due to the rarity of this taxon. Nazri Ramli (1988) illustrated the stratigraphic relationships of a second scheme (the unpublished scheme of ISC, International Stratigraphic Consultants), but no details as to how the zones were defined. The unpublished 'South China Sea' zonation scheme of Robertson Research has also been used in some areas; the relationship between the latter zonation scheme and formational units for the adjacent Natuna Basin have been

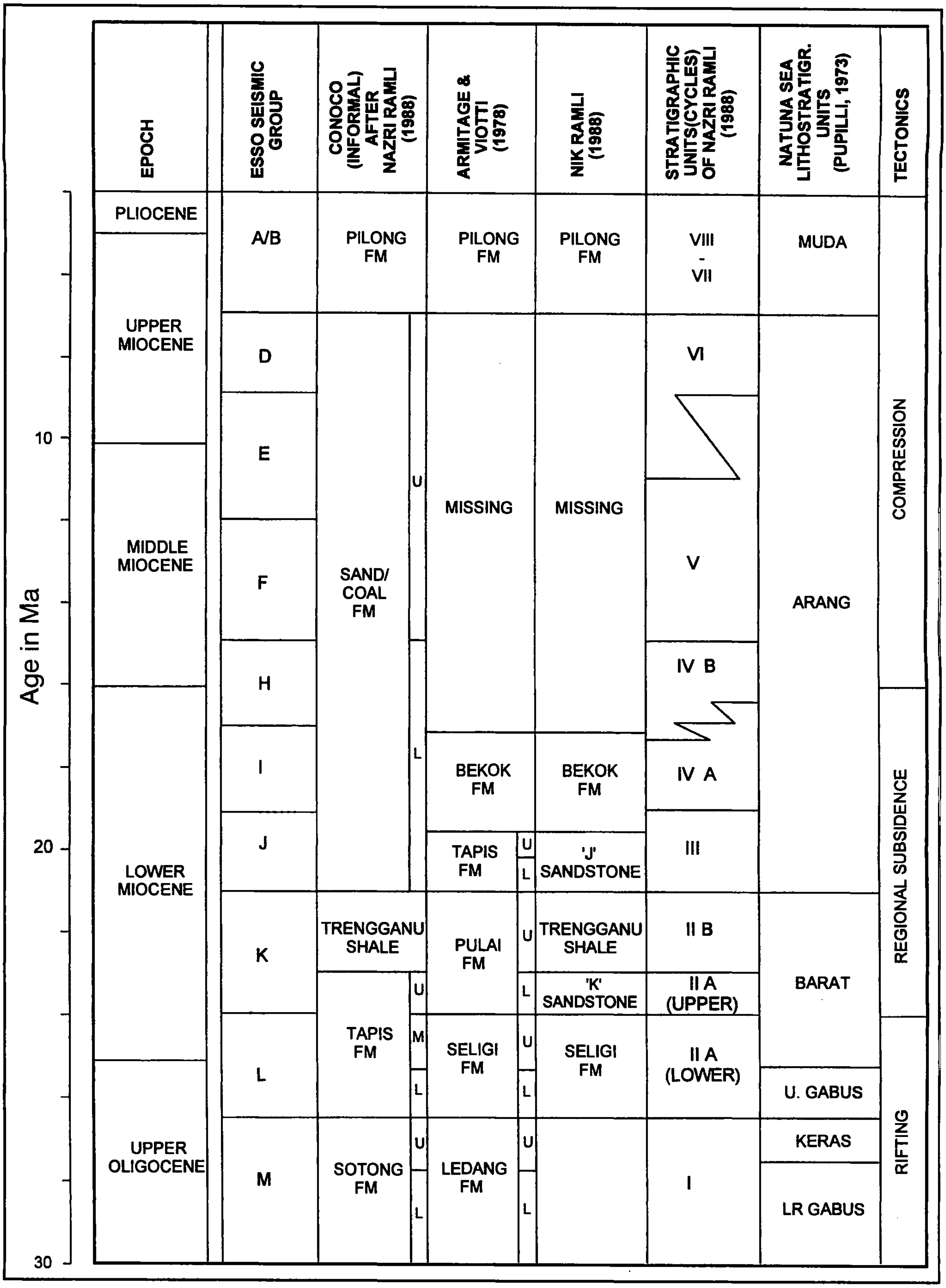

Figure 2. Lithostratigraphic units used in the Malay Basin, and their correlation with units from the adjacent Natuna Sea. Age relationships of all units according to this study.

illustrated by Sutoto (1991). The stratigraphic relationships between each of these zonal schemes is presented in Figure 4.

DATABASE

The wells used for this study are primarily positioned in the south eastern part of the Malay Basin, and along its southwestern flank (Fig. 5). Following a review of all available biostratigraphic data from unpublished reports from the basin, ten additional wells were chosen for which reasonable quality quantitative palynological data was available, together with data on foraminifera and nannofossils. Some of these datasets were subsequently upgraded in order to resolve specific questions which were brought to attention. These studies involved quantitative foraminiferal and nannofossil analyses, in addition to the evaluation of sections rich in algal palynomorphs.

METHODOLOGY

Analytical Methods

Standard methods have been used for the analyses undertaken during this study, and will not be repeated here. However, in order pick out all of the anticipated events based on quantitative data, the following procedures were also followed:

Samples were initially screened for foraminifera using closely spaced samples (10 m intervals or closer). Approximate quantitative estimates of foraminiferal abundance were obtained by recording all of the foraminifera picked from a fixed weight (100 g) of sample.

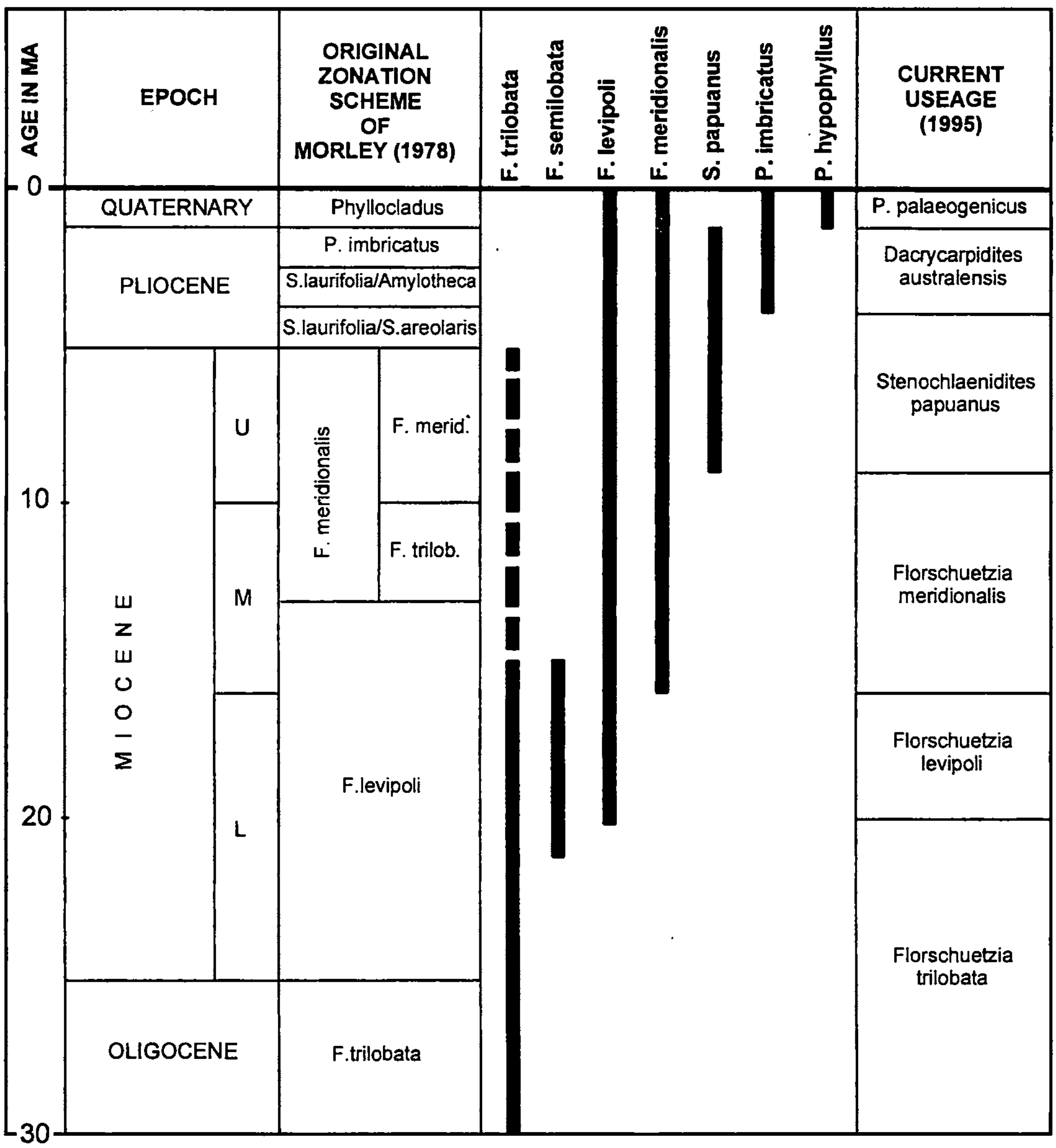

Figure 3. Palynological zones for Southeast Asia based on age-restricted taxa; current status.

Samples thought to represent marine transgressive units on the basis of foraminifera were also examined for nannofossils. Approximate quantitative estimates of nannofossil abundance were made by counting all specimens on a fixed number of traverses per slide.

Unwashed cuttings samples were collected for palynological study at 20–30 m intervals. Care was taken to avoid the use of sieves with a mesh size in excess of 5 microns, since larger mesh sizes, routinely used by many commercial laboratories, effectively remove some of the most important taxa used for correlation and age determination. Miospore counts were maintained at between 100 and 150 nonmangrove specimens per sample. Mangrove pollen and freshwater algae were counted in addition to this sum. Palynological analysis charts were prepared in the form of 'sawtooth' diagrams using a 'pollen' sum of 'total freshwater pollen and spores' for terrestrially derived forms from freshwater habitats, and 'total miospores' for presentation of spectra for mangrove pollen. Algae were presented using a sum of total freshwater miospores + total algae.

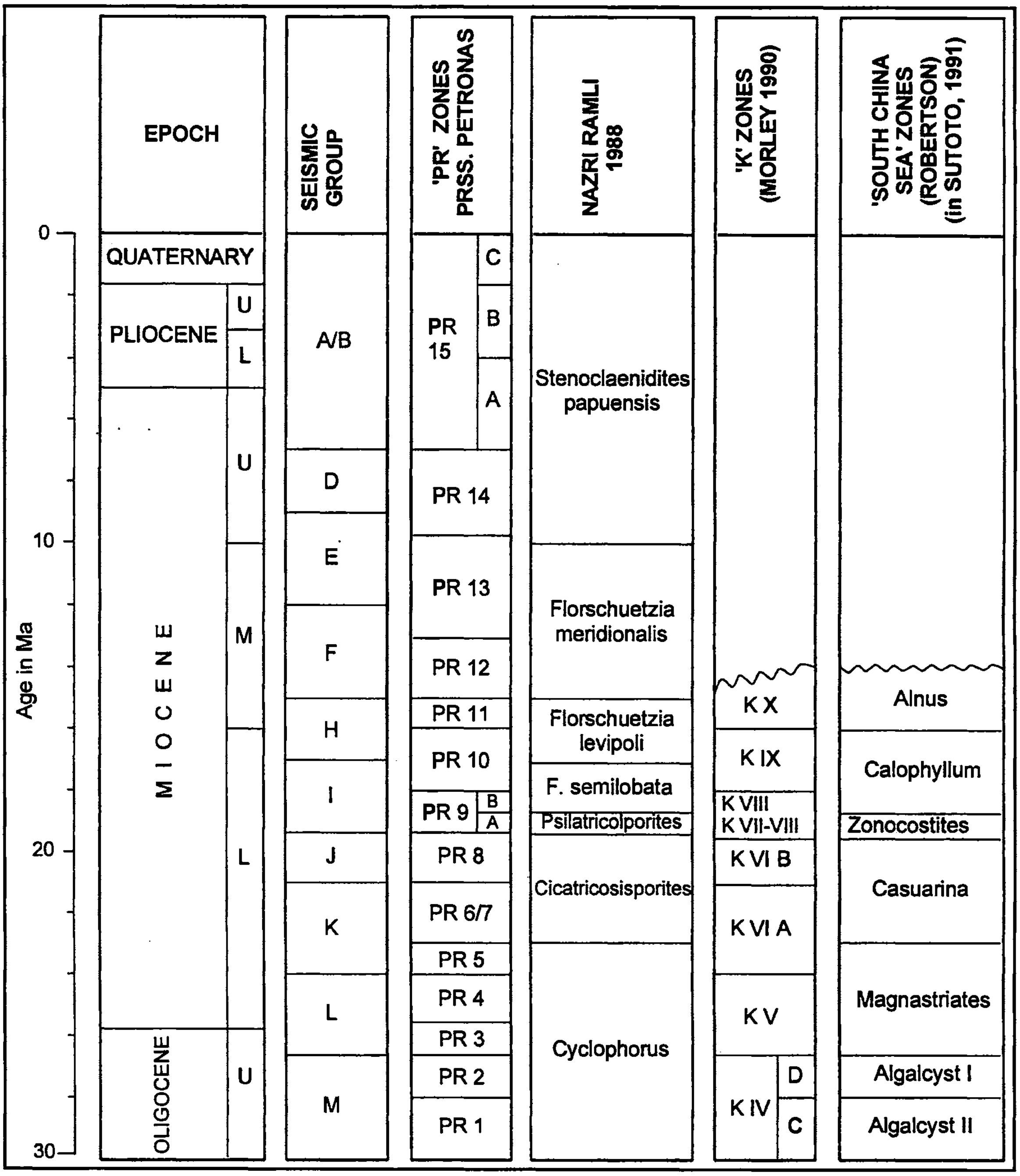

Figure 4. Palynological zones applied to the Malay Basin and adjacent areas.

Form taxon names are used when available and appropriate. For undescribed taxa which can be compared to pollen of extant plants, reference is made to the extant taxon with which the fossil most closely compares. If a fossil pollen type is identical to two or more taxa of the same rank, the name of one of the extant taxa is used, and the suffix 'type' appended (e.g. *Shorea* type pollen may be derived from the dipterocarp genera *Shorea* or *Hopea)*. A list of the taxa referred to in this study, showing form species and extant taxon names, is given in the Appendix.

Methods of interpretation

Biostratigraphic data sets for each discipline were compared in turn for each of the seismic groups, paying careful attention to the wireline log motifs. On the assumption that at least some of the seismic picks were likely to be correct, coincidence between biostratigraphic datasets and seismic tops was taken as evidence for the identification of a stratigraphically significant biostratigraphic event. If biostratigraphic data from three or more well sections were found to coincide with wireline log features and seismic picks, subsequent mismatches were each carefully examined to determine whether alternative positions of biostratigraphic or log picks might be possible. In this manner, a framework of biostratigraphic events and wireline log motifs was brought together which allowed each seismic package to be modelled.

BIOSTRATIGRAPHIC EVENTS IN THE MALAY BASIN

Biostratigraphic events based on palynomorphs, foraminifera and nannofossils need to be considered differently depending on their representation through the stratigraphic succession. Terrestrially derived miospores are ubiquitous throughout the succession, and because of the limited representation of age diagnostic forms, are best interpreted by reference to palynomorph assemblage zones, which through correlation studies, can be demonstrated to have chronostratigraphic significance, rather than interval zones, concurrent range zones or acme zones. As a rule of thumb, a palynological event needs to be observed in at least four well sections, and its chronostratigraphic significance tested against other criteria, such as the position of seismic reflectors, distinctive log breaks or events based on other biostratigraphic disciplines, before it can be accepted as having chronostratigraphic significance. Once calibrated

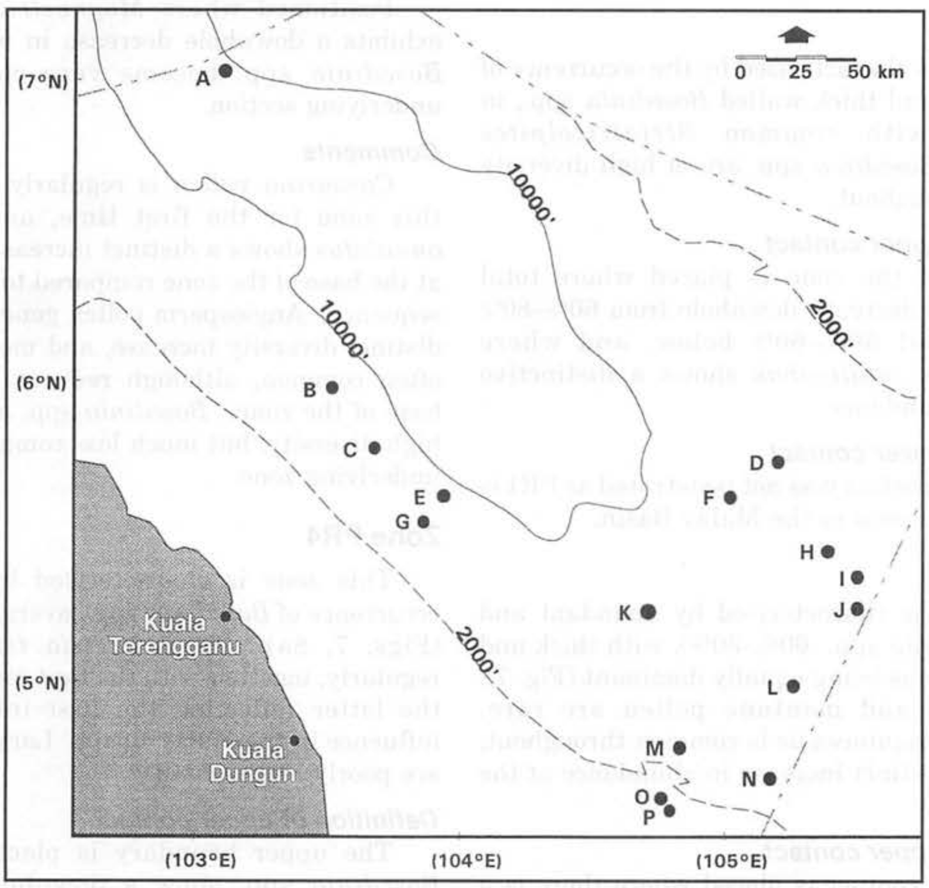

Figure 5. Well locations used for this study.

to the geological time scale, by reference to nannofossils and other events, which have an expression, and have been dated, outside the Malay Basin, these zones can be directly calibrated to the geological time scale, but can only be used in the Malay Basin, where their chronostratigraphic significance has been tested.

Foraminifera occur in discrete pulses, reflecting marine flooding surfaces. These transgressive units can sometimes be characterised on the basis of their foraminiferal content, and their association with nannofossils. They can also be distinguished by their relationship with the proposed scheme of palynomorph assemblage zones. Nannofossils, on the other hand, are valuable for dating the marine flooding surfaces in the more distal parts of the basin by reference to the low latitude zonation scheme of Martini (1971).

PALYNOMORPH ASSEMBLAGE ZONES

Fifteen palynomorph assemblage zones have been established for the basin, using the suffix 'PR'. The criteria on which these zones are distinguished are summarised in Figure 6. Approximate ages for each of these zones is discussed in section 8, below. The zones interpreted are as follows:

Zone PR1

This zone is characterised by the occurrence of common thin and thick walled *Bosedinia* spp., in association with common *Striatricolpites catatumbus*. *Bosedinia* spp. are of high diversity (7–8 spp.) throughout.

Definition of upper contact

The top of the zone is placed where total *Bosedinia* spp. decrease downhole from 60%–80% above to about 50%–60% below, and where *Striatricolpites catatumbus* shows a distinctive increase in abundance.

Definition of lower contact

The lower contact was not penetrated as PR1 is the oldest zone seen in the Malay Basin.

Zone PR2

Zone PR2 is characterised by abundant and diverse *Bosedinia* spp. (60%–80%), with thick and thin walled forms being equally dominant (Fig. 7). Large spores and montane pollen are rare. *Discoidites novaguineensis* is common throughout, and shows a distinct increase in abundance at the top of the zone.

Definition of upper contact

The upper contact is placed where there is a marked downhole increase in abundance of *Bosedinia* spp. from less than 40% to between 60% and 80%. Whereas thin walled forms show a moderate increase at this level, thick walled forms show a marked increase from rare above to very common below.

Definition of lower contact

The lower contact is placed where *Bosedinia* spp. show a downhole reduction in abundance, and miospores, especially *Striatricolpites catatumbus*, become more common.

Comments

Bosedinia spp. are abundant, and of high diversity in this zone. *Bosedinia granulata* is restricted to this and older zones.

Zone PR3

This zone is characterised by the presence of large spores, such as *Magnastriatites howardi* and *Acrostichum*, common bisaccate and monosaccate pollen, and reduced *Bosedinia* spp, (compared to the underlying zone).

Definition of upper contact

The upper contact is positioned where *Magnastriatites howardii* shows a marked downhole increase in abundance.

Definition of lower contact

Positioned where *Magnastriatites howardi* exhibits a downhole decrease in abundance, and *Bosedinia* spp. become very common in the underlying section.

Comments

Casuarina pollen is regularly represented in this zone for the first time, and *Monoporites annulatus* shows a distinct increase in abundance at the base of the zone compared to the underlying sequence. Angiosperm pollen generally exhibits a distinct diversity increase, and montane pollen is often common, although reduces sharply at the base of the zone. *Bosedinia* spp. are of relatively high diversity, but much less common than in the underlying zone.

Zone PR4

This zone is characterised by the common occurrence of *Bosedinia* spp., averaging about 30% (Figs. 7, 8a). *Florschuetzia trilobata* occurs regularly, together with the first marine dinocysts, the latter reflecting the first influx of marine influence in the Malay Basin. Large trilete spores are poorly represented.

Definition of upper contact

The upper boundary is placed where total *Bosedinia* spp. show a downhole increase in abundance to about 20% to 30%.

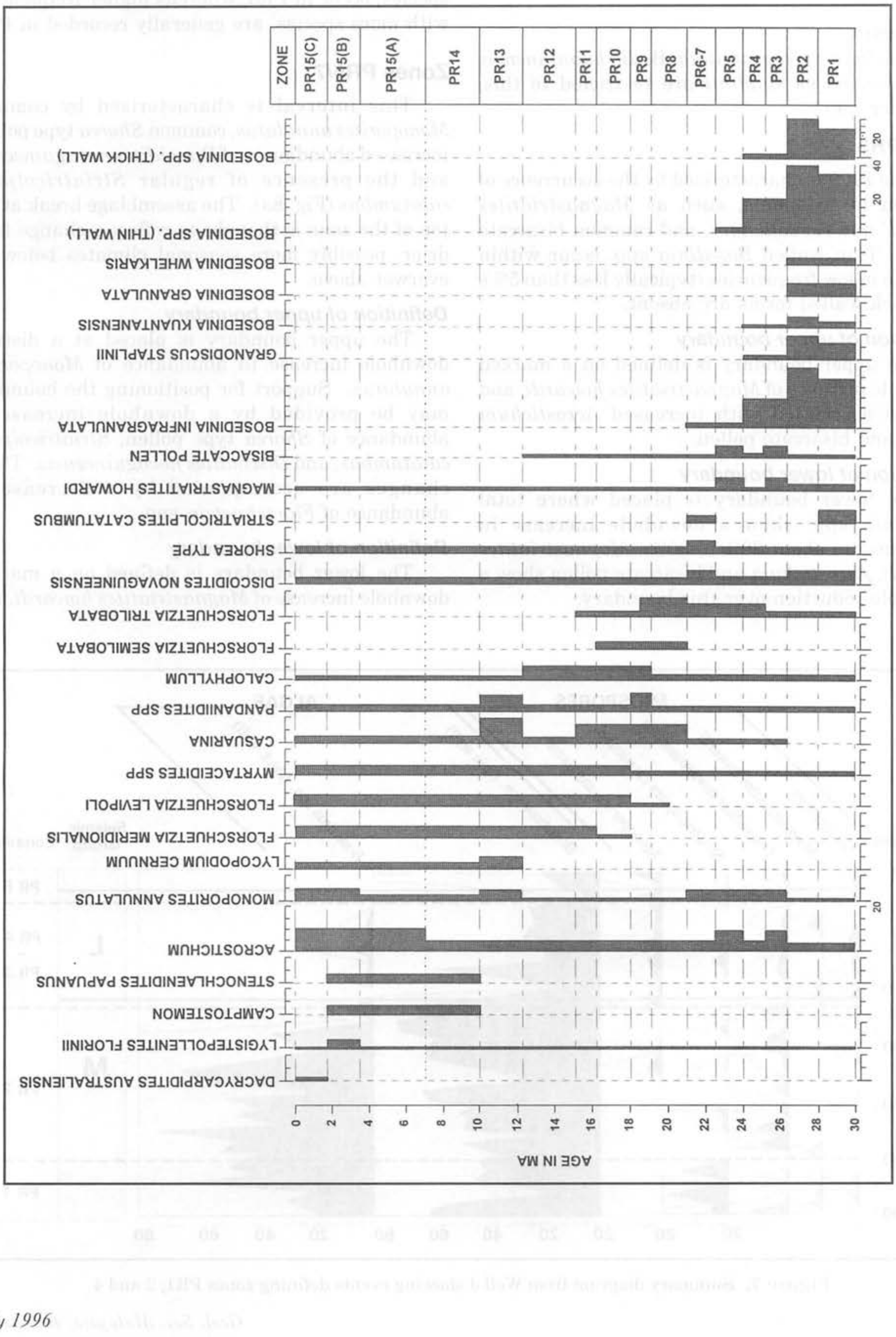

Figure 6. Malay Basin palynological zonation: summary diagram.

Definition of lower boundary

The lower boundary is positioned where large spores, such as *Magnastriatites howardi*, and *Acrostichum*, show a marked downhole increase in abundance.

Comments

Bosedinia infragranulata B, *B. kuantanensis* and *Granodiscus staplinii* are restricted to this, and older zones.

Zone PR5

Zone PR 5 is characterised by the occurrence of common large spores, such as *Magnastriatites howardi* and *Acrostichum*, and common bisaccate pollen. Thin walled *Bosedinia* spp. occur within the zone in low frequencies (typically less than 5%), and thick walled forms are absent.

Definition of upper boundary

The upper boundary is defined on a marked downhole increase of *Magnastriatites howardi,* and is often associated with increased *Acrostichum* spores and bisaccate pollen.

Definition of lower boundary

The lower boundary is placed where total *Bosedinia* spp. show a downhole increase in abundance to about 20% to 30%. *Magnastriatites howardi*, *Acrostichum* and bisaccate pollen show a downhole reduction over this boundary.

Comments

Zones PR3 and PR5 are very similar; they are distinguished by the abundance and type of *Bosedinia* present. Low frequencies, and few species, occur in PR5, whereas higher frequencies, with more species, are generally recorded in PR3.

Zones PR6/7

This interval is characterised by common *Monoporites annulatus*, common *Shorea* type pollen, increased abundances of *Discoidites novaguineensis* and the presence of regular *Striatricolpites catatumbus* (Fig. 8a). The assemblage break at the top of the zone is thought to reflect a change from drier, possibly more seasonal climates below, to everwet above.

Definition of upper boundary

The upper boundary is placed at a distinct downhole increase in abundance of *Monoporites annulatus*. Support for positioning the boundary may be provided by a downhole increase in abundance of *Shorea* type pollen, *Striatricolpites catatumbus*, and *Discoidites novaguineensis.* These changes are accompanied by a decrease in abundance of *Florschuetzia* spp.

Definition of lower boundary

The lower boundary is defined on a marked downhole increase of *Magnastriatites howardi,* and

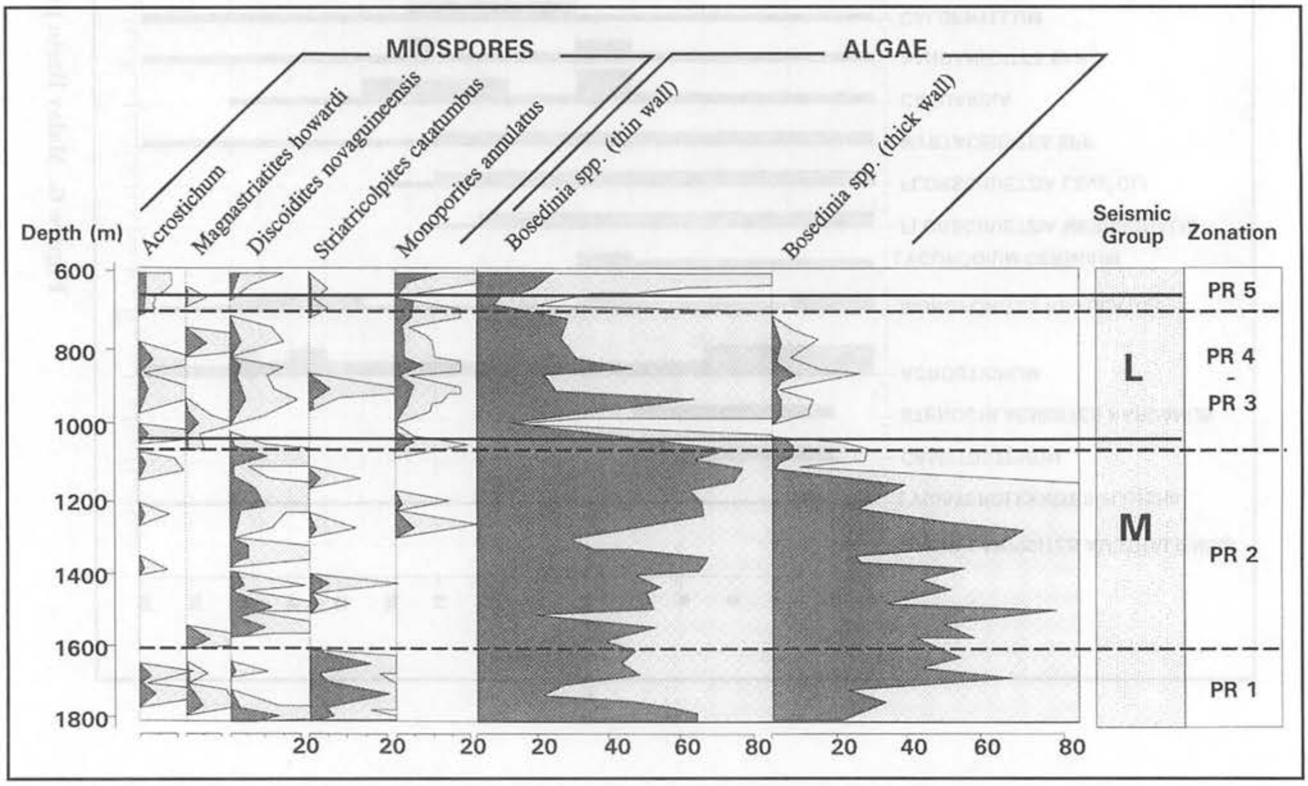

Figure 7. Summary diagram from Well J showing events defining zones PR1, 2 and 4.

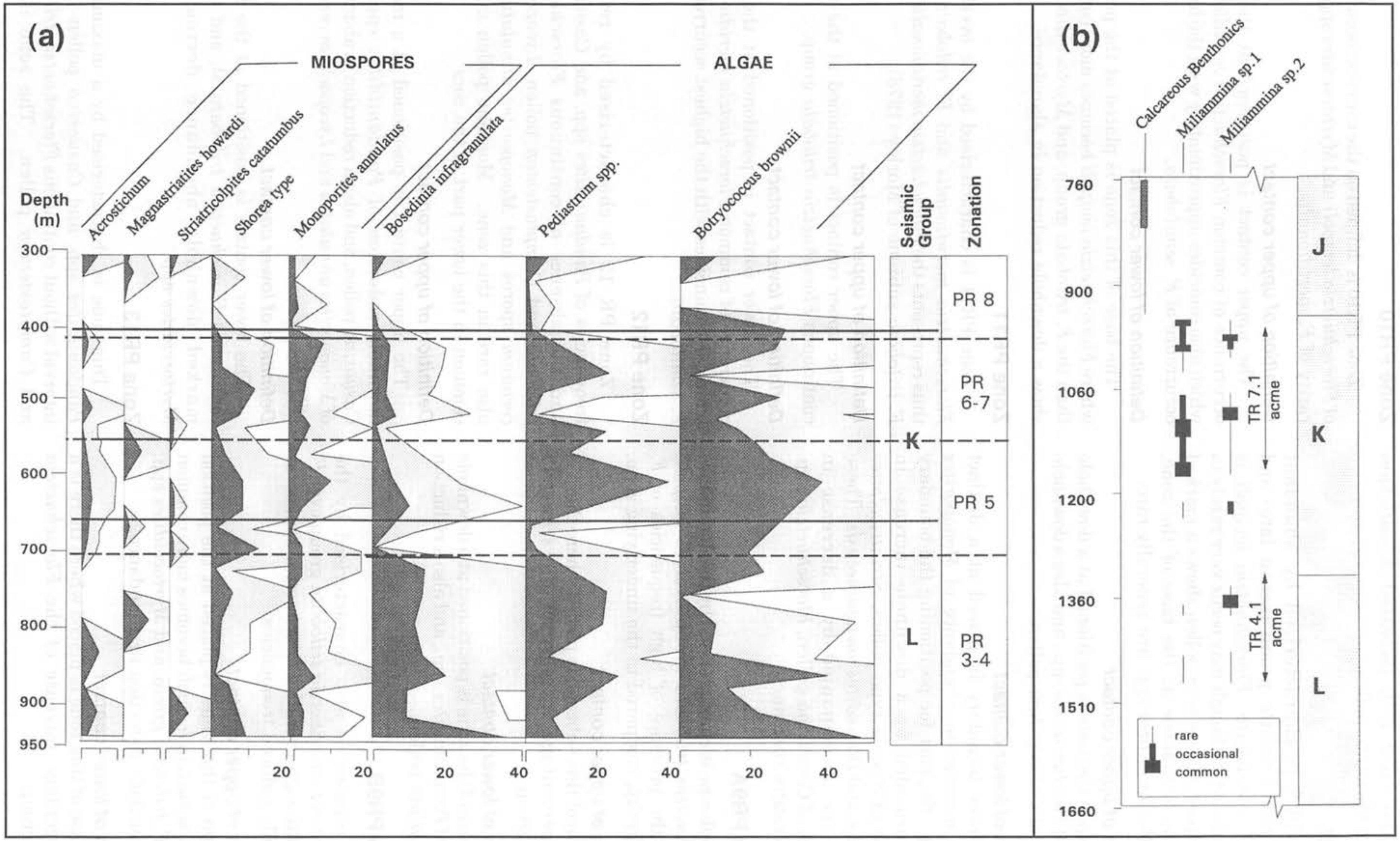

Figure 8. Summary diagrams a) from Well J, showing events defining zones PR4, 5 and 7, and b) influxes of benthonic foraminifera in Well I.

is often associated with increased *Acrostichum* spores and bisaccate pollen.

Zone PR8

Zone PR8 is characterised by abundant *Florschuetzia trilobata* group (sensu lato) and regular *F. semilobata*. *Florschuetzia levipoli* is virtually absent, although may occur very rarely in the upper part. *Casuarina* pollen shows a marked increase in abundance at the base of the zone, whereas *Pandaniidites* spp. are generally rare.

Definition of upper contact

The top of the zone is positioned at a downhole decrease of *Pandaniidites* spp., and also a downhole reduction of *Calophyllum* pollen.

Definition of lower contact

The lower boundary is placed at a distinct downhole increase in abundance of *Monoporites annulatus*. Support for positioning the boundary may be provided by a downhole increase in abundance of *Shorea* type pollen, *Striatricolpites catatumbus*, and *Discoidites novaguineensis*. These changes are accompanied by a decrease in abundance of *Casuarina* pollen, *Florschuetzia* spp. and *Zonocostites ramonae*.

Subzone PR9A

This subzone is characterised by the dominance of *Florschuetzia trilobata* group over *F. levipoli,* and also the presence of high frequencies of *F. trilobata* group, compared to the underlying zone.

Definition of upper contact

The top of this subzone is placed where there is a large percentage increase of *Florschuetzia trilobata* group.

Definition of lower contact

The base of the zone is positioned at a downhole decrease of *Pandaniidites* spp., and also a reduction of *Calophyllum* pollen.

Subzone PR9B

This subzone is also characterised by the dominance of *Florschuetzia trilobata* group over *F. levipoli,* although overall, *Florschuetzia* spp. occur in markedly reduced frequencies.

Definition of upper contact

The top of this zone is placed at the position where *Florschuetzia levipoli* becomes more common than the *F. trilobata* group, and *Myrtaceidites* spp. show a downhole reduction in abundance.

Definition of lower contact

The base of this zone is placed where there is a large percentage increase of the *Florschuetzia trilobata* group.

Zone PR10

Zone PR10 is defined on the common occurrence of *Florschuetzia levipoli* and *Myrtaceidites* spp., and rarity of *F. meridionalis.*

Definition of upper contact

The upper contact is positioned at the base occurrence of common *Florschuetzia meridionalis*, which also coincides approximately with the highest occurrence of *F. semilobata.*

Definition of lower contact

The base of this zone is placed at the position where *Florschuetzia levipoli* becomes more common than the *F. trilobata* group, and *Myrtaceidites* spp. show a downhole reduction in abundance.

Zone PR11

Zone PR11 is characterised by the overlap of *Florschuetzia meridionalis* and *F. trilobata,* and thus represents the *Florschuetzia meridionalis* zone, *F. trilobata* subzone of Morley (1978).

Definition of upper contact

The upper contact is positioned at the top of continuous *Florschuetzia trilobata* group.

Definition of lower contact

The lower contact is positioned at the base occurrence of common *Florschuetzia meridionalis*, which also coincides with the highest occurrence of *F. semilobata.*

Zone PR12

Zone PR 12 is characterised by reduced frequencies of *Pandaniidites* spp. and *Casuarina*, and the absence of continuous *Florschuetzia trilobata* and *Camptostemon* pollen. *Lycopodium cernuum* spores and *Monoporites annulatus* are also rare in this zone. Montane pollen may be common in the lower part of the zone.

Definition of upper contact

The upper contact is positioned at a marked downhole reduction of *Pandaniidites* spp. and *Casuarina* pollen, and also a reduction in abundance of *Monoporites annulatus* and *Lycopodium cernuum* spores.

Definition of lower contact

The lower contact is positioned at the top of continuous *Florschuetzia trilobata* sl, and also a marked downhole abundance decrease of *Myrtaceidites* spp.

Zone PR13

This zone is characterised by a maximum of *Pandaniidites* spp. and *Casuarina* pollen in the interval without continuous *Florschuetzia trilobata* and *Camptostemon* pollen. The zone is also characterised by the occurrence of regular *Lycopodium cernuum* spores and *Monoporites annulatus*. Montane pollen is virtually absent from the zone.

Definition of upper contact

The top of the zone is placed at the lowest occurrence of *Stenochlaenidites papuanus*, and *Camptostemon* pollen, and a downhole increase of *Pandaniidites* spp. and *Casuarina* pollen.

Definition of lower contact

The base of the zone is positioned at a marked downhole increase of peat swamp pollen, and also a downhole reduction in abundance of *Pandaniidites* spp., *Casuarina, Monoporites annulatus* and *Lycopodium cernuum* spores.

Comments

This zone is primarily represented in the northern end of the basin; it has been removed from the southern part as a result of erosion associated with the Middle Miocene unconformity (see below).

Zone PR14

This zone is characterised by the presence of *Stenochlaenidites papuanus,* and *Camptostemon* pollen.

Definition of upper contact

The upper contact is placed at a marked downhole reduction in abundance of *Acrostichum* spores.

Definition of lower contact

The lower contact is placed at the deepest occurrence of *Stenochlaenidites papuanus* and *Camptostemon* pollen, and a downhole increase of *Pandaniidites* spp. and *Casuarina* pollen.

Zone PR15

Zone PR15 occupies the whole of the Pulai Formation, and spans the period from about 7 Ma to 0 Ma. The zone is characterised by an abundance peak of *Acrostichum* spores. The explanation as to why *Acrostichum* is so common in this zone is unclear.

Definition of upper contact

The top of the zone corresponds to the present sea bed.

Definition of lower contact

The basal contact is characterised by a marked downhole decrease in abundance of *Acrostichum* spores.

Comments

Detailed study of this zone would result in numerous subdivisions. At least three subzones can be seen on the basis of presently available data, and this could probably be increased. Detailed analysis of this zone has not been undertaken because the Plio-Pleistocene interval has minor economic importance. Suggested subdivisions are as follows:

A A lower interval with regular *Stenochlaenidites papuanus*, and with relatively low frequencies of *Dacrydium* pollen.

B An intermediate interval with common *Dacrydium* pollen and with the continued presence of *Stenochlaenidites papuanus.* This probably reflects the *Dacrydium* zone of Morley (1978), but note that its age here is late Pliocene.

C An upper interval without *Stenochlaenidites papuanus*, but possibly with *Podocarpus imbricatus* pollen.

Note that *Podocarpus imbricatus* pollen has not yet been found in Malay Basin sediments, but occurs in Pleistocene localities onshore Malay Peninsula. It is tentatively suggested that this species may have migrated into the Malay Peninsula later than into Borneo.

EVENTS BASED ON FORAMINIFERA

Application of planktonic foraminifera

Planktonic and benthonic foraminifera are abundant within the Pilong Formation (especially the upper part) and within this sequence, ages can be interpreted by reference to the scheme of Blow (1979) using planktonic foraminifera. Elsewhere, planktonic foraminifera are of limited occurrence, and can rarely be used to assist in age interpretation.

Foraminiferal acme zones (Fig. 19)

Below the Pilong Formation, planktonic foraminifera are scarce, and the only species generally recorded is *Cassigerinella chipolensis*. Typically, the incoming of this species is referred to planktonic zone N13, but nannofossil data suggests that the age is older, and should be equivalent to N12 or N11.

The remainder of the stratigraphic succession in the Malay Basin is characterised by low diversity benthonic faunas, which have been used previously to assist with environment interpretation, but not for stratigraphic interpretation. Benthonic foraminifera do not occur regularly, but in pulses, reflecting marine flooding surfaces, which can be characterised on the basis of their foraminiferal content, and their association with nannofossils and palynological zones. The boundaries of the foraminiferal pulses can be easily located if quantitative analyses are performed.

The foraminiferal acme zones are suffixed 'TR', and numbered in the same order as the palynological zones. The following foraminiferal acme zones are proposed:

TR-14-2 foraminiferal acme zone

This zone is characterised by abundant *Pseudorotalia* spp and *Asterorotalia* spp., but with more restricted assemblages in the north west of the basin. This zone is largely removed as a result of erosion associated with the Upper Miocene Unconformity.

TR 14-1 foraminiferal acme zone

This zone is generally characterised by specimens of *Vulvulina pennatula*, although this species is by no means restricted to this zone.

TR 12-1 foraminiferal acme zone

This zone is generally characterised by a pulse of benthonic foraminifera indicating middle neritic water depths in the south eastern part of the basin.

TR 11-2 foraminiferal acme zone

The foraminiferal assemblage within this zone reflects deeper, more open marine conditions than seen in any of the other transgressive pulses. The zone often contains the planktonic foraminifer *Cassigerinella chipolensis* as noted above. It comprises the most widespread marine flooding surface seen in the basin, and provides an excellent correlative horizon.

TR 11-1 foraminiferal acme zone

This zone is well represented only in the south east of the basin, and is characterised by common inner neritic foraminifera.

TR 10-1 foraminiferal acme zone

This zone is generally characterised by the presence of inner neritic foraminifera. Calcareous benthonics are generally more common than in the underlying transgressive pulses. This zone is best represented in the south east of the basin.

TR 9-1 foraminiferal acme zone

This zone is also generally reflected by a pulse of inner neritic foraminifera

TR 7-1 and 4-1 acme zones

These zones are characterised by common specimens of the arenaceous genus *Miliammina*. The zones reflects the first marine influence in the Malay Basin at the base of the lower Miocene (Fig. 8b), and occur within the Seligi Shale (upper 'L' seismic group) and the Trengganu Shale respectively.

EVENTS BASED ON NANNOFOSSILS

Calcareous nannofossils are extremely important in helping to establish a chronostratigraphy in the Malay Basin. They are difficult to interpret in isolation, because they are generally present only in the marine flooding surfaces, but when integrated with foraminifera and palynomorphs, help to place the whole sequence of biostratigraphic events into a chronostratigraphic framework.

Nannofossils provide excellent control in the Pleistocene to topmost upper Miocene, where each of the nannofossil zones of Martini (1971) can usually be picked. In the Miocene, however, their distribution is strongly controlled by facies, and care must be used in their application. Within the Miocene, quantitative analysis allows many of the problems associated with facies controls to be resolved. A good example is shown here by the distribution of *Sphenolithus heteromorphus* in the middle Miocene; the highest occurrence is strongly facies controlled (Fig. 13), but an acme, occurring at about 15 Ma, can be easily recognised using quantitative data. The main nannofossil events are listed below:

Zonal markers occurring within the Pilong Formation

Top *Sphenolithus abies* or *Reticulofenestra pseudoumbilica*, reflecting top NN15: 3.5 Ma.

Top *Amaurolithus primus* or *A. tricorniculatus*, reflecting top NN14; 3.8 Ma.

Top *Ceratolithus acutus,* reflecting top NN12; 4.5 Ma.

Top *Discoaster quinqueramus* and *D. berggrenii*, reflecting top NN11; 5.0 Ma.

Zonal markers within seismic group 'F'

Top *Sphenolithus heteromorphus,* approximately reflecting top NN5, and TR 12.1 foraminiferal acme; 13.5 Ma; occurrence irregular.

Zonal markers within seismic group 'H'

The quantitative acme *of Sphenolithus heteromorphus,* marks the TR 11.2 foraminiferal acme, and reflects the marine flooding surface at about 15 Ma; regular occurrence. Top *Helicosphaera ampliaperta,* occurring within the TR 11.1 foraminiferal acme, reflects a marine flooding surface at the top of zone NN4: 16 Ma; irregular occurrence.

Zonal markers within seismic group 'I'

Top *Sphenolithus belemnos,* reflecting the TR 9.1 flooding surface below top NN3; irregular occurrence.

Zonal markers within seismic group 'J'/'K'

Top *Cyclicargolithus abisectus*, reflects flooding surfaces within or below the lower part of zone NN2 (e.g. TR 7.1); irregular occurrence.

BIOSTRATIGRAPHIC CHARACTERISATION OF SEISMIC GROUPS

In this section, foraminiferal, nannofossil and palynological events are reviewed in relation to the positions of seismic groups of EPMI.

SEISMIC GROUPS M AND L

Seismic groups M and L (Figs. 9, 10) each consists of a thick shale package, overlying sands. The shale unit at the top of Unit M, (Ledang Shale) is characterised by abundant (over 90%) and diverse *Bosedinia* spp., reflecting the presence of widespread freshwater lacustrine conditions at the end of seismic group M, and which define palynological zone PR2 (Fig. 7). The assemblages seen here are similar to those of palynological zone K4D, seen in the Keras Formation of Natuna Sea, which is considered to be of Upper Oligocene age (Morley, 1990). The deepest part of seismic group M, seen in Well J, contains reduced frequencies of *Bosedinia* spp., and common *Striatricolpites catatumbus*, and define zone PR1. The assemblage is comparable to zone K4C of Morley (1990), within the top of the Lower Gabus Formation.

Seismic group L consists of an upper shale unit (Seligi Shale), which also overlies sands. The Seligi Shale is characterised by about 30% *Bosedinia* spp. indicating zone PR4 (Fig. 8a). This assemblage is similar to that seen in the lower part of the Barat Shale in the Natuna Sea. The assemblage seen within lower part of seismic group L, ('L' Sands) is characterised by common *Magnastriatites howardi*, *Acrostichum* spores and gymnosperm pollen, defining zone PR3. Zones PR3 and 4 compare to zone K5 of the Natuna Sea scheme (Morley, 1990). The Seligi Shale (and the immediately underlying sands) contain the first marine influence in the Malay Basin, as indicated by the presence of miliamminid foraminifera. In common with the Natuna Sea (e.g. Ginger *et al.*, 1993), it is thought that the first marine influence in this area coincides with the base of the Miocene. The base Seligi Shale represents the basal lower Miocene transgressive surface.

SEISMIC GROUP K

Seismic group K (Fig. 11) is very poor in nannofossils, but yields a consistent recovery of arenaceous foraminifera within the southeast part of the basin. Group K is characterised in particular by the common occurrence of the palynomorphs *Monoporites annulatus, Striatricolpites catatumbus* and *Shorea* type pollen indicating zones PR6/7. The lower part, with common *Magnastriatites howardi,* is referred to zone PR5. These pollen types suggest that the climate for K was drier, and possibly seasonal, compared to the overlying sequence. This pattern is very similar to that seen in the upper part of the Barat Shale in the Natuna Basin. Taking into account palynological and foraminiferal data, it is suggested that the Seligi Shale, and the whole of seismic group K is equivalent to the Barat Shale in Natuna.

SEISMIC GROUPS J, I AND LOWER H

Seismic groups I and J (Fig. 12) are characterised by packages of coals and mudstones with sands, interbedded with mudstones which contain shallow water foraminifera. One prominent foraminiferal pulse, the TR 9.1 foraminiferal acme zone, occurs within seismic group I. These seismic groups also coincide with some major changes in the palynomorph genus *Florschuetzia*, and these provide good age control.

The base of J is characterised by common *Florschuetzia trilobata* group, and abundant *Zonocostites ramonae,* marking the base of zone PR8. This is followed by an expansion of *Pandaniidites* spp., marking the base of PR9A, and the base of seismic group I. The *Florschuetzia trilobata* group remain common within the lower part of I, but show a sudden reduction at the base of PR9B, within mid I. This boundary also marks the top of the TR-9.1 foraminiferal acme zone. Zone PR9B comprises an interval with overall low frequencies of *Florschuetzia,* but with a high diversity of types within *the F. trilobata* group.

The base of zone PR10, characterised by the incoming of regular *F. levipoli* and common *Myrtaceidites spp.,* occurs just within the top of group I, in the basin depocentre, or coincides with the top of I at the basin margins. This may indicate an unconformity associated with top I in basin margin areas, but this is not yet firmly established.

The base of zone PR11, marked by the consistent appearance of *Florschuetzia meridionalis*, occurs within the middle of group H, but below the TR 11.1 foraminiferal acme zone.

A model illustrating stratigraphic events within this interval is presented in Figure 12.

SEISMIC GROUPS UPPER H AND F

Seismic Group H (Figs. 13–15) consists of two upward coarsening, prograding lithological packages, capped with a distinctive marine mudstone. The upper mudstone is characterised by open marine foraminiferal assemblages, dominated by *Ammonia* spp. and *Cassigerinella* *chipolensis*. Provided adjustments are made to seismic picks in two wells, this transgressive unit parallels the top of seismic group H. The mudstone unit also contains the nannofossil index species *Sphenolithus heteromorphus*, the top occurrence of which is taken to mark nannofossil zone NN5. The top of this species sometimes occurs within this mudstone, and sometimes above it (Figs. 13, 14), and so at first glance, nannofossil data might be interpreted to suggest that top H is diachronous. Quantitative examination of the representation of *S. heteromorphus,* however, reveals a clear acme of this species within the top H marine shale, and this event is thought to reflect a major marine flooding surface (maximum flooding surface), and hence is, with most probability, a time-synchronous datum. This illustration clearly indicates that the top occurrence of *S. heteromorphus* is diachronous, although this is the event which would be most regularly brought to attention by biostratigraphers.

Top H also coincides with the quantitative top of *Florschuetzia trilobata,* marking the PR11/12 boundary. The conclusion reached is that, provided a couple of seismic picks in basin margin wells can be readjusted, top H is also a time-stratigraphic datum.

Within the southern end of the basin, there is another marine transgression within H, at the base of the upper progradational unit. This unit is characterised by open marine foraminifera, reflecting TR 11.1 and in some sections, by the presence of the nannofossil marker species *Helicosphaera ampliaperta*, marking the top of nannofossil zone NN4. This event is taken to reflect a further marine flooding surface.

Seismic group F can generally be divided into three lithological packages, a lower, predominantly mudstone unit, overlain by an interval with mudstones and upward coarsening sands, with a further mudstone unit at the top. The base of the sand-bearing unit contains common benthonic foraminifera, reflecting a further flooding horizon (TR 12.1). With adjustments to seismic picks in one well, there is a clear integrity of events within seismic group F which again suggests that the group is a time-synchronous lithological package.

The stratigraphic model for Groups F and H is presented in Figure 15.

SEISMIC GROUPS E AND D

Seismic group E (Figs. 16, 17) comprises a thick package of paralic sediments, overlain by marine mudstones. The paralic sediments are thickly developed toward the north west of the basin, but poorly represented to the south east. The marine mudstones are characterised by a distinct foraminiferal assemblage containing the deep water arenaceous foraminifer *Vulvulina pennatula* (the TR 14.1 foraminiferal acme zone). This zone

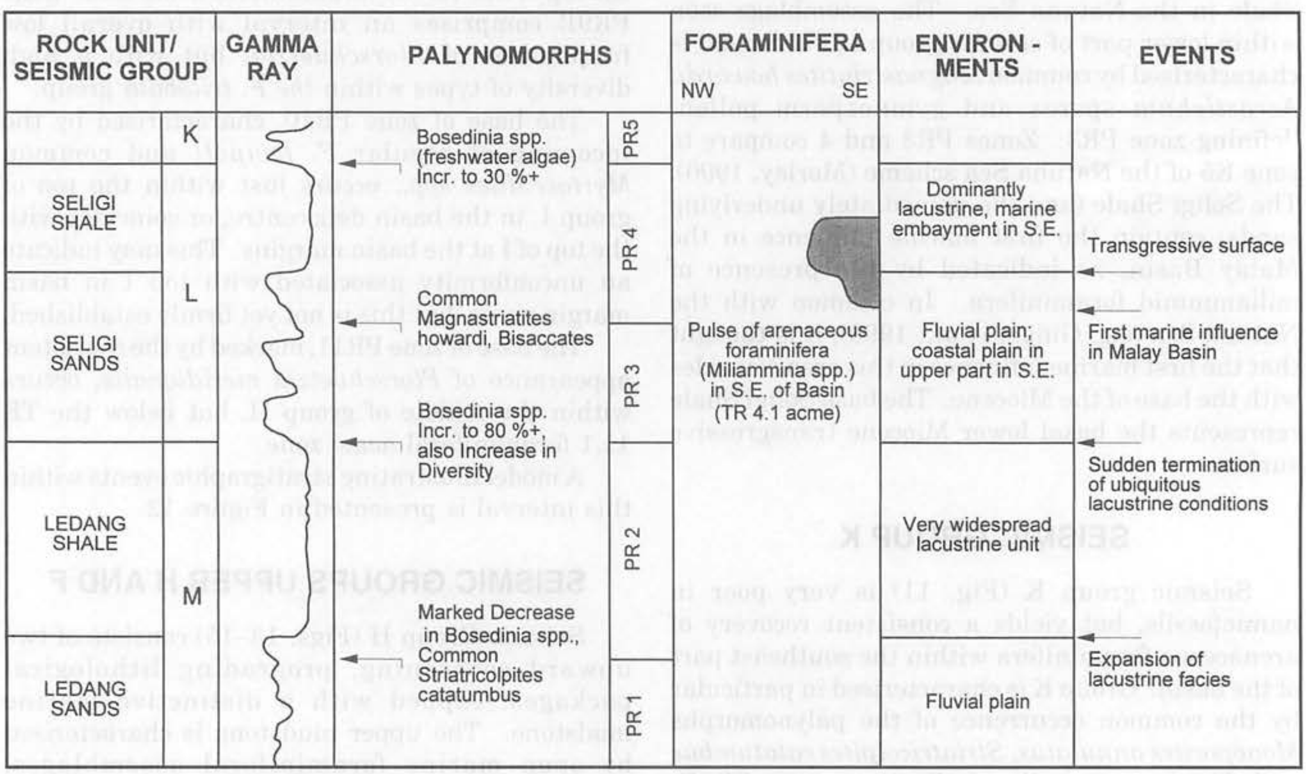

Figure 9. Biostratigraphic event framework for seismic groups L and M.

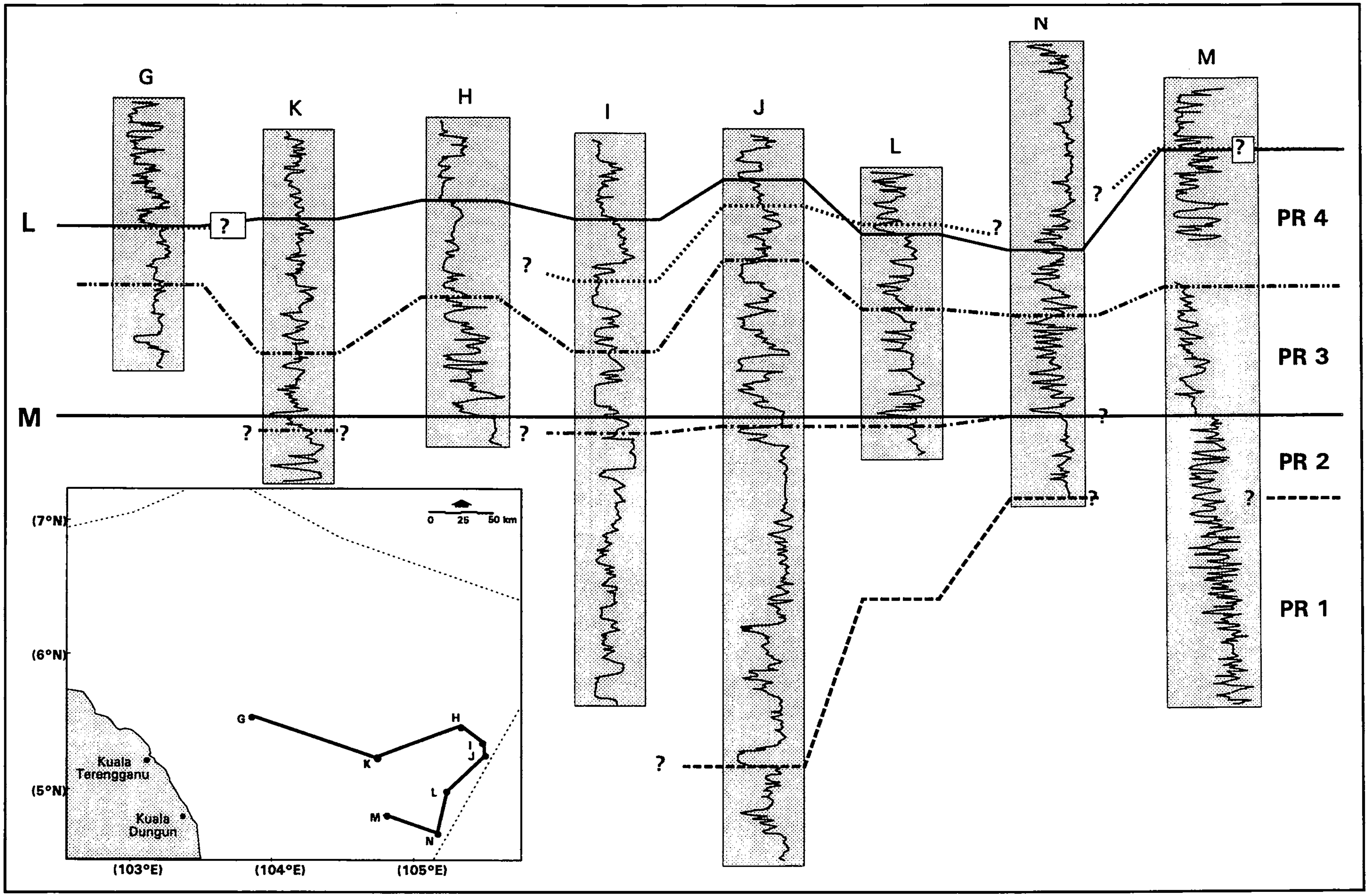

Figure 10. Relationship between seismic groups L and M and palynological zones PR1-4. Note that zones PR3 and 4 are depressed in Well I due to poor quality data in that well.

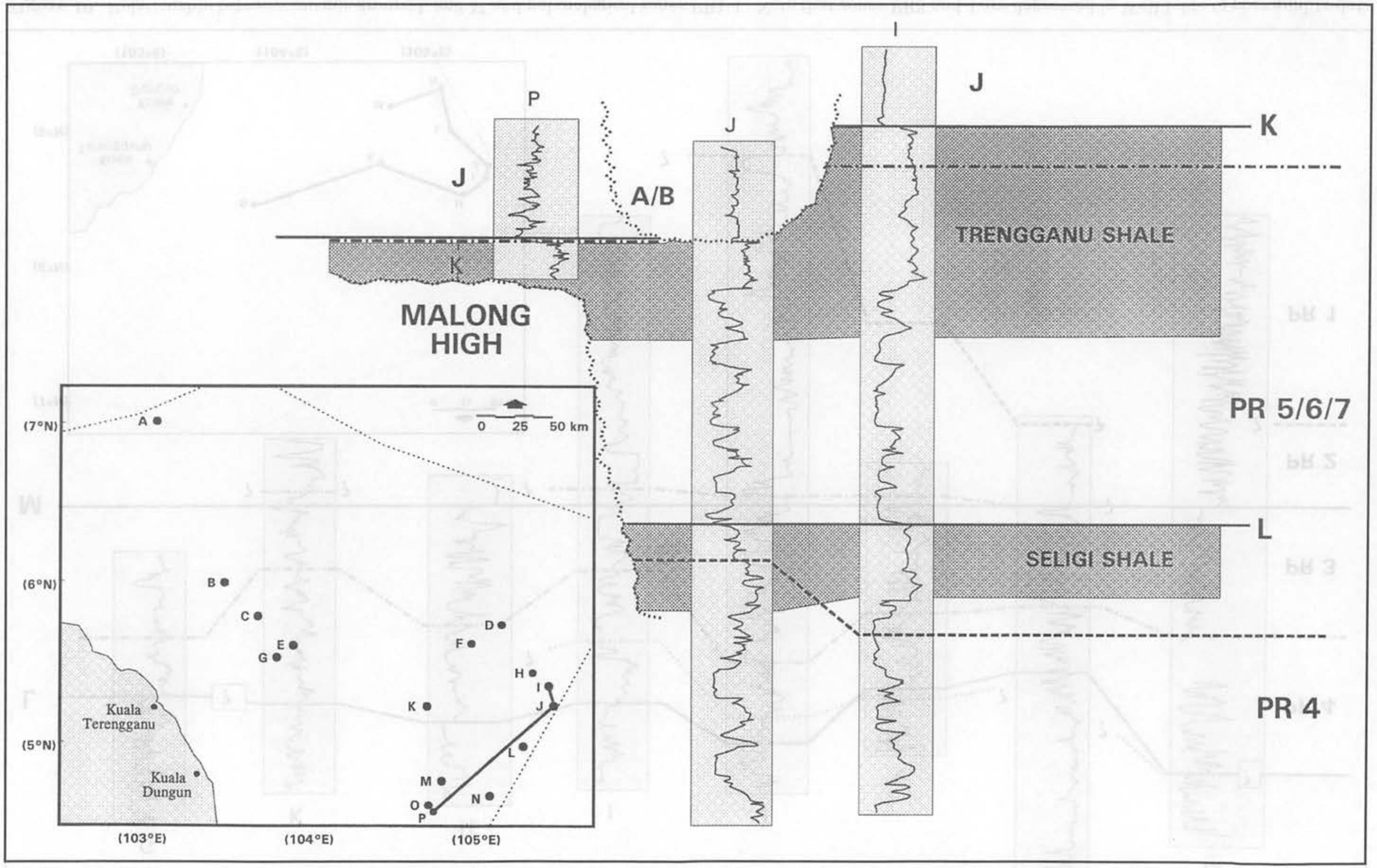

Figure 11. Relationship between seismic groups K and L and palynological zones PR4-7.

parallels the top of seismic group E, provided that top E is repositioned in one well. No age diagnostic nannofossils have so far been found within this transgressive unit.

Palynological data from this unit is available for just three wells; a marked reduction in abundance of *Casuarina* pollen near the base of the *Vulvulina* event within each of these wells provides support for considering this feature as a time-synchronous event. The reduction in abundance of *Casuarina* pollen defines the zone PR13/PR14 boundary.

Since the *Vulvulina* zone is characterised by mudstone lithologies in all sections studied, it is thought to represent a marine flooding surface; the reduction of *Casuarina* pollen near the base of the zone is thought to reflect the retreat of coastal vegetation with the transgression. The coincidence with zone PR13/14 boundary, and parallelism with most seismic marker E picks strongly suggests that the top E seismic marker is a time-synchronous datum, although in some wells, it may be mispicked.

Seismic group D is variously represented across the Malay Basin, its thickness being controlled by the degree of erosion associated with the upper Miocene unconformity, which marks the base of seismic group B. Where this unit is thin, it is characterised by low diversity calcareous benthonic foraminifera, and agglutinated forms. When it is thicker, the upper part is typically characterised by deeper water faunas with more diverse assemblages dominated by calcareous benthonics, within which *Asterorotalia* spp. and *Pseudorotalia* spp are dominant.

The upper, rotalid-dominated unit reflects a broad marine transgression across the basin (TR14.2 foraminiferal acme zone), which has subsequently been largely removed by erosion. Unfortunately, no nannofossils have been found within this unit with which this event can be more accurately dated.

The proposed stratigraphic model for seismic group D and E is presented in Figures 16 and 17.

ESTIMATION OF AGE OF BIOSTRATIGRAPHIC AND SEISMIC GROUP BOUNDARIES

The chronostratigraphic framework for the Malay Basin is based on the following datums, which can be tied to absolute dates. The absolute dates of nannofossil events based on the zonation of

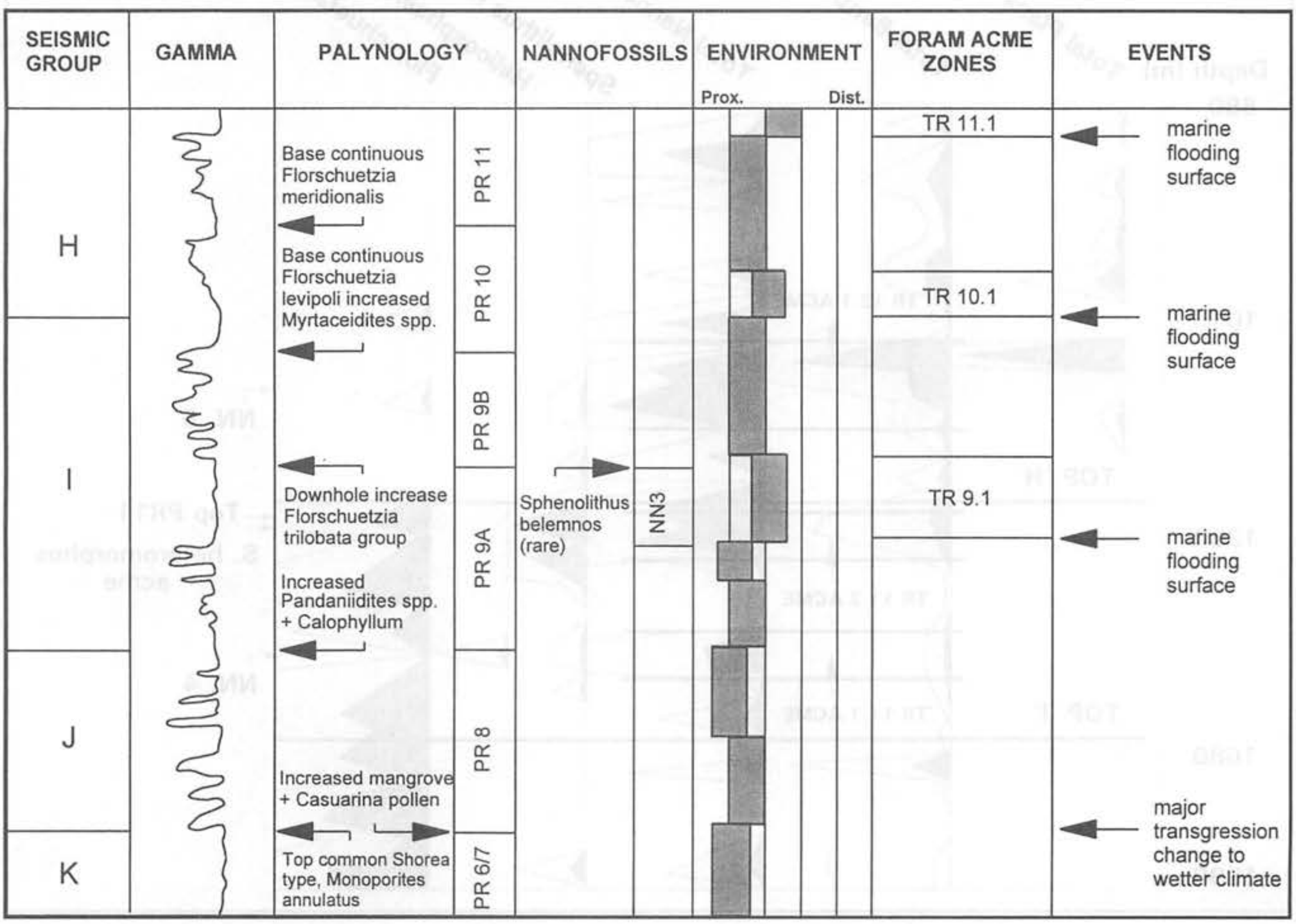

Figure 12. Biostratigraphic framework for seismic groups J and I.

Martini (1971) refer to the scheme of Haq *et al.* (1988), whereas chronostratigraphic interpretations for other datums are explained individually. The important datums, and their representative well sections, are as follows:

Top *Sphenolithus abies* or *Reticulofenestra pseudoumbilica*, reflecting top NN15: 3.5 Ma (seen in Well K).

Top *Amaurolithus primus* or *A. tricorniculatus*, reflecting top NN14: 3.8 Ma (seen in Well K).

Top *Ceratolithus acutus*, reflecting top NN12: 4.5 Ma (seen in Well D).

Top *Dicoaster quinqueramus*, reflecting top NN11: 5.0 Ma (seen in Well D).

Base *Stenochlaenidites papuanus*, marking base of palynological zone PR14, and occurring within upper 'E', first appearance occurring within planktonic foraminiferal zone N15, at about 9 Ma (Rahardjo *et al.*, 1994; Morley, unpublished) (seen in Wells O, P and D).

Top *Sphenolithus heteromorphus*, reflecting top NN5, and TR12.1 foraminiferal acme zone, 13.5 Ma (seen in Wells D and K).

Quantitative acme *Sphenolithus heteromorphus*, marking TR 11.2 foraminiferal acme zone, reflecting marine flooding surface at about 15 Ma (seen in Wells A, D, M and N).

Top *Helicosphaera ampliaperta*, occurring within TR11.1 foraminiferal acme zone, reflecting marine flooding surface at the top of zone NN4, at 16 Ma (seen in Well D).

Palynological zone PR9B/PR10 boundary, based on the position at which *Florschuetzia levipoli* becomes dominant over *F. trilobata*, marking a datum corresponding to approximately to top I, at about 17.1 Ma; age determined by reference to well dated sections in Sarawak and Mahakam Delta (seen in Wells K, O and D).

Palynological zone PR7/PR8 boundary, marking transgressive surface at 20.9 Ma, by reference to

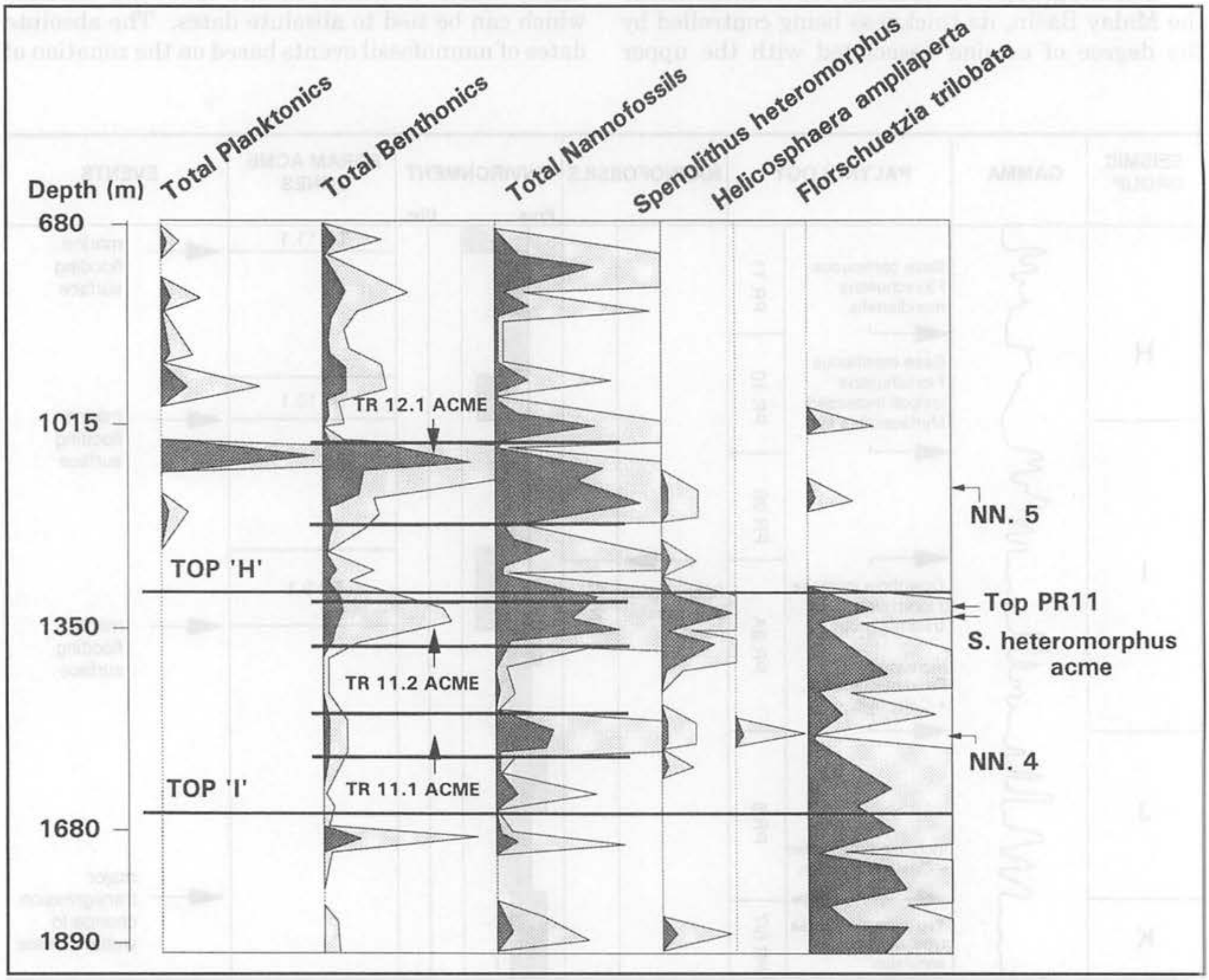

Figure 13. Foraminiferal, nannofossil and palynological events characterising top H seismic group, example from Well D.

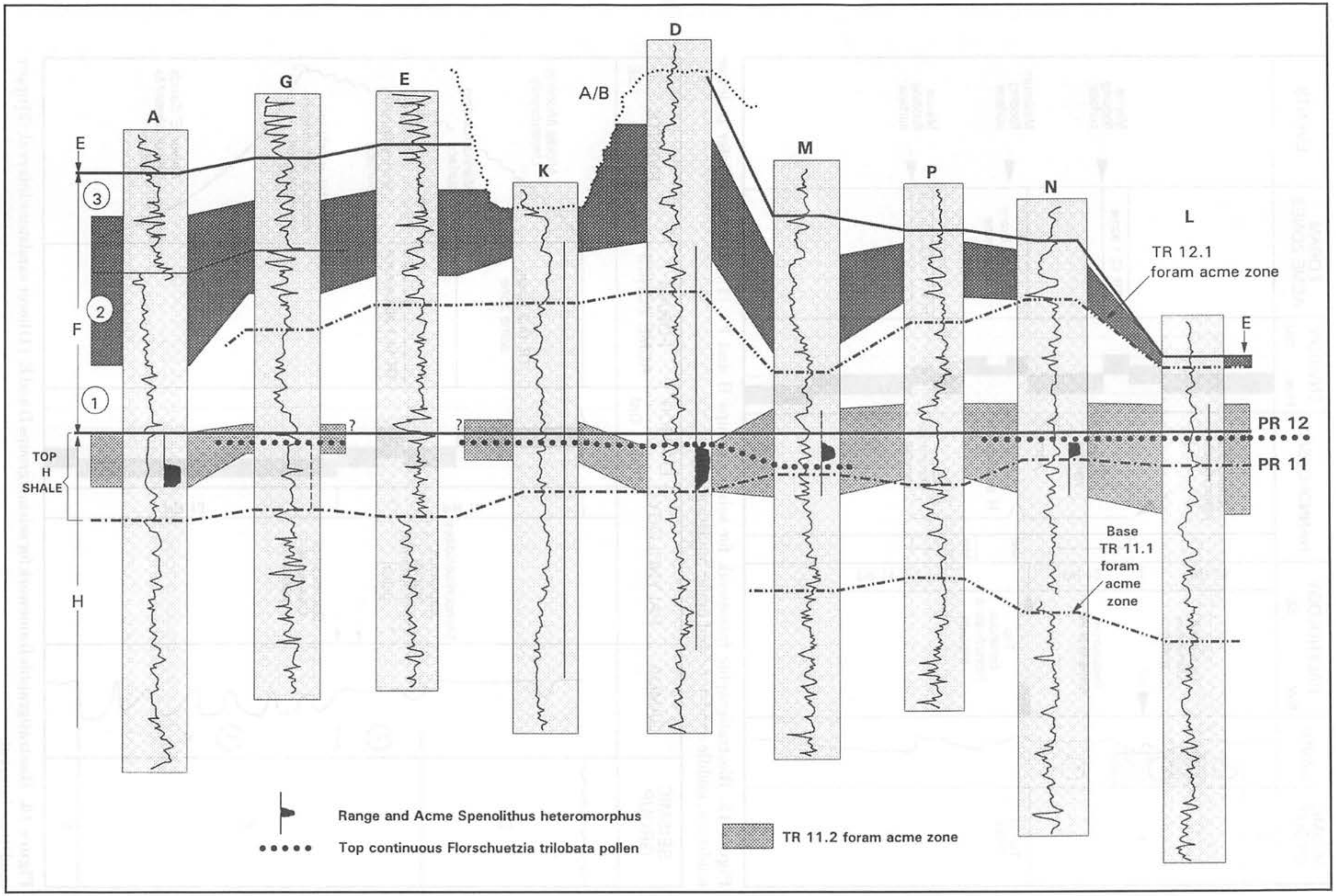

Figure 14. Relationship between seismic groups H and F, and biostratigraphic events in the studied well sections. (1), (2) and (3) refer to lower mudstone, middle sandstone and upper mudstone units.

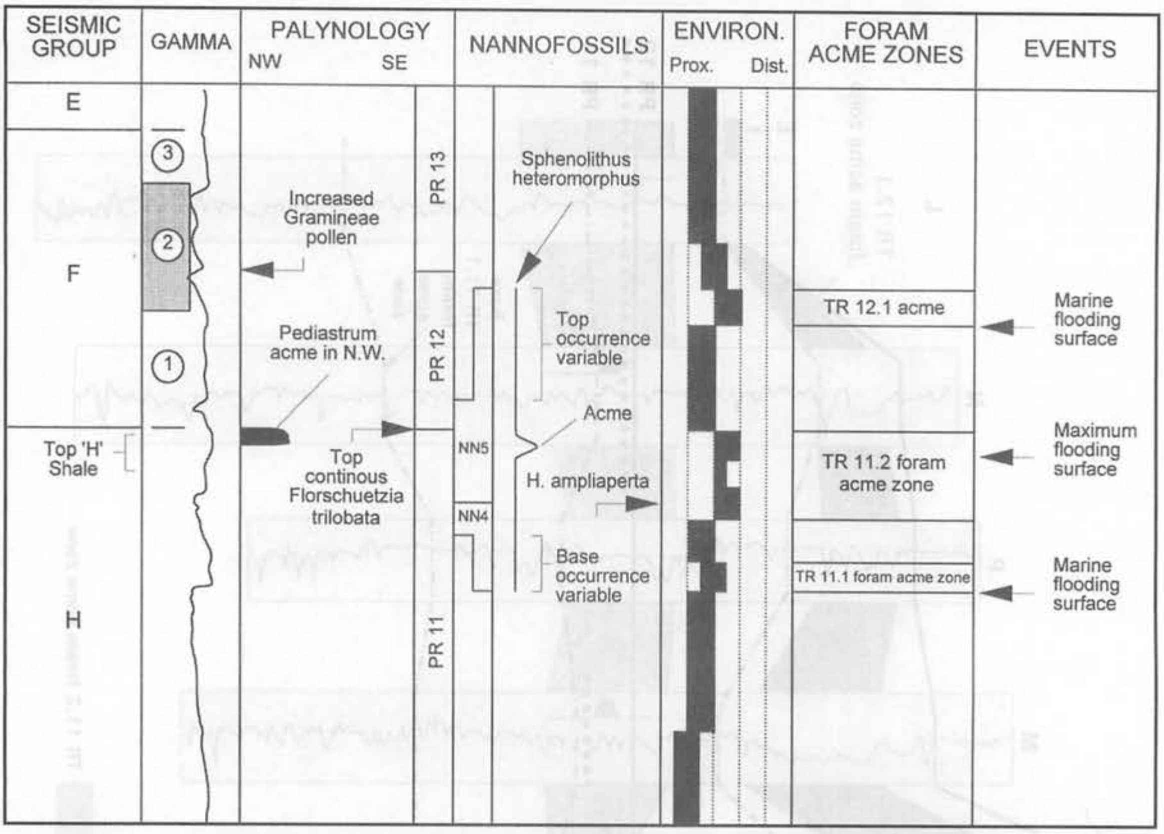

Figure 15. Biostratigraphic framework for seismic groups H and F. (1), (2) and (3) refer to lower mudstone, middle sandstone and upper mudstone units.

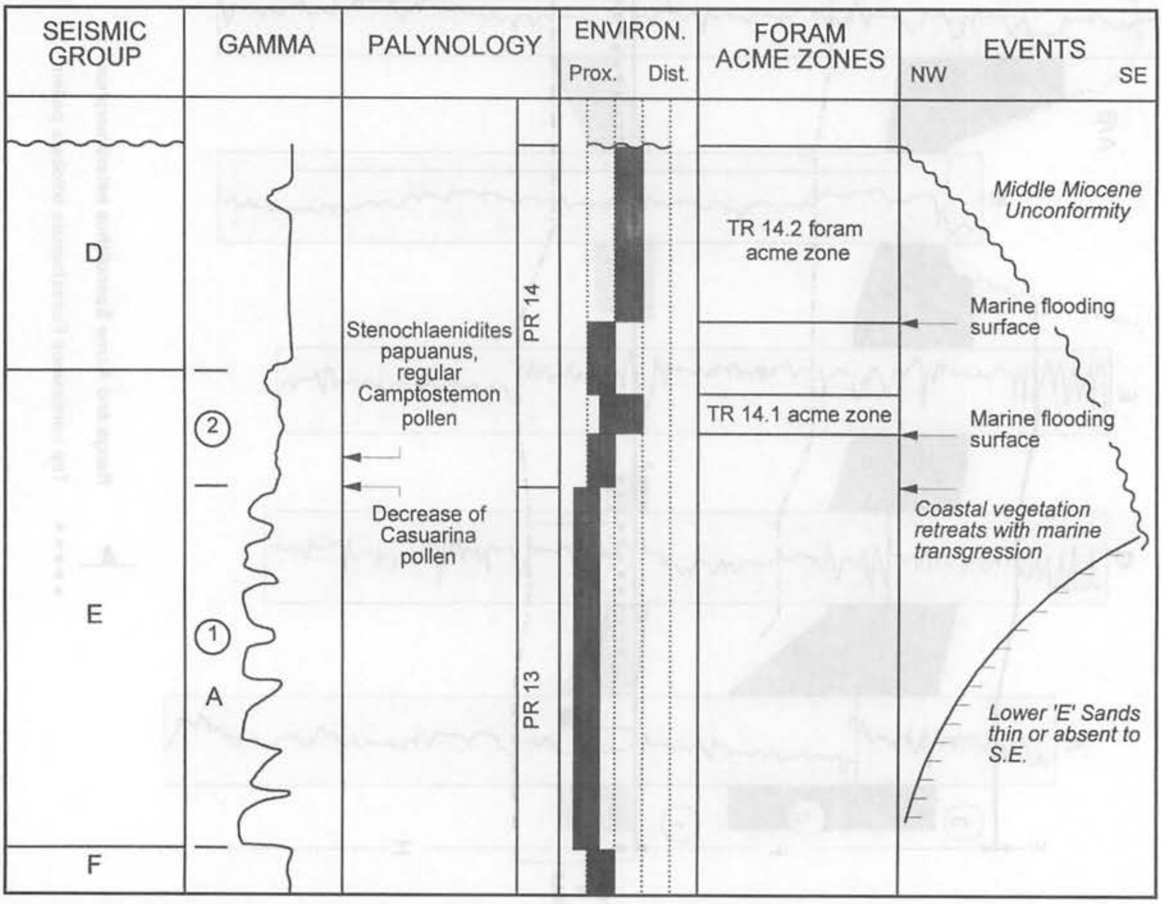

Figure 16. Biostratigraphic framework for seismic groups D and E. (1) lower sandstone interval; (2) upper mudstone interval.

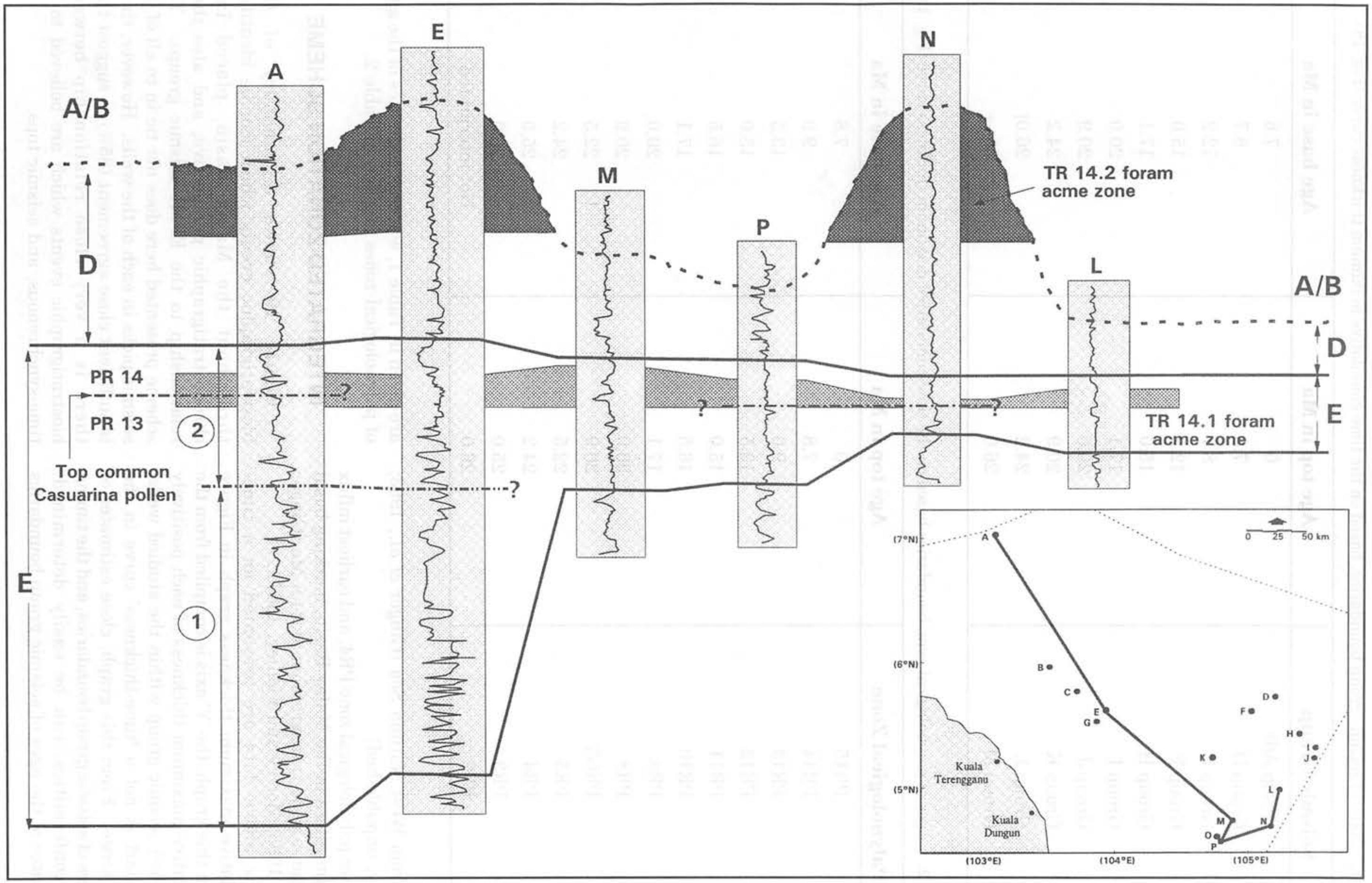

Figure 17. Relationship between seismic groups D and E, and biostratigraphic events in the studied well sections.

Table 1. Ages of seismic group boundaries, based on the time-cumulative maximum thickness curve (Fig. 18).

Seismic Group	Age top in Ma	Age base in Ma
Group A/B	0	7.8
Group D	7.8	8.7
Group E	8.7	12.2
Group F	12.2	15.0
Group H	15.0	17.1
Group I	17.1	20.0
Group J	20.0	20.9
Group K	20.9	24.2
Group L	24.2	26.0]
Group M	26.0	30++

Table 2. Ages of palynological zone boundaries based on the time-cumulative maximum thickness curve (Fig. 18).

Palynological Zone	Age top in Ma	Age base in Ma
PR15	0	7.8
PR14	7.8	9.0
PR13	9.0	13.5
PR12	13.5	15.0
PR11	15.0	16.5
PR10	16.5	17.1
PR9	17.1	20.0
PR8	20.0	20.9
PR6/7	20.9	22.5
PR5	22.5	24.2
PR4	24.2	25.0
PR3	25.0	26.0
PR2	26.0	Not interpreted

data from West Natuna Sea (Ginger *et al.*, 1993; Morley, unpublished)

Base palynological zone PR4, and earliest influx of foraminifera in the Malay Basin, marking basal Miocene marine transgression at 24.8 Ma (Ginger *et al.*, 1993; Morley and Flenley, 1987) .

The above data are presented on a time-cumulative maximum thickness graph in Figure 18. On this graph, the 'Y' axis is compiled from the cumulative maximum thickness of each positively identified seismic group within the studied wells. The chart is not a 'time-thickness' curve in the usual sense. From this graph, close estimates of the ages of seismic group boundaries, and the timing of unconformities, can be easily determined. Estimates of the ages of seismic group boundaries are given in Table 1, whereas estimates of the ages of palynological zones is given in Table 2.

INTEGRATED ZONATION SCHEME

Figure 19 shows a summary of the biostratigraphic events which can be identified throughout the Malay Basin, placed into chronostratigraphic perspective, and also their relationship to the EPMI seismic groups. The scheme presented here does not tie in to all of the seismic picks in each of the wells. However, there is sufficient close agreement (85%) to suggest that there is a very close relationship between biostratigraphic events which are believed to be time-synchronous, and seismic tops.

UNCONFORMITIES IN THE MALAY BASIN

The ages of two unconformities can be accurately identified using Figure 18 as follows:

Intra upper Miocene unconformity, at ca 7.8 Ma. This unconformity, often mis-named the 'Middle Miocene unconformity', can confidently be placed in the upper Miocene on the basis of this study. If termed the Middle Miocene unconformity, this unconformity, which reflects a basin inversion (Ginger *et al.*, 1993) may be confused with the 10.0–10.5 Ma unconformity which was caused as a result of a major fall in sea level (see below). It is proposed here that it should be termed the 'Upper Miocene Unconformity'.

Top Middle Miocene unconformity. This unconformity is thought to have formed as a result of a major sea level fall at the base of the Late Miocene, and has resulted in non-deposition during, or the removal of much of the sediments in seismic group 'E' from the eastern part of the basin. It is proposed that this should be termed the 'Middle Miocene unconformity. Both of these unconformities tie in closely with unconformities observed elsewhere in the Southeast Asian region.

Reference is often made to a further unconformity within seismic unit M, but data is insufficient within this project to ascertain the age, or stratigraphic position, of this break. Several minor unconformities, relating to sequence boundaries, can be observed, but are difficult to follow across the region using biostratigraphic and well data.

CONCLUSIONS

This study demonstrates that a detailed biostratigraphic zonation can be constructed for the paralic Malay Basin despite the rarity of age-diagnostic microfossils. The zonation scheme is based on a framework of palynological assemblage zones. Marine flooding surfaces can be distinguished on the basis of foraminiferal acmes, which in turn can be calibrated by reference to the scheme of palynomorph assemblage zones. Nannofossils occur only in the more distal facies of the marine flooding events, but when found, permit

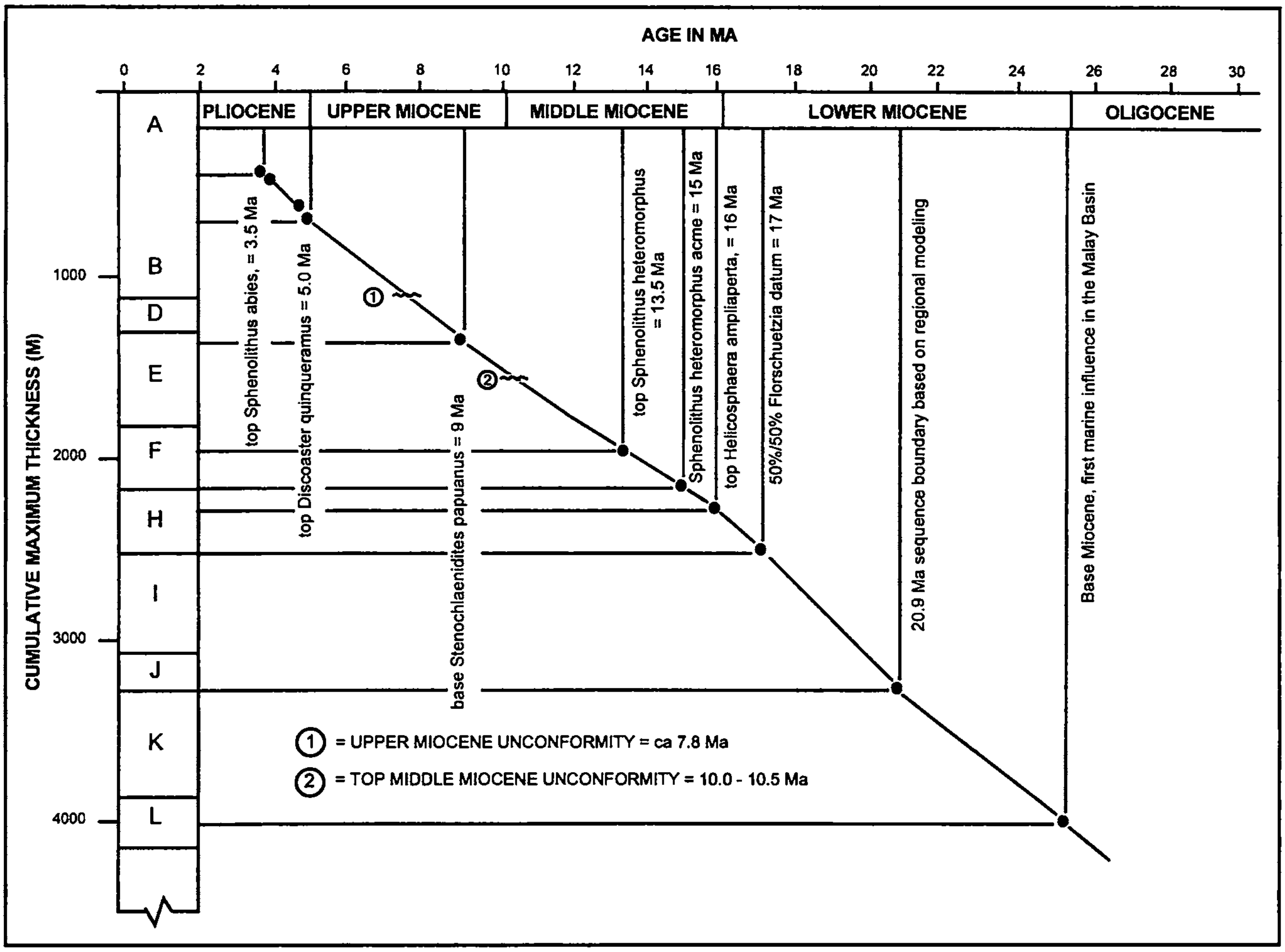

Figure 18. Time-cumulative maximum thickness curve for the Malay Basin.

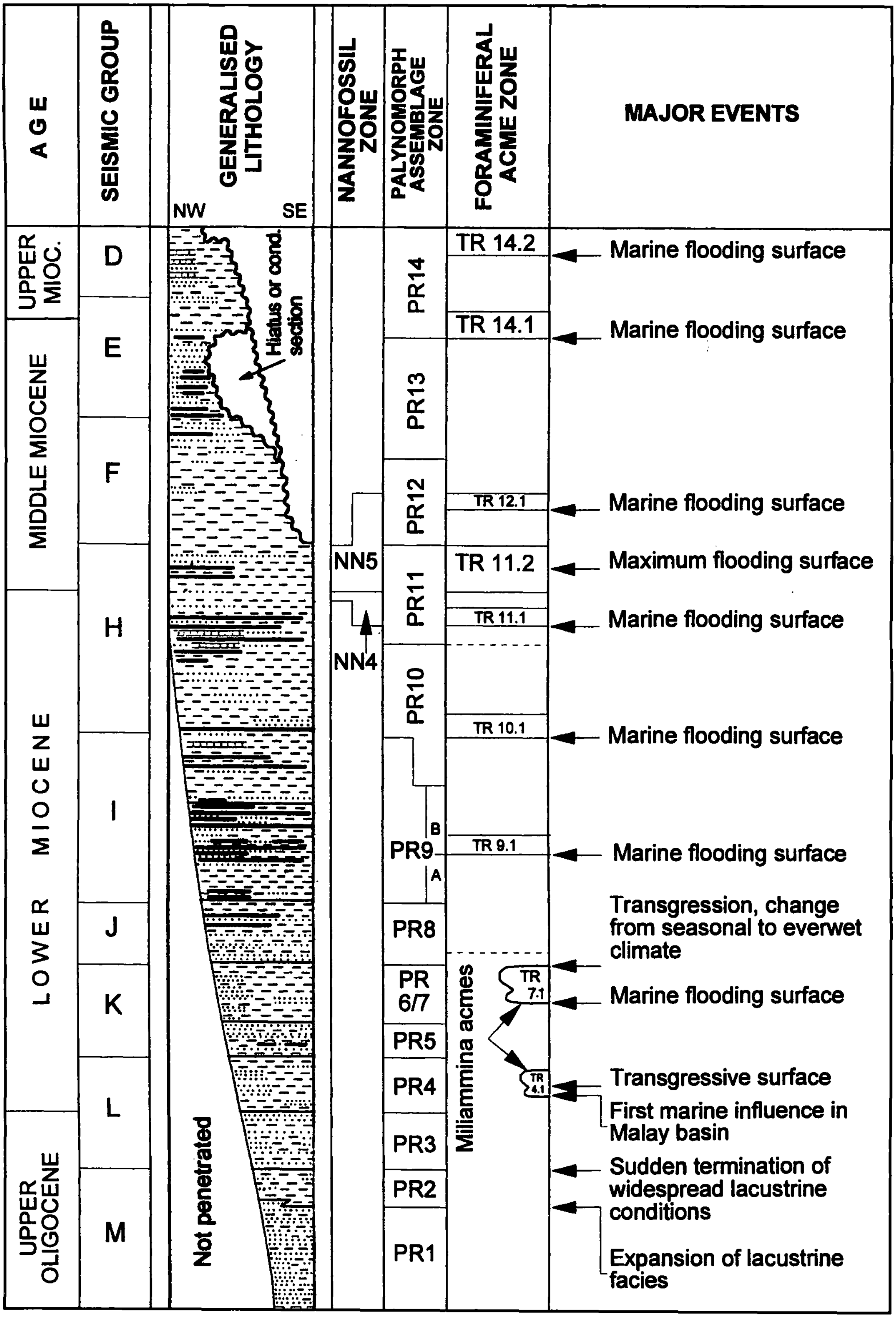

Figure 19. Integrated biostratigraphic zonation scheme for Malay Basin.

the transgressive pulses to be dated by reference to the nannofossil zonation scheme of Martini (1971), and in turn, allow the ages of many of the palynological assemblage zones to be placed into an absolute time framework.

Comparison of the biostratigraphic zones which have been determined for the 16 wells and which formed the database for this study demonstrate that the EPMI seismic group boundaries invariably represent time-stratigraphic datums, but that in a few instances where there was a clear discrepancy with biostratigraphic events, it is believed that alternative interpretations of seismic data is possible.

Biostratigraphic modelling of each seismic group indicates that each has a clear biostratigraphic response, and that if seismic and biostratigraphic studies were undertaken hand in hand, the resulting interpretations of seismic group boundaries could be undertaken to a much higher degree of confidence than is possible using seismic data alone.

Through consideration of maximum accumulation rates within the wells studied, absolute ages have been applied to the biostratigraphic and seismic boundaries. It is suggested that the oldest sediments so far drilled in the Malay Basin are upper Oligocene in age, and that the Oligocene/lower Miocene boundary coincides with the base of the Seligi Shale, within the mid part of seismic group L. This coincides with the first significant marine transgression in the Malay Basin, coinciding with the base Miocene in the adjacent Natuna Basins, where a more precise position for the boundary can be suggested from marine microfossils. The lower/middle Miocene boundary occurs within the upper part of seismic group H; independent dating for this event is obtained by reference to nannofossils, whereas the top of seismic group D, coinciding to a regional tectonic unconformity, is dated at about 7.8 Ma, in the upper Miocene. A second widespread unconformity within the lower part of seismic group E is dated at about 10.0–10.5 Ma, and is thought to relate to a period of erosion following a major fall in sea level.

ACKNOWLEDGMENTS

The authors wish to thank the management of PETRONAS for their permission to publish this paper. Many individuals at PRSS have contributed to this study.

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Manuscript received 13 February 1996

APPENDIX

Names attributed to palynomorphs used in the zonation scheme

Form Taxon	Extant Taxon Name	Also Characteristic of following extant taxa
Bosedinia granulata		
Bosedinia infragranulata		
Bosedinia kuantanensis		
Bosedinia whelkaris		
Dacrycarpidites australiensis	*Podocarpus imbricatus* (Podocarp)	
Discoidites novaguineensis	*Brownlowia* type (Tiliaceae)	Pentace, Jarandersonia
Florschuetzia levipoli	*Sonneratia caseolaris* (Sonnerat.)	
Florschuetzia meridionalis	*Sonneratia alba* (Sonneratiaceae)	
Florschuetzia semilobata	*Sonneratiaceae*	
Florschuetzia trilobata	*Sonneratiaceae / Lythraceae*	
Granodiscus staplinii		
Lygistepollenites florinii	*Dacrydium* (Podocarpaceae)	
Magnastriatites howardi	*Ceratopteris thalictroides* (Adiant.)	
Meyeripollis naharkotensis		
Monoporites annulatus	*Gramineae*	
Myrtaceidites spp.	*Myrtaceae*	
Pandaniidites spp.	*Pandanus* (Pandanaceae)	
Phyllocladites palaeogenicus	*Phyllocladus* (Podocarpaceae)	
Stenochlaenidites papuanus	*Stenochlaena milnei* type (Blech.)	Stenochlaena *cumingii*
Striatricolpites catatumbus	*Crudia* (Caesalpiniaceae)	
Zonocostites ramonae	*Rhizophora* type (Rhizophoraceae)	Bruguiera, Ceriops, Kandelia
	Acrostichum (Pteridaceae)	
	Casuarina (Casuarinaceae)	
	Calophyllum (Guttifereae)	
	Camptostemon (Bombacaceae)	
	Lycopodium cernuum (Lycopod.)	
	Shorea type (Dipterocarpaceae)	Hopea