Calcareous Nannoplankton and Planktonic Foraminifera from the Neogene Offshore Northwest Borneo

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Abstract

The sediments penetrated by hydrocarbon wells offshore NW Borneo consist mainly of Neogene clastics. Sedimentation rates are very high, resulting in a demand for high-resolution stratigraphy. As a result of often unfavorable environments and poor preservation, age diagnostic planktonic foraminifera and calcareous nannofossils are rare or absent in many wells. Although deepwater deposits are relatively rich in planktonics, compared to other areas the yield and preservation are poor.

This paper describes the sequence of events (first and last occurrences) commonly encountered offshore NW Borneo, with indications of the reliability of the observed events.

Introduction

The study area is situated offshore NW Borneo in the southeastern part of the South China Sea (Figure 1). Subduction of the South China Sea under Borneo during the Early Tertiary formed a broad deformation zone, the Rajang - Crocker belt, which acted as the main sediment source for the Tertiary deltas along the NW Borneo Margin. Sedimentation rates were very high, resulting in rapid progradation, overpressured clays and the formation of clay diapirs and growth faults. Reliable high-resolution stratigraphy is needed to correlate from shelf to slope deposits and across faults, discontinuities and poor seismic data zones. The major oil and gas fields produce from top sets in coastal plain to inner neritic settings. Deeper wells and wells situated further offshore penetrate more open marine deposits.

Accurate and reliable age determinations rely on an integration of all available biostratigraphical tools (nannoplankton, foraminifera and palynology) with palaeoenvironmental data, lithological data, logs and seismic, to arrive at a sequence stratigraphic interpretation. A high biostratigraphical resolution can frequently be achieved by detailed examination of the planktonic foraminifera and by closely spaced analyses for foraminifera and nannoplankton. The potential and limitations of the nannofossils and planktonic foraminifera are discussed below. Observations are based on interpretation of analyses carried out over the last 20 years by several people within Shell and by contractors, and partly on observations and re-examinations by the author.

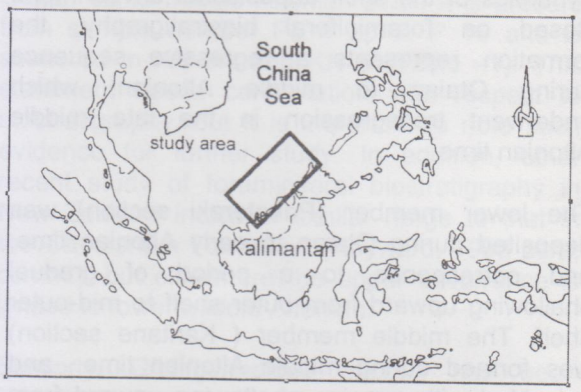


Figure 1: Location map of the study area

Calcareous Nannoplankton

The application of calcareous nannoplankton for age determinations has become increasingly popular worldwide since the first comprehensive Tertiary zonation was published (Martini, 1971). Initial attempts at nannoplankton analysis by Shell on material from offshore Borneo in the 1970's were very discouraging. Most samples that were tested proved barren of nannofossils, and the experiment was abandoned. Later efforts concentrated on experiments with preparation techniques, which showed that considerable improvements in nannofossil yield could be achieved by applying concentration methods such as centrifuging. Such analyses are now routinely carried out for all wells for which stratigraphical studies are carried out. Results are generally poor due to the organic-rich nature of the sediments, which causes dissolution of the nannofossils. Yields tend to get lower downhole, and particularly when old samples are analyzed, decalcification of large intervals is obvious. It is clear that dissolution

takes place partly during diagenesis but to a large extent also during sample storage, as fresh samples show far better results. Hence, the sooner the samples are prepared, the better the results.

As nannofossils are important age indicators, even very limited yield has resulted in considerable improvement in reliability of age determinations. Analysis results are sufficient for simple event-stratigraphy, but are of insufficient quality for application of quantitative morphometric stratigraphical criteria (Young, 1990; Cheng & Wang, 1997; Huang, 1997) due to dissolution effects. Where nannofossils are present, diversity is low and first and last occurrences of marker species are often unreliable. Careful recording of first and last occurrences in different wells with respect to clearly defined seismic horizons can show which events occur consistently around the same level, and which are totally unreliable. Although this checking and recording is an ongoing process, some events (first or last occurrences) were shown to be unreliable, while others appear more consistent, at least in a small area (see Table 1 for details). Apart from low numbers, an additional cause for the inconsistent occurrences appears to be the species concept, as some species that are notoriously difficult to distinguish consistently, proved to be the most unreliable. The analyses were carried out by different persons and different analysts may have different species concepts.

Even if events occur fairly consistently at the same level, correlation to the absolute timescale is at times problematical. Literature gives many different ages for useful bio-events, partly because some events are diachronous and partly because different time scales have been used (e.g. Thierstein, Geitzenauer, et al., 1977; Hills & Thierstein, 1989; Spencer-Cervato et al., 1994; Berggren et al., 1995a,b). Correlation to the timescale is to some extent possible by recording the position of the event with relation to the global sequence and systems tracts. Working from the hypothesis that the global sea-level curve can be recognized in the systems tracts, and that the age of the sequence boundaries is global, the approximate ages may be derived, at least in relation to the presumed ages of sequence boundaries and flooding surfaces (Figure 2).

Useful events, their sequence of occurrence, their relationship to the occurrence of other biostratigraphic events and their approximate relationship to the global sea-level curve and absolute timescale, are indicated in Figs. 2 and 3 and Table 1. For convenience, the events are related to the Martini (1971) zonation, as this is the most widely known and applied nannoplankton zonation. For estimates of absolute age of the events, several literature sources were referred to (e.g. Martini, 1971; Okada & Bukry, 1980; Perch-Nielsen, 1985; Hills & Thierstein, 1989; Wei, 1993; Spencer-Cervato et al., 1994; Young et al., 1994; Berggren et al. 1995a,b; Hine & Weaver, 1998; Young, 1998) as well as Shell proprietary data and published ages of planktonic foraminifera and eustatic sea-level movements. Only the important species are listed. Species that occur only occasionally or those of which the ranges are unknown, are excluded.

Planktonic Foraminifera

As for calcareous nannofossils, dissolution of planktonic foraminifera occurs frequently, seriously limiting their application in this region. Although seabottom samples may be extremely rich in well-preserved planktonic foraminifera, quantities rapidly diminish downhole. Numbers of planktonics recovered from samples are mostly too low to allow meaningful statistical analyses, interpretations of ratios or even consistent recording of coiling reversals or evolutionary changes. Moreover, many of the specimens found appear to be stunted, suggesting conditions were not always favorable for planktonics.

Because a full, detailed analysis is very time consuming, analysis of planktonic foraminifera is normally not carried out to the ultimately possible resolution. The standard Shell zonations (e.g. Postuma, 1971) used only a limited number of species as markers, as did the older published zonations (Blow, 1969; Stainforth et al., 1975). Consequently, routine analysis tends to be selective and many species that are not thought to have stratigraphical significance are often grouped together under the generic name (e.g. Globigerinoides spp.) or identified imprecisely. This is particularly true for groups that show a wide morphological variation and are therefore difficult to split up into individual species. Because many of the variations are now thought to have stratigraphical or palaeoclimatic significance (Bolli & Saunders, 1985; Kennett & Srinivasan, 1985; Sprovieri et al., 1996; Novaretti & Bicchi, 1996; Hilbrecht, 1997) a re-examination of the available planktonics has shown to yield a higher resolution stratigraphy.

Some examples of improvements or potential for improvements are:

Table 1: Biostratigraphic events with their estimated ages

The occurrences quoted are from intervals with common nannofossils / planktonic foraminifera. Over poorer intervals first or last occurrences may differ considerably. No events older than Late Miocene are reported, as insufficient observations are available for the older part of the timescale. (LAD = Last Appearance Datum; FAD = First Appearance Datum)

Event	Est. age (Ma)	Remark
LAD *Pseudoemiliania lacunosa*	0.44	A commonly used nannofossil that defines top NN19. Very rare towards the top of its range, this extinction event is usually depressed. It is often found below 1.3 Ma.
FAD *Helicosphaera inversa*	? 0.5	This nannofossil not commonly used as a marker. It has a reported range of 0.5 to 0.15 Ma, but is recorded by the contractor far below the published range. Consequently, species concept and range needs to be reviewed.
FAD *Globorotalia ungulata*	? 0.8	Foraminifer of the *G. menardii* group not commonly used as a marker or even identified. Has been observed several times but not consistently logged. Age only approximately known
FAD *Gephyrocapsa oceanica*	0.9	Traditional nannofossil marker for base NN19D, which is notoriously difficult to distinguish from closely related species. Recorded by contractor, but far below published range. Consequently, species concept needs to be reviewed.
LAD *Globorotalia tosaensis*	1	Traditionally the age of this event was published at about 1.6 Ma, but more recent publications give occurrences as young as 0.65 Ma (Berggren et al., 1995). Observations in the study area indicate that isolated specimens may occur up to 1 Ma, but regular occurrence has a LAD at 1.3 Ma.
LAD *Helicosphaera sellii*	1.2	The extinction of this nannofossil defines top NN19B. Rare towards the top of its range, if nannoplankton is common it is often found below 1.3 Ma.
LAD *Calcidiscus macintyrei*	1.5	Nannofossil that defines top NN19A. Very rare towards the top of its range, this extinction event is usually depressed and frequently occurs well below 2 Ma.
LAD *Ceratolithus rugosus*	1.6	Like most of the Ceratolithus group, this traditional nannofossil marker is extremely rare and of not much practical use.
FAD *Gephyrocapsa caribbeanica*	1.8	This nannofossil is poorly defined. Recorded by the contractor, but far below the published range. Consequently, the species concept needs to be reviewed before it can be considered a useful marker.
LAD *Discoaster*	1.95	This traditional nannofossil marker (D. brouweri) defines top NN18. Very rare towards the top of its range, this extinction event is often depressed.
FAD *Globorotalia truncatulinoides*	2	Commonly used foraminiferal marker, is known to be diachronous. Very rare in this area, usually absent but useful when present
LAD *Globigerinoides extremus*	2?	The age of the extinction of this foraminifer is uncertain, and is not consistent. The form is usually restricted to sediments older than 2.4 Ma, but it occasionally occurs higher. However, it does not appear to occur in sediments younger than 2.0 Ma.
LAD *Discoaster pentaradiatus*	2.4	The extinction of this characteristic nannofossil defines the top of Zone NN17, and often forms a reliable event. Depressed when assemblages are poor.
Globorotalia menardii event	2.5	The change in the coiling direction of *G. menardii* from dextral to sinistral (uphole). Even in widely spaced occurrences this change is easily recognised and it is therefore one of the most useful events.
LAD *Discoaster surculus*	2.6	This event defines the top of NN16, but as the species is extremely rare offshore NW Borneo, the event is not very useful.
LAD *Globorotalia multicamerata*	2.6?	The published age for this event is 3.3 Ma, but although the species is very rare it has been found as high as at 2.6 Ma.
LAD *Discoaster asymmetricus*	2.9	*D. asymmetricus* marks the top of nannoplankton Subzone NN16L, but tends to be rare at its top.
LAD *Discoaster variabilis*	2.9	This nannoplankton marker is often found and the event is commonly not far depressed.
LAD *Globoquadrina altispira*	2.95	One of the more reliable foraminiferal events, as this species can be common. However, the species is frequently rare near the top of its range and the LAD depressed to 3.6 Ma.
FAD *Globorotalia tosaensis*	3.3	Criteria such as the FAD of *G. tosaensis* tend to be too rare to be of practical use.
LAD *Reticulofenestra pseudoumbilicus*	3.5	Although this is the official marker for top NN15, it is more difficult to recognise and therefore less reliable than the LAD of *Sphenolithus*.
LAD *Sphenolithus*	3.5	The LAD of this easily recognisable, usually abundant, and therefore reliable, marker defines the top of nannoplankton Zone NN15.
LAD *Globorotalia margaritae*	3.6	This classical foraminiferal marker defines the top of SN19, but is rare and restricted to deep water.
LAD *Globigerina venezuelana*	3.6	Not frequently reported, this foraminifer is occasionally useful.
LAD *Sphaeroidinellopsis seminulina*	3.6	Not always consistently distinguished, the age of this event shows a range from as little as 1.8 Ma to as much as 7.4 Ma, but potentially useful
LAD *Amaurolithus*	3.8	Very rare in NW Borneo, when present this nannofossil characterises the top of NN14

LAD *Ceratolithus armatus*	3.8	Very rare in Brunei, this nannofossil characterises the top of NN14 elsewhere in the region
LAD *Globigerina nepenthes*	3.9	Often used as a marker species elsewhere, this foraminifer is very rare in this region.
FAD *Sphaeroidinella dehiscens*	4	Easily recognisable, though often incorrectly identified, this appears to be a reliable foraminiferal marker when present.
LAD *Globigerinoides obliquus*	4?	This foraminifer is easily confused with other species and according to some authors has a LAD much younger. Occasional occurrences in younger sequences may confirm this, making it an unreliable marker at best.
LAD *Globorotalia plesiotumida*	4?	Although a classical foraminiferal marker, in practice its range was found to be very variable, probably due to the morphological variability of the entire group. It has been found as high up as 2.5 Ma.
LAD *Ceratolithus acutus*	4.1	This nannofossil event marks the top of NN13 in NW Borneo
FAD *Ceratolithus cristatus*	4.5	This nannofossil is moderately rare and occasionally useful.
FAD *Ceratolithus rugosus*	4.8	This nannofossil marks the base of NN13, but occurs only rarely.
LAD *Globoquadrina dehiscens*	5	This event marks the top of foraminiferal zone SN18, but because it is found so rarely, SN18 and SN19 can usually not be distinguished
FAD *Ceratolithus*	5.2	Although this nannofossil genus is rare, it is unmistakable, and therefore a reliable marker.
FAD *Globorotalia tumida*	5.2	An easily recognisable form, it is a useful marker in deepwater deposits.
FAD *Globorotalia crassaformis*	5.3	Although literature reports this foraminiferal event at this level, in NW Borneo it is rarely found this deep.
FAD *Globorotalia margaritae*	5.3	A traditional marker species that defines the base of foraminiferal zone SN18. However, *G. margaritae* only occurs in deep water.
FAD *Neogloboquadrina dutertrei*	5.3?	This normally common tropical species is fairly rare in NW Borneo in its strict definition. If including forms with a thick wall and transitional to *N. humerosa*, the species may be found as low as 5.3 Ma.
FAD common *Globigerinoides ruber*	5.3?	*G. ruber* is usually common, even in fairly shallow water. Below N18 it is rarely reported, and the forms that occur from N13 down are smaller and more compact, and are referred to *G. quadratus*.
LAD *Discoaster quinqueramus*	5.6	A usually abundant nannofossil, *D. quinqueramus* is the marker species for NN11 and a reliable marker. However, it frequently is only present in sediments older than 6 Ma
LAD *Discoaster berggrenii*	6	The precise level of this nannoplankton event is unknown, but it is most commonly observed in sediments older than 6.3 Ma
FAD *Pulleniatina*	6.4	Although this foraminifer tends to be rare, it is easily recognised and when present may give a clear age indication.
FAD *Globorotalia extremus*	7.2	Because this event reflects the evolution of the foraminifer from its precursor *G. obliquus*, the actual first occurrence is often difficult to know with certainty.
FAD *Amaurolithus*	7.2	Although generally a rare nannofossil in NW Borneo, this event is occasionally useful.
FAD *Sphaeroidinellopsis seminulina*	7.2	A potentially useful marker species, but rather rare near its base
LAD *Minilithya convallis*	7.8	The nannofossil *M. convallis* is poorly known and difficult to recognise, but can be abundant. When recognition is good, it is a reliable marker. It has been reported from Sabah, but not from Brunei.
FAD *Discoaster pentaradiatus*	7.8	This characteristic nannofossil is easy to recognise, but tends to be rare in the lower part of its range. In this region its FAD occurs above the FAD of *D. quinqueramus*. Globally, its FAD is reported to be much older (Young, 1998).
FAD *Discoaster quinqueramus*	8.3	This nannofossil is usually common and therefore its FAD forms a reliable marker. Globally, its FAD may be slightly older.
LAD *Discoaster bollii*	8.5	This nannofossil is rare in the region, and hence does not form a reliable marker. In literature its LAD is reported to be much older (Berggren et al., 1995)
FAD *Neogloboquadrina humerosa*	8.5	*N. humerosa* tends to be fairly common down through N17, then becomes rarer. It is predominantly dextral but is sinistral near the base of its range.
FAD *Globorotalia lenguaensis*	8.6	If *G. lenguaensis* is present, it forms a reliable marker. Unfortunately it tends to be rare.
LAD *Discoaster hamatus*	8.9	*D. hamatus* is a reliable, though infrequent nannoplankton marker, which defines NN9 (total range)
LAD *Catinaster coalitus*	8.9	Slightly more common than *D. hamatus*, *C. coalitus* is thought to have the same extinction level.
FAD *Neogloboquadrina acostaensis*	10.2	This is a fairly unreliable event, as the early forms of *N. acostaensis* are not very typical and not always recognised. However, it defines base N16 and it therefore important.
LAD *Sphenolithus moriformis*	10.4	This nannofossil can be used to subdivide NN9 into an upper and lower part, although the correct species identification is critical.
LAD *Globorotalia mayeri*	10.4	The LAD of *G. mayeri* defines the top of N14. It coincides with the LAD of *S. moriformis* and occurs above the FAD of *D. hamatus*, proving that there is an overlap between NN9 and N14.

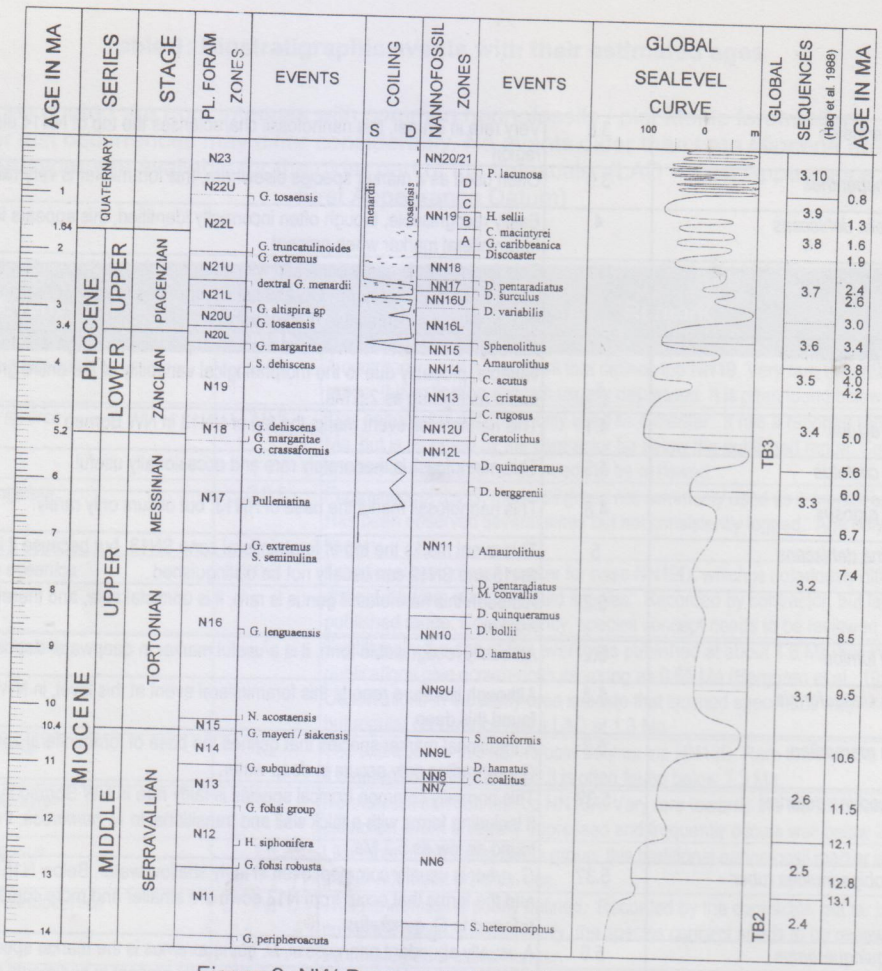


Figure 2: NW Borneo stratigraphic scheme

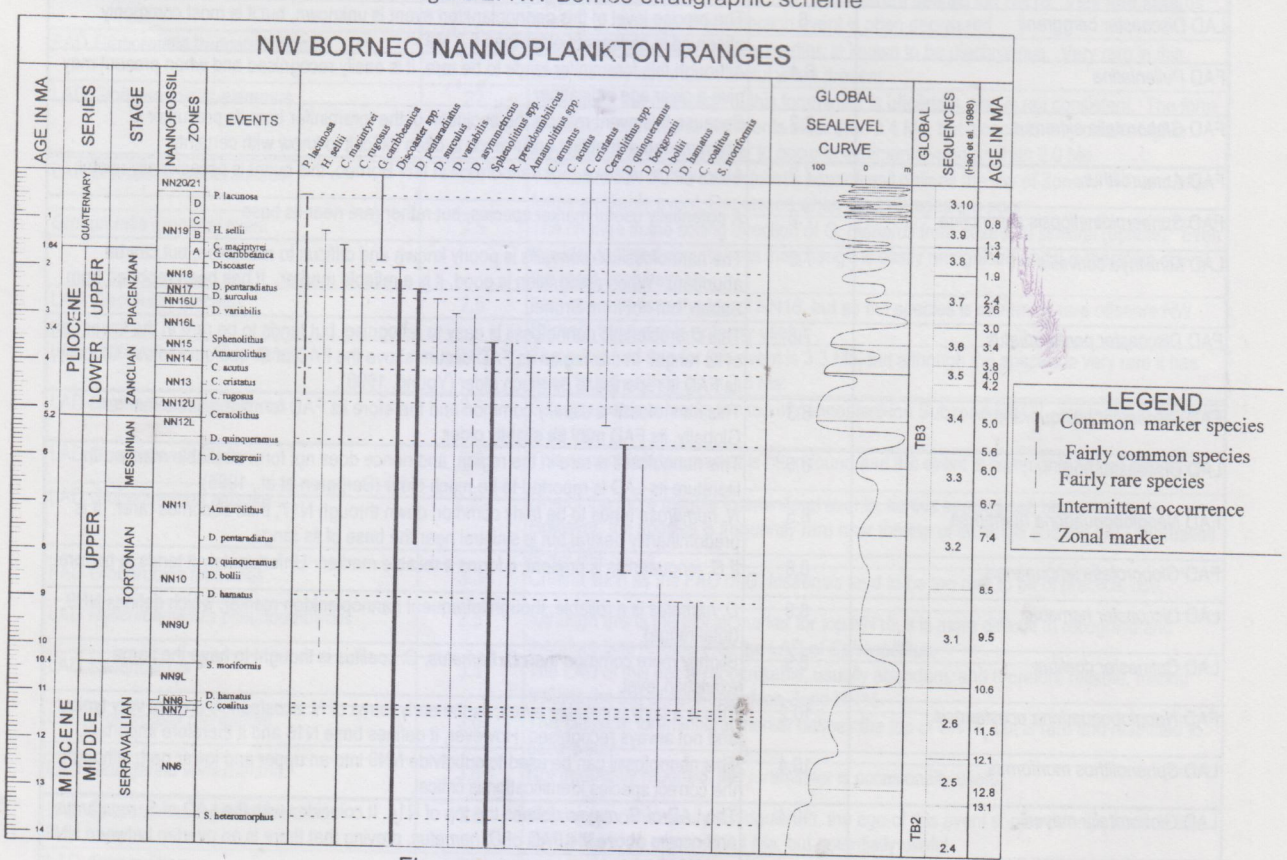


Figure 3: Nannoplankton range chart

1. *Globorotalia crassaformis, Globorotalia tosaensis* and *Globorotalia truncatulinoides* are three members of the same evolutionary lineage. Because one species evolves into the next, a critical examination is needed to differentiate between them, which was often not done in old analyses. By careful observation it is possible to distinguish between *G. truncatulinoides* with a distinct keel along all the chambers, *G. tosaensis* without any keel, and transitional forms that have a keel only along the last two or three chambers. Consistent separation of these species makes the FAD of *G. truncatulinoides* (defines base N22) and LAD of *G. tosaensis* (defines top N22L) reliable events. The precise range of the transitional form has not yet been established. According to literature (Rögl, 1974; Bolli & Saunders, 1985) a further subdivision of *G. tosaensis* and of *G. crassaformis* should yield additional biostratigraphical events, but the criteria to split the subspecies consistently could not (yet) be identified.

2. Some groups of planktonic foraminifera show consistent variations in coiling direction. This phenomenon has been extensively studied and it is suggested that for particular species there is a relationship between original temperature of the water mass and dominant coiling direction (Saito, 1976; Bolli & Saunders, 1985; Calieri, 1996; Lagoe & Zellers, 1996). Hence, changes in coiling direction for these species can be used to indicate different water masses, which in a small region is expected to be a synchronous event. Moreover, a change in water mass is likely to be triggered by changes in oceanic circulation and hence by changes in climate. Coiling directions for the *G. tosaensis – G. truncatulinoides* group, for the *Globorotalia menardii* group, for *Neogloboquadrina* and for *Pulleniatina* have been recorded. Those for the *G. menardii* group proved the most useful so far, as the group is predominantly sinistral in the beginning of its range in N17, switches to predominantly dextral halfway through N17 (although with several brief reversals), and back to exclusively sinistral halfway through N21. The latter event is well recorded and appears to coincide with the maximum flooding surface of TB3.7 at 2.5 Ma. It also coincides with a change in species composition of the *G. menardii* group, as several morphotypes become extinct at this level. *Globorotalia tumida*, a close relative of the group, does not appear to be affected and remains predominantly sinistral throughout.
Frequent reversals occur in both the *Pulleniatina* and the *G. tosaensis* lineage, although both are predominantly dextral. The changes in coiling direction appear to be consistent, but are too frequent to be useful when the group is only intermittently present. The last temporary reversal to sinistral appears to occur high in N21. *G. truncatulinoides* appears to be almost exclusively dextral.
Neogloboquadrina is predominantly dextral over most of its range, except for the lowermost part in N16, where it is sinistral.

3. Considerable variation in wall thickness, compactness, size and number of chambers in the last whorl occurs in several groups, most noticeably in *Neogloboquadrina* and *Globigerinoides*. Similar variation is known to occur geographically, where low latitude forms tend to be larger, more lobate, and more open and have a thinner wall than forms from higher latitudes (Hilbrecht, 1997; Yeh et al., 1989). It is therefore thought that the occurrence of this variation in this region may reflect changes in palaeo-temperature which should be directly related to climatic changes and hence to sequence stratigraphical systems tracts. This relationship has not yet been convincingly proven and is still being investigated.

4. Several groups (*G. menardii – G. tumida, Neogloboquadrina, Globigerinoides, Globigerina*) show a wide range of morphological variation, some of which has been described in literature (e.g. Bolli & Saunders, 1985; Kennett & Srinivasan, 1985; Sprovieri et al., 1996). In many cases, it has so far proved impossible to apply a consistent species concept, particularly when different investigators are involved and the species are not very common. Only a few morphotypes have been separated so far, and these are being tested as marker species (e.g. *Globorotalia ungulata, Globorotalia multicamerata, Globigerina eamesi*, and some unnamed types). Preliminary results show that many forms are potentially useful, if sufficient time is dedicated to detailed analysis.

5. Some of the traditional lineages and the marker species derived from them (*Globigerinoides obliquus – G. extremus, Sphaeroidinellopsis – Sphaeroidinella, Pulleniatina, Globoquadrina*) require more study, as different investigators have different species concepts or may not always take the time to differentiate between the different members of the lineage. Their stratigraphic potential is well known, but many do not occur frequently enough in this region to record them consistently.

Although the sequence of events can be established, absolute ages can only be estimated, as those reported in literature show significant differences (compare e.g. Bolli & Saunders, 1985; Kennett & Srinivasan, 1985) and several are known to be strongly

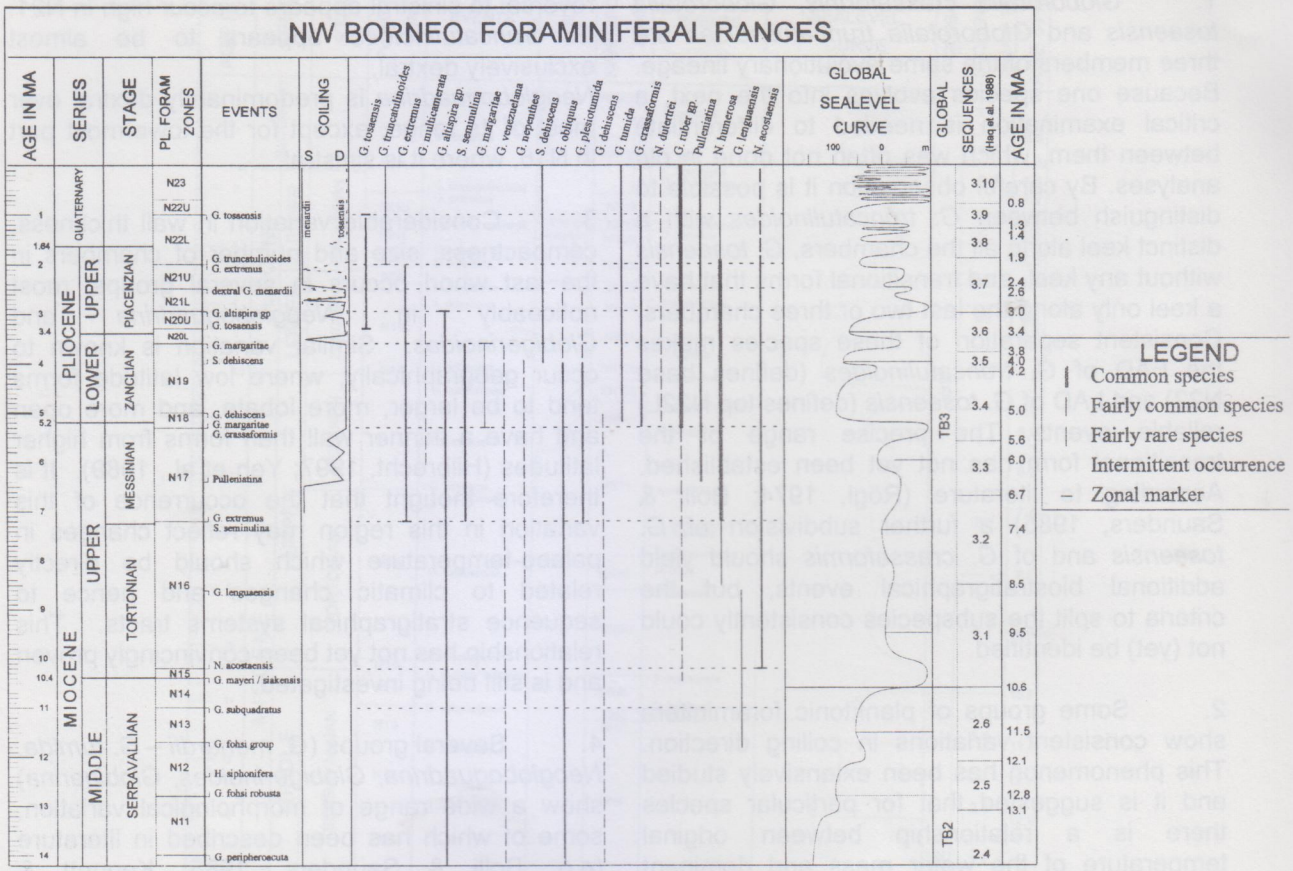


Figure 4: Planktonic foraminiferal range chart

diachronous (e.g. Weaver & Bergsten, 1991; Spencer-Cervato et al., 1994; Berggren et al., 1995a,b). Hence the age of the events offshore NW Borneo needs to be established more accurately. An attempt to do so through the application of stable isotopes failed, because the planktonic foraminifera needed for this investigation were not common enough in the test well, and aliasing prevented matching of the obtained curve to the global oxygen isotope stages.

Useful events, their sequence of occurrence, their relationship to the occurrence of other biostratigraphic events and their approximate relationship to the global sea-level curve and absolute timescale, are indicated in Figs. 2 and 4 and Table 1. For convenience, the events are related to the Blow (1969) zonation, as this is the most widely known and applied foraminiferal zonation. For estimates of absolute age of the events, several literature sources were referred to (e.g. Blow, 1969; Postuma, 1971; Stainforth et al., 1975; Bolli & Saunders, 1985; Kennett & Srinivasan, 1985; Weaver & Bergsten, 1991; Spencer-Cervato et al., 1994; Berggren et al. 1995a,b;) as well as Shell proprietary data and published ages of planktonic foraminifera and eustatic sea-level movements. Only the important species are listed. Species that occur only occasionally or those of which the ranges are unknown, are excluded.

Conclusion

Although calcareous nannoplankton and planktonic foraminifera are frequently scarce offshore NW Borneo, both groups are extremely useful for providing biostratigraphical input for a sequence stratigraphical interpretation. In particular the planktonic foraminifera are not yet used to their full potential. Re-examination of older slides frequently offers possibilities for a more detailed and consistent zonal subdivision.

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