40. PALEONTOLOGY SYNTHESIS OF DEEP SEA DRILLING RESULTS FROM LEG 22 IN THE NORTHEASTERN INDIAN OCEAN

Stefan Gartner, Jr., Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Coral Gables, Florida

David A. Johnson, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

and

Brian McGowran, University of Adelaide, Adelaide, South Australia

CORRELATION OF MICROPALEONTOLOGICAL DATUM LEVELS, SITE 214

Of the several sites drilled during Leg 22, Site 214 is of special interest to biostratigraphers because this continuously cored section contains well-preserved siliceous and calcareous microfossils cooccurring over part of the cored interval. Planktonic foraminifera and calcareous nannofossils occur from the Recent at the top of the hole down to Paleocene sediments. Progressively shallower facies towards the bottom of the hole, and possible hiatuses just above this shallow facies, make this portion of the section less useful than the middle Eocene to Recent interval. Nannofossils as well as planktonic foraminifera occur in normal succession above the middle Eocene, though somewhat attenuated in the Eocene and Oligocene. Usable Radiolaria occur only from the middle Miocene up.

Selected datum levels of the three microfossil groups as they occur at this site are plotted in Table 1. The relatively wide spacing of datum levels in the Neogene reflects the higher sedimentation rate during this time, which in turn may be attributable to higher productivity of the overlying water masses as is indicated by abundant siliceous microfossils. Epoch boundaries are drawn on the basis of calcareous fossils as there is good agreement between planktonic foraminifera and calcareous nannofossils. In all cases, the two fossil groups indicate an epoch boundary within less than two meters of each other, and even this difference may reflect sample spacing or core recovery. Radiolaria datum levels do not always coincide as precisely with calcareous fossil datum levels or epoch boundaries as would be predicted from previously compiled correlation charts, but this may reflect the limited number of sections in which such correlations could be made previously. The cores from Site 214 therefore afford an opportunity to refine previous correlations.

SEDIMENT ACCUMULATION RATES— SELECTED SITES, LEG 22

From a biostratigraphic viewpoint, only seven of the eight sites drilled during Leg 22 are of general interest. The sediments at Site 211 yielded good biostratigraphic ages only near basement, below an intrusive sill. Consequently, a sediment accumulation rate curve would have to be based on only two reliable points, the sediment water interface and the oldest sediment above basement. No variations could be ascertained over a period of more than 70 m.y. This site, therefore, merits no further discussion.

Sediment accumulation rate curves for the remaining seven sites are plotted on Figure 1. At Site 212, the sediment accumulation rate plots as a step-like curve. The upper 170 meters of sediment accumulated at more than 1 cm/1000 years, a reasonable rate for calcareous pelagic sediments. However, these sediments are turbidites and their accumulation rate is not particularly significant. Below 170 meters, the sediments consist of three relatively thick carbonate units separated by thin brown clay units. Each of the three carbonate units consist chiefly of calcareous nannofossils and fine debris with only a minor percentage of planktonic foraminifera and other constituents. These units represent relatively short time spans in the middle Miocene, middle Eocene, and Upper Cretaceous, respectively, and each unit has essentially the same age at the top and bottom. All three of these calcareous units are interpreted to be redeposited, probably from suspension, and, hence, nothing can be ascertained about their accumulation rate. The brown clays between the calcareous units probably represent the prevalent mode of pelagic sedimentation at this site and very likely represent most of the sedimentary history of the site. Their accumulation rate probably is less than 0.1 cm/1000 years, although this cannot be definitely established.

Sites 213 and 215, on either side of Ninetyeast Ridge, have had similar histories of sedimentation. During Pliocene-Pleistocene time, these sites received pelagic sediments in the form of siliceous ooze and the accumulation rate has been just over 1 cm/1000 years. From early Eocene to Pliocene time, both sites accumulated unfossiliferous pelagic brown clays, and the sediment accumulation rate of 0.04 to 0.12 cm/1000 years is within the range of values expected for this type of sediment. During the late Paleocene and early Eocene, pelagic calcareous sediments accumulated at both sites, and the greater sediment accumulation indicated by the change in slope of the curve are more nearly characteristic of this type of sediment.

Sites 214, 216, and 217 are along the crest of Ninetyeast Ridge; Site 214 being farthest south. These three sites have a similar history of sediment accumulation, but one which is markedly different from Sites 213 and 215 on either side of the ridge. From early middle Miocene to Recent, pelagic sediments of a mixture of calcareous and siliceous ooze accumulated at a rate of about 1 cm/1000 years. Below this is another interval of pelagic sediment which accumulated at a lesser rate and commenced at different times at each of the three sites. This episode of pelagic sedimentation was initiated apparently when each of the
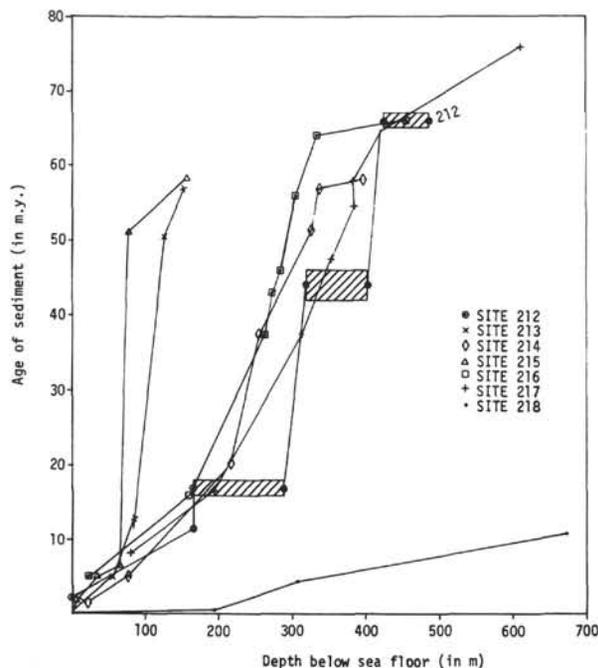
Figure 1. *Sediment accumulation rates, DSDP, Leg 22.*

sites successively sank below the photic zone and no longer received sediments other than pelagic contributions. At Site 214, this change occurred in late Paleocene time; at 216, in late Maastrichtian time; and at 217, in Campanian time. The average sediment accumulation rate for this interval is about 0.2 cm/1000 years. At each of these three sites, the slope of the sediment accumulation rate curve changes markedly some distance above basement, indicating an increase in sedimentation which relates closely with the change from a primarily pelagic sedimentation above to pelagic and detrital sedimentation below. The relative proportion of detrital constituents increases downward until pelagic constituents are completely excluded. With progressive exclusion of pelagic constituents, precise biostratigraphic determinations cannot be made and further changes in sediment accumulation rates cannot be ascertained.

Site 218, located on the Bengal Fan, has an entirely different history of sediment accumulation than any of the other sites as is shown on Figure 1. The principal constituents are detrital, and the pelagic contributions are greatly diluted. Because of the intermittent coring, no datum levels were found and the dates have relatively wider limits. The curve on Figure 1 is plotted using interpolated avarage values for nannofossil zones encountered at a particular depth, and this rather flat line indicates the high sedimentation rate of this site. The change in slope of the curve at about 200 meters and at about 300 meters indicates that during Pliocene time the amount of detrital material supplied to the site was generally less than during late Miocene time and considerably less than during the late Pleistocene.

CRETACEOUS BIOFACIES: EVIDENCE FOR RAPID MOVEMENT OF INDIAN PLATE RELATIVE TO AUSTRALIAN PLATE

Evidence is summarized elsewhere in this volume (Chapter 41) for concluding that the Ninetyeast Ridge was part of the Indian plate before it became fused with the Australian plate early in Eocene time and that rapid sinking occurred during the latest Cretaceous and earliest Tertiary. Thus, diachronous facies changes prove that the environment of sediment accumulation at Sites 217, 216, and 214 passed from very shallow marine (and nonmarine at 214) to oceanic during the Campanian-Maastrichtian, late Maastrichtian, and late Paleocene-Early Eocene, respectively. At Site 216, more than 100 meters of shallow-marine sediment succeeded by about 20 meters of deeper water sediment, in which solution and corrosion already are in evidence, are placed entirely in the Late Maastrichtian *Nephrolithus frequens* Zone (about 2 m.y.). At Site 214, Harris (Chapter 24) has found evidence for a sharp decrease in total terrestrial palynomorphs as the environment changed from nonmarine to shallow-marine; since the preservation of palynomorphs remains good, as evidenced by the dinoflagellate assemblages in the marine sediments, this would seem to be excellent negative evidence for rapid drowning of the terrestrial flora during sinking at that site.

In the context of plate tectonic models, rapid sinking implies rapid lateral movement. Since movement by the Indian plate, including the Ninetyeast Ridge, was in a south-to-north direction, it might be expected that biogeographic data have some bearing on conclusions derived from sea floor geomagnetic, sedimentological, and biofacies studies. The reason is that organisms, including planktonic microorganisms, are distributed in patterns and trends broadly parallel to latitude as a reflection of major climatic and ocean-current trends. This section summarizes our qualitative biogeographic evidence that the Ninetyeast Ridge did indeed move rapidly northward during the Late Cretaceous while it was sinking rapidly.

It is well known that more rapid evolution by speciation and greater taxonomic diversity occur in planktonic foraminiferal faunas in warmer water masses generally ("tropical" or "Tethyan" provinces) than in cooler waters and at higher latitudes ("Boreal" and "Austral" provinces). For example, Bandy (1967) has expressed this by "*Globotruncana-Rotalipora* lines" beyond which keeled Cretaceous planktonics are not found as one moves northward in the Northern Hemisphere. Stehli, Douglas and Newell (1969) have presented data showing that Maastrichtian planktonic foraminifera form latitudinal gradients in diversity in the Northern Hemisphere similar to the gradients typically found in living organisms. Sliter (1972) has classified Late Cretaceous assemblages on the eastern North Pacific margin as Tethyan, central, intermediate, and boreal. In the later part of the Maastrichtian, the most diverse planktonic foraminiferal assemblages may be summarized as including the following groups: *Globotruncanella* (*G. citae*, *G. intermedia*, *G. mayaroensis*); single-keeled *Globotruncana* (*G. elevata/stuartiformis*, *G. stuarti*, *G. conica*, *G. gansseri*);

double-keeled *Globotruncana* (Groups of *G. arca, G. contusa/caliciformis, G. aegyptiaca*); *Rugoglobigerina* (*R. rugosa, R. scotti*, etc.); and Heterohelicidae (*Gublerina, Heterohelix, Pseudotextularia, Racemiguembelina, Planoglobulina, Pseudoguembelina*). There are other elements, but this broad characterization applies to assemblages below oceanic water columns at low latitudes where solution has not biased unduly the composition of the residues. Of the elements comprising the groups, the last species to emerge phyletically is *Globotruncanella mayaroensis*, and this event is taken as the highest major biostratigraphic horizon in the Maastrichtian (e.g., Pessagno, 1967; van Hinte, 1972), estimated at about 67 m.y. (Berggren, 1972) or at 66 m.y. (van Hinte, 1972). Therefore, almost all of the foraminiferal evolution producing this rich Tethyan or low-latitude fauna had taken place by the end of the time represented by the *Globotruncana gansseri* Zone (see, e.g., Pessagno, 1967; Marks, 1972).

Biogeographic Change: Indian Plate

The assemblage outlined above occurs in the *Globotruncanella mayaroensis* Zone in the upper part of the Valudavur Formation near Pondicherry, south India, about 12°N (Govindan 1972). The "large," benthonic, orbitoidal foraminifera of tropical distribution in the Maastrichtian are known from this area (Geol. Soc. India, Mem. No. 2, 1968). Both the orbitoidal benthonics and the entire spectrum of planktonics, with the exception of *G. mayaroensis*, are known from Pakistan (reviews by Nagappa 1959; McGowran 1968; unpublished studies) where the occurrences are on the Indian Shield side of the Quetta and Indus lines (Gansser 1966) and, therefore, on the Indian plate.

The tropical planktonic foraminiferal assemblage appears to be virtually complete at Site 217 (about 9°N), just below the Cretaceous/Tertiary boundary. Thus, Core 17, Section 1 includes all single-keeled *Globotruncana* except *G. gansseri*, all double-keeled *Globotruncana* listed above, all *Globotruncanella*, and the full range of morphological variation among late Maastrichtian Heterohelicidae.

This assemblage contrasts strikingly with the assemblage just below the Cretaceous/Tertiary boundary at Site 216 (about 1.5°N) where, in Core 23, double-keeled *Globotruncana arca* and *G. contusa* are relatively common but the *G. aegyptiaca* group was not observed; the single-keeled *G. stuarti* group is present but developed poorly compared to Site 217; the Heterohelicidae flourish much less; *Globotruncanella mayaroensis* is unusually common; and the overall size of specimens is less.

All assemblages listed from the Indian plate contain *Globotruncanella mayaroensis* and *Globotruncana contusa* and so are Tethyan according to criteria listed by Sliter (1972). However, there is a distinction to be made between Site 216 and the localities further north. The relatively impoverished nature of the Site 216 assemblage cannot be ascribed to a short water column because the water was deep enough for solution to cause corrosion and fragmentation; nor can it be ascribed to selective removal by the latter process because solution effects were greater at Site 217. It is concluded, therefore, that the difference is biogeographic in reflecting a latitudinal diversity gradient.

Biogeographic Change: Australian Plate

The strato-tectonic provenance of foraminiferal records in the vicinity of the present northern edge of the Australian plate is complicated by extreme sinistral shearing, whereby New Guinea was assembled from several postulated tectonic units moving to the northwest (Audley-Charles et al., 1972). Part of the tropical planktonic foraminiferal assemblage is listed by Visser and Hermes (1962), who also figure Maastrichtian orbitoids. In Papua (about 6°S), the full range of planktonics (including *Globotruncanella mayaroensis*) occurs in fine clastics of fairly deep-water accumulation.[1] In the Port Moresby district in Papua, about 9.5°S, the same assemblage occurs in the Bogoro Limestone and oribtoids occur in the Barune Sandstone (summarized in McGowran 1968). All of these records come from just outside the edge of the Australian continent, which includes "south New Guinea" (e.g., Audley-Charles et al., 1972), but paleotectonic reconstructions do not lessen the biogeographic significance of the assemblages as typically tropical.

Worsley and Martini (1970, Figures 1 and 2) imply that *Globotruncanella mayaroensis* and *Nephrolithus frequens*, considered as tropical and extratropical, respectively, are mutually exclusive in western Australia. However, both records refer to the Miria Marl in the Carnarvon Basin, about 23°S. Other planktonic foraminifera present in the Miria Marl are *Globotruncana arca, G. contusa, G. elevata* (with some specimens approaching *stuartiformis*), *G.* cf. *falsostuarti, Rugoglobigerina rugosa, Globotruncanella citae, Pseudotextularia elegans/deformis,* "*Racemiguembelina fructicosa,*" *Gublerina cuvillieri* and *Heterohelix* spp. (Edgell 1957; Belford 1958; McGowran 1962 unpublished; Edgell's *G. elevata* referred here to *G.* cf. *falsostuarti?,* his *G. lugeoni* to *G. elevata,* his *G. planata* to *G. mayaroensis*). The presence of *Globotruncana contusa* and *Globotruncanella mayaroensis* indicates the Tethyan province (Sliter 1972), but notable absences, with respect to coeval assemblages to the north, include the *Globotruncana aegyptiaca* group, the late members of the group of single-keeled *Globotruncana* (*G. stuarti* s.s. and *G. conica*), the *scotti* morphotype of *Rugoglobigerina*, and several heterohelicids. Planktonic foraminifera and ammonites are common, and the presence of *Globotruncana elevata* and *Globotruncanella citae* means that the absence of important tropical elements cannot be explained away by the lack of a fully oceanic water column above this carbonate-shelf environment in either the vertical distribution model or the faunal tolerance model presented by

---

[1] Material released for study and publication through courtesy of Dr. M. F. Ridd, British Petroleum (Australia) Ltd., Melbourne.

Sliter (1972). Accordingly, it is apparent from this negative evidence that the northern part of the Carnarvon Basin was extratropical (in the sense employed here) during the latest Maastrichtian. That is, the latitudinal variation on the Indian plate is seen also on the Australian plate within the limits of the data available for the late Maastrichtian.

The Korojon Calcarenite, underlying the Miria Marl disconformably and of upper Campanian to lower Maastrichtian age, is an Inoceramus calcirudite, calcarenite, and calcilutite with a restricted planktonic foraminiferal assemblage even though planktonic specimens can comprise more than 70 percent of the total Maastrichtian assemblage (Edgell 1957). Planktonics are dominated by *Rugoglobigerina rugosa*, double-keeled *Globotruncana* (the latter being a variable complex of *G. linneiana-lapparenti-arca*), *Heterohelix* and *Gublerina*; *Globotruncana elevata*, *G.* cf. *falsostuarti*, *Globotruncanella citae* and *Pseudotextularia* are rare to very rare. Thus, the extratropical nature of the planktonic assemblage in the Korojon Calcarenite is apparent. The change from the Korojon assemblage to the Miria assemblage can be ascribed entirely to microfaunal evolution during the Maastrichtian in a marginal Tethyan or extratropical locale.

The lower part of the Korojon Calcarenite (upper Campanian) and upper part of the Toolonga Calcilutite (lower Campanian) were also deposited in a carbonate-shelf environment in the Carnarvon Basin (Edgell 1957; Belford 1958, 1960). Upper Campanian assemblages are dominated by double-keeled *Globotruncana* (*linneiana/lapparenti* group and *arca*) and *Rugoglobigerina* with other *Globotruncana* (*cretacea, ventricosa, fornicata*) occurring more rarely. In the lower Campanian, *G. arca* is not recorded and *Globotruncana* assemblages include the *G. lapparenti/linneiana* group, *G. ventricosa*, *G. bulloides*, and rare *Archaeoglobigerina cretacea*.

Late Cretaceous at Site 217

In broad terms, the four-part lithological section at Site 217 matches closely changes in foraminiferal facies. Four facies are distinguished as follows:

Facies 4—Nannofossil chalk; Cores 17 to 22 (420 m to 480 m)

Planktonic foraminifera of oceanic aspect, stained with brown clay; solution increases upwards (intense in Core 18). Assemblages very diverse at top, as noted above; reduction in overall diversity downhole to Core 23 (disappearance of *Globotruncana aegyptiaca* group; reduction in numbers and morphotypic variation in single-keeled *Globotruncana*; reduction in morphotypic variation and diversity in Heterohelicidae); however, *Globotruncanella mayaroensis* continues into upper part of next unit.
Age: Late Maastrichtian (*Globotruncanella mayaroensis* Zone)
Environment: Oceanic

Facies 3—Micarb chalk, partly shelly (Inoceramus abundant lower, decreasing upwards); Cores 23 to 30 (480 m to 550 m)

Planktonic foraminifera abundant, corrosion increases upwards; assemblages dominated by *Rugoglobigerina*, double-keeled *Globotruncana* mostly *arca*, *Gublerina*, *Heterohelix* and *Globigerinelloides*; diversity much lower than in upper part of unit 4; single-keeled *Globotruncana* virtually absent, *Pseudotextularia* rare.
Age: Late Maastrichtian at top (*Globotruncanella mayaroensis* Zone); Maastrichtian (? to Campanian)
Environment: Outer shelf to oceanic

Facies 2—Micarb chalk, cherty, Inoceramus less prominent than in unit 3; Cores 31 to 36 (550 m to 600 m)

Planktonic foraminifera rare at base, increasing upwards; mostly an association of *Archaeoglobigerina blowi*, *A. cretacea*, *Globotruncana linneiana/lapparenti*, (with *G. arca* more prominent at top), *Globigerinelloides* and *Heterohelix*. Benthonics more common than in higher units.
Age: Campanian
Environment: Inner shelf

Facies 1—Dolarenite, cherty, partly shelly; Cores 37, 12A to 17A (600 m to 664 m). Foraminifera absent to very rare.

Interpretation

There is a distinct parallelism in foraminiferal assemblages and ages between facies 2, 3 and 4 at Site 217 on the one hand, and the Toolonga Calcilutite, Korojon Calcarenite, and Miria Marl, in the Carnarvon Basin, on the other. Facies 2 and 3 contain numerous benthonic foraminiferal species in common with Carnarvon Basin assemblages described by Belford (1960), and planktonic assemblages in both sequences are dominated by globigeriniform, double-keeled *globotruncanid*, and biserial forms. The gross similarity between the *Inoceramus*-bearing facies 3 and the Korojon Calcarenite is particularly striking, even though facies 3 seems to have accumulated in somewhat deeper water, at least in the upper part. Condon et al,(1956) figure in outcrop a valve of *Inoceramus* about 36 inches long, and so far as could be seen, a very similar thick-shelled form was sampled at Site 217; it is most unlikely that these *Inoceramus* were pelagic, as van Hinte (1972) has suggested might be the case for at least some members of the genus.

The present latitudinal range of the Carnarvon Basin is approximately 20°S to 28°S. The paleolatitude in the Late Cretaceous was substantially higher before Australia's northward movement during the Cenozoic and regardless of problems of polar wandering and Antarctica's Cretaceous position. The planktonic assemblages were extratropical, and the assemblages in facies 2 and 3 at Site 217 are interpreted as having been extratropical also. Pessagno (1967) has suggested that *Archaeoglobigerina* is especially well developed outside the Tethyan region, and he points out that the *Globotruncana linneiana* group also occurs widely (see also Sliter 1972).

The main microfaunal change at Site 217 occurs in the higher part of the section. The change from facies 3 to facies 4 and the development of a deep-sea nannofossil ooze happens above the lowest occurrence of *Globotruncanella mayaroensis*, which in turn is about 10 meters above the lowest occurrence of *G. intermedia*. Therefore, at least part of the mid-Maastrichtian *Globotruncana gansseri* Zone is present even though the nominate species was not found, and the lithofacies and biofacies changes are not heightened

by any recognized hiatus in accumulation. As noted above, microfaunal evolution producing the rich, tropical assemblages in the late Maastrichtian is mostly completed before the incoming of *Globotruncanella mayaroensis.* At Site 217, the reverse situation occurs. Van Hinte (1972) lists seven distinctive biohorizons for erecting an idealized biostratigraphic scheme for the late Campanian and Maastrichtian, and of these, not one has been recognized at Site 217 below base *G. mayaroensis,* which is at the top of van Hinte's biostratigraphic succession. Moreover, the chalks low in the *G. mayaroensis* Zone have a less-than-complete tropical assemblage and it is only right at the top of the Cretaceous section that the full tropical assemblage is found.

The assemblages low in the *G. mayaroensis* Zone at Site 217 resemble, in the mutual occurrence of *G. mayaroensis* and *Globotruncana contusa* and the absence of numerous tropical elements, the assemblages high in the *G. mayaroensis* Zone at Site 216 to the south and in the Miria Marl in the Carnarvon Basin. The assemblage high in the *G. mayaroensis* Zone at Site 217 is much closer, on the other hand, to those further north on the Indian plate and near the present northern edge of the Australian plate.

There are four potential factors which have to be considered in analyzing the changes at Site 217; changes with depth, with time, with watermass distribution reflecting climate, and with latitude.

The situation at Site 217 cannot be ascribed to the effects of solution with increasing depth because the trend in faunal development occurs in the same direction, i.e., upwards, as the trend in deteriorating preservation; indeed, the richest assemblage is sandwiched between the Cretaceous/Tertiary boundary and an interval which must have accumulated close to carbonate compensation depth. A second depth-dependent parameter is the height of the water column: in shallow water, planktonic microfaunas are less diverse than in the open oceans. This point is not relevant here because the water was deep enough (on the evidence of corrosion by solution) before the tropic assemblages appeared at Site 217 and certainly no less deep than the assemblages cited from India and Pakistan. As pointed out above, the well-known increase in phenotypic variation in the late Maastrichtian is opposite to the situation at Site 217 with reference to the horizon of initial appearance of *Globotruncanella mayaroensis.* The next possibility is that the change within the *G. mayaroensis* Zone at Site 217 merely reflects a sudden southward shift by the tropical belt with its diverse fauna, reflecting in turn a general climatic amelioration in the late Maastrichtian. However, the small amount of evidence on climatic trends from the Senonian toward the Maastrichtian and the Cretaceous/Tertiary boundary seems to indicate, if anything, the opposite trend overall (for example, Stevens and Clayton 1971; Saito and Van Donk 1971). At a smaller scale, Stevens and Clayton summarized oxygen isotopic and paleontological evidence for a drop in temperatures in the lower Maastrichtian followed by improvement in the upper Maastrichtian. This trend correlates well with the pattern of evolutionary diversification. It would explain the contrast in assemblages between the late Maastrichtian Miria Marl and the Campanian-lower Maastrichtian in the Carnarvon

Basin, especially since Berggren (1962) and others have noted a northward migration of typically Tethyan forms into Boreal Europe at about the same time. In neither case are the assemblages more than marginal-Tethyan, and an essential point in the present discussion is the contrast, in change with time, between Site 217 and the Carnarvon Basin. It should be noted also that we are discussing a 1 or 2 m.y. interval closer to the Cretaceous/Tertiary boundary with a postulated drop in temperature and rise in calcite compensation depth (Worsley 1971) than to the time of rapid evolutionary diversification just before the time of the *Globotruncanella mayaroensis* Zone.

There remains the fourth factor: migration of the site of accumulation from an extratropical biogeographic belt or province into a tropical belt. The microfaunal change within the Maastrichtian at Site 217 is explained here as being due to rapid northward movement of the Indian plate relative to the Australian plate during the Maastrichtian.

Summary and Conclusions

1.) Changes in the foraminiferal assemblages at Site 217 are more pronounced than would be expected from the known Campanian-to-Maastrichtian foraminiferal evolution and diversification. Of a series of distinctive biostratigraphic events, only the highest, the initial appearance of *Globotruncanella mayaroensis* (1 m.y. or 2 m.y. below the Cretaceous/Tertiary boundary at 65 m.y.) was recognized at this site. Below this horizon, assemblages are of inner shelf, outer shelf, and oceanic environments, and biogeographically extratropical. Above the horizon, assemblages are oceanic but fully tropical only at the very top of the section.

2) This change with time at Site 217 matches a latitudinal change across part of the Indian plate. On criteria adopted here, Site 216 to the south is extratropical in the latest Maastrichtian while assemblages in south India and Pakistan are tropical.

3) The foraminiferal succession below the *G. mayaroensis* horizon at Site 217 parallels the succession in the Carnarvon Basin, western Australia (shelf carbonate facies, extratropical, Australian plate). But the highest part of the succession at Site 217 matches, not the coeval assemblage in western Australia, but rather the assemblages in Papua, i.e., on or near the present northern edge of the Australian plate.

4) Factors including microfaunal evolution, height of water column, deep-sea solution, and paleoclimatic change are considered insufficient to explain these similarities and contrasts.

5) Accordingly, the change in foraminiferal assemblage through the Maastrichtian at Site 217, from extratropical in complexion to tropical, is explained by a substantial northward movement of the Indian plate relative to the Australian plate during that time.

Finally, it must be stressed that this analysis has been kept at the qualitative level for three reasons. The first is that statistical faunal comparisons must await detailed taxonomic analysis (now in progress). Secondly, possible paradigms provided by studies in the Northern Hemisphere indicate a northward displacement, relative to the geographic equator, of "Tethyan" assemblages. This is the

phenomenon of displacement and skewing of the thermal equator (Stehli 1973). Data available from the Southern Hemisphere (reviewed briefly by Webb 1968) provide no comparison at the level of refinement required here. The third reason for avoiding quantification is the sampling gap on the Australian plate. To imply that Site 217 moved $10°$ or more to the north during the Maastrichtian is not necessarily incorrect, but it is misleading when the comparative material is available from $6-10°S$ and $23°S$ and not as yet from the intervening gap.

REFERENCES

Audley-Charles, M. G., Carter, D. J., and Milsom, J. S., 1972. Tectonic development of eastern Indonesia in relation to Gondwanaland dispersal: Nature Phys. Sci., v. 239, p. 35-39.

Bandy, O. L., 1967. Cretaceous planktonic foraminiferal zonation: Micropaleontology, v. 13, p. 1-31.

Belford, D. J., 1958. Stratigraphy and micropalaeontology of the Upper Cretaceous of Western Australia: Geol. Rundschau, v. 47, p. 629-647.

———, 1960. Upper Cretaceous foraminifera from the Toolonga Calcilutite and Gingin Chalk, Western Australia: Bur. Miner. Resour. Geol. Geophys. Australia Bull., v. 57, p. 1-198.

Berggren, W. A., 1962. Some planktonic foraminifera from the Maastrichtian and type Danian Stages of southern Scandinavia: Stockholm Contrib. Geol., v. 9, p. 1-106.

———, 1972. A Cenozoic time-scale—some implication for regional geology and paleobiogeography: Lethaia, v. 5, p. 195-215.

Condon, M. A., Johnstone, D., Prichard, C. E., and Johnstone, M. H., 1956. The Giralia and Marilla Anticlines, north west division, western Australia: Bur. Miner. Resour. Geol. Geophys. Australia Bull., v. 25, p. 1-86.

Edgell, H. S., 1957. The genus *Globotruncana* in northwest Australia: Micropaleontology, v. 3, p. 101-126.

Gansser, A., 1966. The Indian Ocean and the Himalayas. A geological interpretation: Eclog. Geol. Helv., v. 59, p. 831-848.

Govindan, A., 1972. Upper Cretaceous planktonic foraminifera from the Pondicherry area, south India: Micropaleontology, v. 18, p. 160-193.

Marks, P., 1972. Late Cretaceous planktonic foraminifera from Prebetic tectonic elements near Jaen (southern Spain). Rev. Espanola Micropal., Num. Extraord., p. 99-123.

McGowran, B., 1962. Foraminifera and biostratigraphy of the Australian Maastrichtian and Paleocene. Unpublished thesis, University of Adelaide.

———, 1968. Late Cretaceous and early Tertiary correlations in the Indo-Pacific region: Geol. Soc. India Mim., v. 2, p. 335-360.

Nagappa, Y., 1959. Foraminiferal biostratigraphy of the Cretaceous-Eocene succession in the India-Pakistan-Burma region: Micropaleontology, v. 5, p. 145-192.

Pessagno, E. A., 1967. Upper Cretaceous planktonic foraminifera from the western Gulf Coastal Plain: Paleontographica Am., v. 5(37), p. 243-445.

Sliter, W. V., 1972. Upper Cretaceous planktonic foraminiferal zoogeography and ecology—eastern Pacific margin: Palaeogeog., Palaeoclimatol., Palaeoecol., v. 12, p. 15-31.

Saito, T. and Van Donk, J., 1971. Oxygen isotopic measurements of Late Cretaceous sediments: Geol. Soc. Am. (Abstr. with Prog.), p. 692-693.

Stehli, F. G., 1973. Review of paleoclimate and continental drift. Earth-Science Rev., v. 9, p. 1-18.

Stehli, F. G., Douglas, R. G., and Newell, N. D., 1969. Generation and maintenance of gradients in taxonomic diversity: Science, v. 164, p. 947-949.

Stevens, G. R. and Clayton, R. N., 1971. Oxygen isotope studies on Jurassic and Cretaceous belemnites from New Zealand and their biogeographic significance: New Zealand J. Geol. Geophys., v. 14, p. 829-897.

van Hinte, J. E., 1972. The Cretaceous time-scale and planktonic-foraminiferal zones. Proc. Kon. Nederl. Akad. Wetensch. Amsterdam, ser. B., v. 75, p. 1-8.

Visser, W. A. and Hermes, J. J., 1962. Geological results of the exploration for oil in Netherlands New Guinea: Verh. geol.-mijnb. Genoot. Ned. Kolon., v. 20, p. 1-265.

Webb, P. N., 1968. Comments on Late Cretaceous marine climates in New Zealand and related areas: Tuatara, v. 16, p. 8-10.

Worsley, T. R., 1971. Terminal Cretaceous events: Nature, v. 230, p. 318-320.

Worsley, T. R. and Martini, E., 1970. Late Maastrichtian nannoplankton provinces: Nature, v. 225, p. 1242-1243.

Depth (m)	Core No.	Planktonic Foraminifera	Core No.	Radiolaria	Core No.	Calcareous Nannofossils	Epoch
	1		1		1	Base *Emiliania huxleyi* Top *Pseudoemiliania lacunosa*	PLEISTOCENE
10	2	Base *Sphaeroidinella dehiscens excavata* Base *Pulleniatina obliquiloculata finalis*	2		2		
20	3	Top *Globorotalia exilis* Top *Globigerinoides quadrilobatus fistulosus* Base *Globorotalia truncatulinoides* Top *Globorotalia multicamerata*	3	Top *Pterocanium prismatium* Base *Theocorythium trachelium* Base *Amphirhopalum ypsilon*	3	Base *Gephyrocapsa* Top *Discoaster brouweri* Top *Discoaster surculus* Top *Discoaster asymmetricus*	
30	4	Base *Pulleniatina obliquiloculata* s.s. Top *Globoquadrina altispira*	4		4		
40	5	Top *Sphaeroidinella seminulina*	5	Top *Stichocoris peregrina*	5		PLIOCENE
50	6	Base *Globigerinoides quadrilobatus fistulosus*	6	Top *Artostrobium doliolum* *Spongaster tetras* ↑ *Spongaster*	6	Top *Reticulofenestra pseudoumbilica* Top *Sphenolithus abies* Base *Pseudoemiliania lacunosa*	
60	7		7		7		
70	8		8	↑ *Ommatartus tetrathalmus* *Ommatartus penultimus* ↑ *Spongaster pentas* *Spongaster klingi*	8	Base *Discoaster asymmetricus* Top non-birefringent ceratoliths	
80	9	Top *Globigerina nepenthes* Base *Sphaeroidinella dehiscens immatura* Base *Pulleniatina obliquiloculata praecursor*	9	Base *Pterocanium prismatium*	9	Base birefringent ceratoliths	
90	10	Base *Globorotalia tumida* s.s.	10	Top *Phormostichoartus corona*	10	Top *Discoaster quinqueramus* s.l.	MIOCENE
100	11		11	Top *Solenosphaera omnitubus* Top *Acrobotrys tritubus*	11		

TABLE 1 – *Continued*

Depth (m)	Core No.	Planktonic Foraminifera	Core No.	Radiolaria	Core No.	Calcareous Nannofossils	Epoch
						Top *Triquetrorhabdulus rugosus*	
110	12		12		12		
		Base *Pulleniatina primalis*		Base *Solenosphaera omnitubus*			
120	13		13	↑ *Stichocorys peregrina* / *Stichocorys delmontensis*	13	Base non-birefringent ceratoliths / Top *Discoaster neohamatus*	
				Base *Spongaster klingi*			
130	14		14	Base *Acrobotrys tritubus*	14		
		Base *Globorotalia acostaensis humerosa*		Top *Ommatartus hughesi* / *Ommatartus penultimus*			
140	15		15	↑ *Ommatartus antipenultimus*	15	Base *Discoaster quinqueranus*	
	16		16	↑ *Ommatartus hughesi* / *Cannartus pettersoni*	16		
150		Top *Globoquadrina dehiscens* s.s.		↑ *Ommatartus antipenultimus* / *Cannartus laticonus*		Top *Catinaster calyculus* / Top *Discoaster hamatus*	MIOCENE
		Base *Globorotalia merotumida*					
	17	Base *Globorotalia acostaensis*	17	Top *Carpocanopsis bramlettei*	17	Base *Discoaster neohamatus* / Base *Catinaster caliculus* / Top *Catinaster coalitus*	
160		Base *Globorotalia siakensis*		↑ *Lithopera bacca* / *Lithopera neotera*		Base *Discoaster hamatus*	
	18	Base *Globigerina nepenthes*	18	Base *Cannartus pettersoni* / Top *Dorcadospyris alata*	18	Top *Cyclicargolithus floridanus* / Top *Cyclolithella nitescens*	
170		Top *Globorotalia fohsi* s.l.					
	19		19		19		
180						Base *Triquetrorhabdulus rugosus*	
	20	Base *Sphaeroidinellopsis subdehiscens*	20	↑ *Cannartus laticonus* / *Cannartus mammiferus*	20		
190		Base *Globorotalia fohsi* s.l.				Base *Cyclococcolithina leptopora* / Top *Sphenolithus heteromorphus*	
	21	Top *Globigerinatella insueta*	21		21		
200		Top *Globigerinita dissimilis*				Base *Sphenolithus heteromorphus* / Top *Sphenolithus belemnos*	
	22		22		22		

TABLE 1 — *Continued*

Depth (m)	Core No.	Planktonic Foraminifera	Core No.	Radiolaria	Core No.	Calcareous Nannofossils	Epoch
	22	▶ Top *Globigerina binaensis*	22		22		MIOCENE
210		Top *Globorotalia kugleri* Base *Globoquadrina dehiscens* s.s.					
	23	Top *Globigerina sellii* Base *Globigerina binaensis*	23		23	Top *Triquetrorhabdulus carinatus*	
220		Base *Globigerinoides*				Base *Sphenolithus belemnos* Top *Sphenolithus ciperoensis*	
	24	Base *Globorotalia kugleri*	24				
230	25	Base *Globorotalia mendacis* Top *Chiloguembelina*	25			Top *Reticulofenestra scissura* Top *Sphenolithus distentus*	OLIGOCENE
240	26	Top *Subbotina angiporoides*	26			Base *Sphenolithus ciperoensis* Top *Discoaster tani*	
		Top *Pseudohastigerina*				Top *Reticulofenestra umbilica*	
250	27	Top *Globorotalia gemma* Base *Globigerina sellii*	27			Top *Cyclococcolithina formosa* Top *Bramletteius serraculoides*	
		Base *Globigerina tapuriensis* Top *Globigerinatheka index* Top *Globorotalia cerroazulensis* Top *Globigerinatheka*				Top *Discoaster barbadiensis* Top *Discoaster saipanensis* Top *Cyclicargolithus reticulatus*	
260	28		28				
						Base *Cyclicargolithus reticulatus* Top *Chiasmolithus grandis*	
270	29						EOCENE
280	30					Top *Sphenolithus furcatolithoides* Top *Nannotetrina alata* Base *Reticulofenestra umbilica* Base *Bramletteius serraculoides*	
290	31						

NOTE: On the left are shown the depth below sea floor (in meters) and the cores drilled at this site. The three columns indicate selected datum levels for planktonic foraminifera, Radiolaria, and calcareous mannofossils. On the extreme right are indicated epoch boundaries. Datum levels may be indicated by a short horizontal mark against the vertical line, which usually indicates that the datum occurs between adjacent cores, possibly in an interval of core loss. Most datum levels are indicated with triangles against a vertical line, in which case the base of the triangle corresponds to either the spacing of adjacent samples, or the interval over which a transition occurs. Upward pointed arrows indicate evolutionary transition in a lineage of radiolaria.