Post-Cretaceous record of larger foraminifera from the Shillong Plateau, India : an evidence of environmental recovery during Early Cenozoic

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The Late and post-Cretaceous succession of larger benthic foraminifera and planktic microfossils from the Shillong Plateau indicates events of extinction and recovery of the biotic forms. These events are interpreted using a conceptual framework involving biological responses to environmental changes caused by eustatic and climatic variations. Stratigraphic distribution shows that the Late Maastrichtian larger benthic foraminiferal assemblage disappears earlier than the planktic microfossils at the boundary interval. After their last occurrence in the Upper Maastrichtian, the larger foraminifera reappear in the carbonates of the Lakadong Formation dated by *Glomalveolina primaeva* as the Thanetian (P4).

The event of first appearance of larger foraminifera in the Shillong Plateau correlates with the zone P4. When compared with other Tethyan sections (e.g., Mediterranean) where they start occurring in the strata equivalent to zone P3b, the event of their reappearance appears to be slightly delayed in the studied section. The P3b zone is the interval marked by onsetting of habitable conditions on shelves (oligotrophic environments) and is followed by an interval (equivalent of the P4 zone) of extensive carbonate generation, during which highly diversified larger foraminiferal assemblages evolve and become widely distributed. The Shillong assemblage, therefore, marks the phase of "expanded oligotrophy" in which recovery of carbonate platform environments occurred on a large scale on shallow neritic shelves.

Key-words— Larger foraminifera, Shillong Plateau, Cretaceous, Thanetian, India.

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सारॉंश

भारत में शिलौंग पठार से बृहत फोरामिनीफरों का पश्च-क्रीटेश्यस अभिलेख : प्रारम्भिक सीनोजोइक कल्प में पर्यावरण में सुधार का एक प्रमाण

अनिक कुमार जौहरी

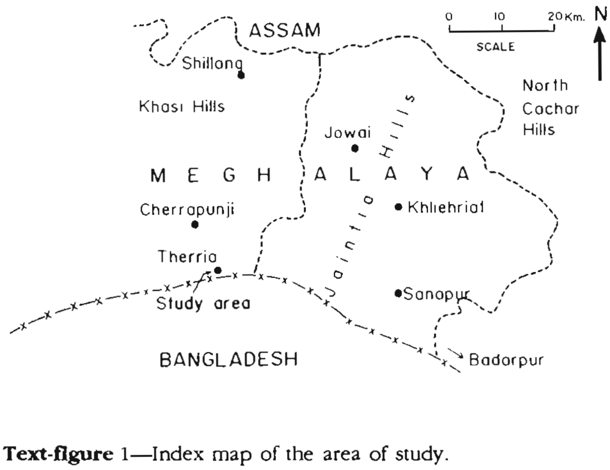
शिलौंग पठार से बृहत् फोरामिनीफरों एवं प्लवकीय सूक्ष्मजीवाश्मों के अनंतिम एवं पश्च-क्रीटेश्यस अनुक्रम से जीविता के विलोप एवं पुनरुज्जीवन की घटनायें प्रदर्शित होती हैं। सुस्थितिक और जलवायवी उतार-चढ़ावों के कारण पर्यावरण के प्रति जैविक प्रतिक्रिया नामक अवधारणा के आधार पर इन घटनाओं की व्याख्या की गई है। स्तरिकीय वितरण से प्रदर्शित होता है कि अनंतिम मास्ट्रिक्शियन बृहत् नितलस्थ फोरामिनीफर समुच्चय का सीमा अन्तराल पर प्लवकीय सूक्ष्मजीवाश्मों से पहले ही विलोप हो गया था। उपरि मास्ट्रिक्शियन में इनकी अन्तिम उपस्थिति के बाद बृहत् फोरामिनीफर थनेटियन कालीन लाकाडौंग शैल-समूह के कार्बोनेटों में पुनः मिलने लगते हैं।

शिलौंग पठार में बृहत् फोरामिनीफरों की प्रथम उपस्थिति की घटना पी-4 मंडल से तुलनीय है। जब अन्य टेथीय खंडों (मास्ट्रिक्शियन), जहाँ ये पी. 3 बी मंडल के समतुल्य स्तरों में मिलने प्रारम्भ हो जाते हैं, से इनकी तुलना की जाती है तो इनकी पुनः उपस्थिति अध्ययन किये गये खंड में थोड़ी सी बाद में प्रतीत होती है। पी. 3 बी. मंडल वह अन्तराल है जो अल्पपोषी पर्यावरण का प्रादुर्भाव व्यक्त करता है। इसके बाद अत्याधिक कार्बोनेट की उत्पत्ति वाला ऐसा अन्तराल (पी. 4 मंडल के समतुल्य) आया जिसमें विविधतायुक्त बृहत् फोरामिनीफरों का विकास हुआ तथा दूर-दूर तक इनका प्रसार हो गया। अतएव शिलौंग समुच्चय ''विस्तृत अल्पपोषी'' अवस्था का निरूपण करती है।

THE Cretaceous/Tertiary (K/T) boundary witnessed the major turnover in the taxonomic composition of mariné biotic groups. The change is well seen in the fossils record of both the benthic and planktic organisms. During this time, the well established biotic communities of the Mesozoic oceans of the world became extinct, and new biotic forms evolved in the aftermath of the terminal Cretaceous extinction. The evolution of Early Cenozoic larger foraminifera has been considered a consequence of environmental regeneration after the terminal Cretaceous event of major extinction. The geologic record of larger benthic foraminifera from the Late Maastrichtian and Early Palaeogene from different parts of the world presents a picture which, in conjunction with the fossil record of other benthic invertebrates and planktic microfossils, suggests a pattern of extinction and diversification which seems to be related to the sensitivity of organisms and their adaptation of reproductive strategy to changes in shallow, neritic environments (nutrient-related factors). It has been shown that the sensitivity depends on whether organisms are facies dependent (benthic) or facies independent (pelagic), and that their reproductive strategy varies with climate and eustatic cycles (Pianka, 1970; Fischer & Arthur, 1977; Caron & Homewood, 1983).

Some studies, in recent years, in the Mediterranean and adjoining regions have documented the pattern of extinction and origination among the shallow-water invertebrates. In the opinion of the author, however, these studies have not quite considered such pattern in the light of earth-bound processes influencing environments and responses of organisms to such influences often preserved in the rock record of the K/T boundary interval.

The present paper presents a study of the larger foraminiferal record from a K/T boundary succession in the South Shillong region (Text-figure 1), examines the biostratigraphic significance of the events of disappearance and reappearance of larger benthic taxa against the background of the data of planktic microfossils (Pandey, 1990; Garg & Jain, 1995), and attempts to relate them to factors which seem to be significant in the phenomenon of extinction and recovery of such taxa.

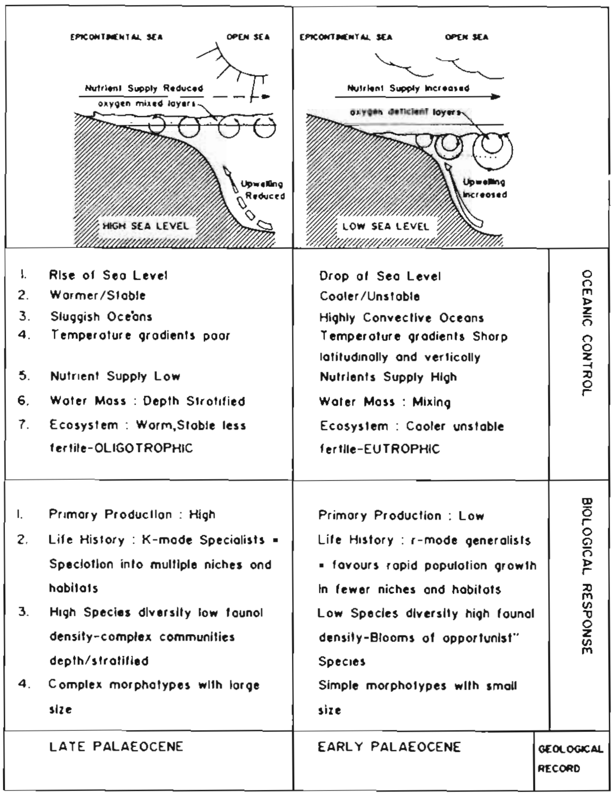


Text-figure 1—Index map of the area of study.

CONCEPTUAL BACKGROUND

The framework used in the present study for interpreting the Shillong succession of the fossil biota is borrowed from the models relating to biological responses to environmental changes brought about by eustatic and climatic variations (Pianka, 1970; Fischer & Arthur, 1977; Hallock *et al.*, 1991; Brasier, 1995). Its salient features (illustrated in Text-figure 2) are summarised below.

The ecosystem of the sea is under profound influence of oceanic control which operates through interaction mainly of factors of climate, sea level, influx of nutrients (terrigenous input), oceanic mixing, etc. As these factors change through time, the ecosystem of sea also undergoes changes. Two broad environmental states generated by aforesaid changes have alternately developed from time to time. They are termed the Oligotrophic and Eutrophic states of ecosystem. Biological response to each state of ecosystem is different and results in the accommodation of biotic forms which will be excluded in the other state; the oligotrophic state



Text-figure 2—Biological strategies in response to changes in marine ecosystem due to fluctuations in major oceanic controls (e.g., sea level, nutrient supply, temperature, rate of upwelling, etc.) (modified after Caron & Homewood, 1983).

promotes a high biotic diversity with low faunal density, whereas the eutrophic state yields a low biotic diversity with rich faunal density.

The state of oligotrophy is generated during high stand of sea level when climate is warmer and sea waters are sluggish, with highly partitioned habitats and low nutrient supply. This situation is stress free and suits species having complex morphologies and larger size. It allows them to adapt to variety of niches which are enhanced during oligotrophy. Such forms are known as k-mode specialists which take long to mature and show low reproductive potential and high degree of specialisation in adaptation to increased number of niches and habitats. Because of decreased terrigenous input and increased production of carbonate-precipitating organisms, oligotrophy enhances carbonate generation on shallow shelves (Hottinger, 1987; Hallock *et al.*, 1991).

Eutrophic conditions, on the other hand, develop during low stand of sea level when climate is cooler and sea waters are highly convecting, with considerable mixing of water mass and the enriched state of nutrient supply. This situation gives rise to unstable (stressful) environments which favour "opportunist" species with simpler morphologies and smaller size, called r-mode generalists. They are able to increase their population densities in fewer niches and habitats by high reproductive potential and early maturation. Because of increased terrigenous input and considerable reduction of carbonate-precipitating organisms, carbonate platform environments are destroyed on shallow shelves (Hottinger, 1987; Hallock *et al.*, 1991).

Larger foraminifera are k-mode specialists adapted to stable oligotrophic environments characterized by a wide range of ecological niches and habitats, as available in carbonate platforms on shallow shelves. They are characterised by relatively longer life cycle, low reproductive potential, large size, complex morphologies and usual dependence on symbiotic algae —the characters which make them adaptive to stable environments deficient in nutrients. On the other hand, smaller benthic foraminifera, in general, have characteristics such as high reproductive potential, smaller life cycle, simple morphology, small size and non-dependence on symbiotic algae, which allow them to flourish in nutrient-rich eutrophic environments (Hottinger, 1982, 1983).

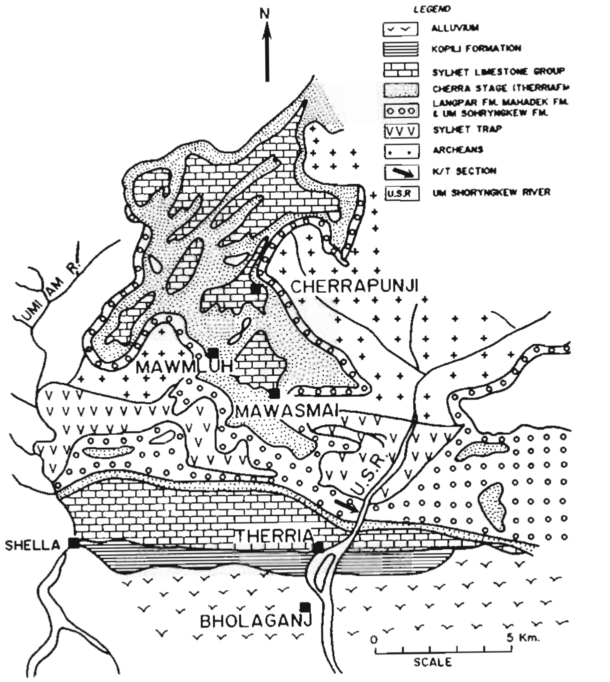
GEOLOGICAL SETTING

The area of study is a part of the Assam shelf which is the northeastern extension of the Indian Peninsular Shield (Murty, 1983). It includes the Shillong Plateau, Garo, Khasi, Jaintia and Mikir Hills and the Upper Assam Valley. Structurally, this part of the shield is dissected by a number of faults. The Shillong Plateau is an uplifted part of the basement bounded by nearly east-west aligned faults towards the northern and southern boundaries of the plateau.

The studied section is located at the southern fringe of the plateau on the western bank of Um Sohryngkew River northeastward of the village Therria in the foot-hills of the East Khasi Hills (Text-figure 3). The Late Maastrichtian to the earliest Palaeocene interval is represented by the upper part of the Mahadeo Formation, and the Early Palaeocene by the Langpar Formation. The Therria Formation and the lower part of the Lakadong Formation represent the Late Palaeocene (Pandey & Ravindran, 1988; Pandey, 1990).

Upper Maastrichtian is represented by the calcareous to silty shales which are followed by a reddish-brown 1.5 cm clay layer which forms the contact between the Cretaceous shales and the overlying 1.5 m greyish to yellowish brown shales which represent the lowest Palaeocene. The succeeding 34 m shales of the Langpar Formation represent the Lower Palaeocene. The topmost part of this formation and the overlying Therria Formation, poor in diagnostic species, are considered to represent the lower part of Upper Palaeocene on the basis of position in sequence. The lower part of the Lakadong Limestone distinguished by larger benthic foraminifera represents the Uppermost Palaeocene (Pandey & Ravindran, 1988; Garg & Jain, 1995; Jauhri, 1996).

Platform conditions were established during the Late Cretaceous and Early Palaeocene and the sediments were mainly deposited in shallow marine environment. During the Late Palaeocene, when the supply of terrigenous clastics was least, carbonate deposition took place. The latter, though interrupted occasionally due to increased supply of clastics and shallowing, continued until the close of the limestone deposition in the topmost part of the Sylhet Limestone Group (Prang Formation) (Murty, 1983; Ghose, 1976).



Text-figure 3—Geological map of the area (after Garg & Jain, 1995).

BIOSTRATIGRAPHY

Upper Maastrichtian and K/T Boundary

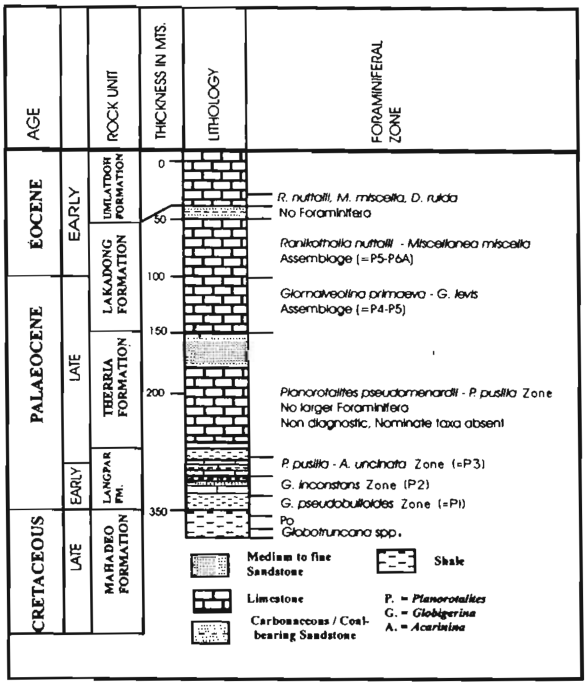
Nagappa (1959) was first to indicate the K/T boundary interval in the South Shillong Plateau (Therria section). He recorded the larger benthic assemblage of *Siderolites calcitrapoides* and *Orbitoides* sp. from the calcareous bands near the top of the Mahadeo Formation. It is characteristic of the Upper Maastrichtian and is comparable with the similar assemblage of foraminifera from the Upper Maastrichtian of the Haymana-Polatli area of Central Turkey (Sirel *et al.*, 1986).

The age control for this section of the Shillong area has been provided by the planktic microfossils, e.g., planktic foraminifera (Pandey, 1981, 1990; Pandey & Ravindaran, 1988) and nannoplankton and dinoflagellates (Garg & Jain, 1993, 1995). The observations on these microfossils have helped establish the K/T boundary interval and the associated terminal event in this section precisely.

The silty shales immediately below the 1.5 cm reddish reddish-brown clay layer have yielded *Globotruncana stuarti*, *Rugoglobigerina scotti* and *R. rotundata* which broadly correlate with the *Abathomphalus mayaroensis* Zone. However, the clear evidence of the terminal Maastrichtian has been provided by Garg and Jain (1995) who established the presence of *Micula prinsii* Zone in this section. The overlying 1.5 m greyish to yellow-brown shales are referable to *Guembelitria cretacea* Zone (Po) (Pandey & Ravindran, 1988; Pandey, 1990), in which Garg and Jain (1993) record FAD of *Danea californica*, etc. *G. cretacea* Zone marks the earliest Palaeocene. It is overlain by 22.5 m thick *"Globigerina" eugubina* Zone (P_1) (Pandey & Ravindran, 1988; Pandey, 1990). The K/T boundary is geochemically marked by 1.5 cm reddish-brown clay layer containing positive anomalies of iridium (Bhandari *et al.*, 1994).

Post-Cretaceous Fauna

Danian sediments that overlie the Upper Maastrichtian do not show development of larger benthic foraminifera. On the other hand, the Langpar shales overlying the *"G." eugubina* Zone (P_1) have yielded planktic foraminiferal species which establish zonal equivalence with planktic zones *'Globigerina' inconstans* Zone ($=P_2$) and *Planorotalites pusilla - Acarinina uncinata* Zone ($=P_3$). The topmost part of the Langpar Formation and the Therria Formation



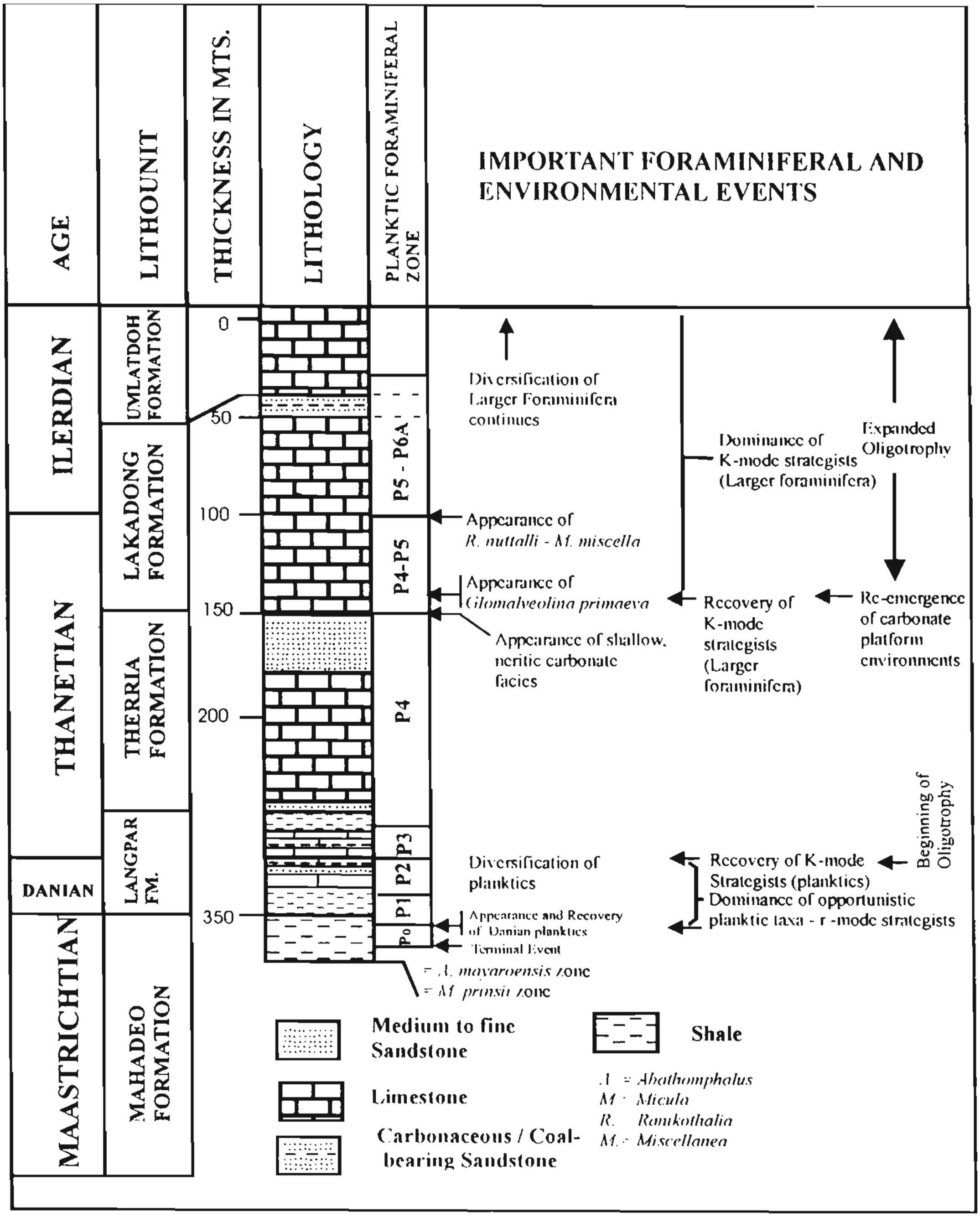
Text-figure 4—Biostratigraphy of the post-Cretaceous succession of the Um Sohryngkew River section (Therria) (modified after Pandey & Ravindran, 1988).

referred to *Planorotalites pseudomenardii - P. pusilla* Zone (=P_4) on the basis of their position in sequence (Pandey & Ravindran, 1988); see Text-figure 4.

In the post-Cretaceous succession, the larger foraminifera are first seen in the basal part of the Lakadong Formation of the Sylhet Limestone Group. The rich foraminiferal assemblage includes some markers which indicate precise correlation with the Palaeocene-Eocene stages of the type sections in the Mediterranean (Hottinger, 1994) and provide a good age control for the succession of the Shillong region in which planktic microfossils are absent.

Stratigraphically, the sequence is divisible into two major assemblages :

(i) Lower *Glomalveolina primaeva- G. levis* assemblage correlative with P_4-P_5 Zones (Thanetian).



Text-figure 5—Main foraminiferal and environmental events inferred from the post-Cretaceous succession of the larger foraminifera in the studied section of Shillong Plateau.

(ii) Upper *Ranikothalia nuttalli-Miscellanea miscella* assemblage correlative with P_5 Zone (Ilerdian).

FAUNAL EXTINCTION AND RECOVERY

Stratigraphic distribution shows that the Upper Maastrichtian larger benthic foraminiferal assemblage disappears earlier than the planktic microfossils (e.g., foraminifera, nannoplankton, etc.) at the boundary interval (Pandey, 1990; Garg & Jain, 1995).

After their last occurrence in the Upper Maastrichtian, the larger foraminifera reappear in the carbonates of the Lakadong Formation dated by *Glomalveolina primaeva* as the Thanetian (P_4) (Jauhri, 1994).

The different levels of disappearance of planktic microfossils and larger foraminifera in the studied section suggests that the phenomenon of extinction was a prolonged episode and may have occurred due to changing environmental conditions set in before the major extinction event at the K/T boundary.

The extinction of Upper Maastrichtian larger benthics has been related to loss of carbonate environments (indicated by extensive development of clastic facies in the studied area) on the shelves in response to environmental changes (progressive cooling, higher influx of clastic material, etc.). These changes resulted in a decrease of primary production and loss of ecological niches in carbonate platforms on shallow shelves. This imbalance in the environment in the beginning affected the larger benthic foraminifera and host of other carbonate-producing groups of mega-invertebrates such as rudistid bivalves, and finally, when it became devastating in proportion, wiped out a wide spectrum of animal groups, especially planktic ones, at the K/T boundary transition.

The delayed first appearance of the larger benthics during Palaeocene in the Shillong region shows that they were under a prolonged period of stress which lasted through P_o, P_1, P_2 and P_3 planktic foraminiferal zones. During this period, they could not recolonise the shallow, neritic regimes of the Shillong shelf. Their appearance in the carbonates of the Lakadong Formation dated as Thanetian (*Glomalveolina primaeva* Zone = P_4 Zone) indicates that the stress-free conditions became available only when carbonate environments were regenerated in the area during the zone P_4. When compared with that of the planktic microfossils, the event of first appearance of the larger benthics during Palaeocene seems to be a delayed one and may have occurred approximately after 7 Ma of the K/T boundary event.

In the comparable sections of the Mediterranean (e.g., the Pyrenean and Central Turkish ones), the larger benthics, represented by *Operculina, Miscellanea,* etc., appear early in the Thanetian, coinciding with the first appearance of morozovellids and acarininids (k-strategists among planktic foraminifera) indicative of P_{3b} Zone (Hottinger, 1994). The zone P_{3b} is, in fact, the interval that marks the onset of large scale generation of carbonate environments in response to oligotrophic conditions in euphotic zones of sea. This event is considered to mark the beginning of the recovery of larger benthic foraminifera and the k-strategists among planktic foraminifera in the Cenozoic after the terminal Cretaceous extinction event. It is followed by an interval of extensive development of carbonate platforms on the shallow shelves of tropical seas in the world, the phenomenon being referred to as "expanded oligotrophy" (Hallock *et al.*, 1991). Larger benthic foraminifera which are k-strategists, attain maximum diversity and complexity and became widely distributed during this phase. Usually, they are well preserved in the carbonate deposits of the Old World and are referable to the planktic foraminiferal zone P_4 (Hottinger, 1987, 1994; Hallock *et al.*, 1991).

The carbonate deposits of the Shillong area record the event of "expanded oligotrophy" which is indicated by the rich assemblage of larger foraminifera dominated by *Glomalveolina primaeva* (Reichel) in the lower part of the Lakadong Limestone; other common species are *Miscellanea juliettae villattae* Leppig, *Miscellanea* spp., *Broeckinella arabica* Henson, *Aberisphaera gambanica* Wan, *Orbitolites* sp., etc. (Jauhri, in review). Some of these forms are illustrated in Plate 1. This assemblage is characteristic of P_4 Zone. The older assemblage of larger foraminifera correlated with the P_{3b} Zone in the Mediterranean sections is, however, missing in the Shillong successions as the habitable carbonate environments could not be generated due to delayed development of state of oligotrophy in the Shillong area.

DISCUSSION AND CONCLUSION

The larger benthic foraminiferal horizon of the uppermost Maastrichtian was deposited in a shallow, neritic carbonate environment which showed a change to terrigenous clastic environment in the succeeding horizons. This change which decimated the Upper Maastrichtian larger foraminifera, seems to have been introduced due to loss of carbonate environments on the shelves. This has been attributed to a decrease in primary production caused by progressive cooling, increased bottom water circulation and higher influx of nutrients-all contributing to reduction of ecological niches on tropical shelves (Hallock, 1987; Hallock *et al.*, 1991). The effect of this change which began well before the K/T boundary transition, became considerably pronounced at the end of the latest Cretaceous *Micula prinsii* Zone (Garg & Jain, 1995) resulting in the decimation of a wide spectrum of organisms, including plankton. It appears that the environmental deterioration responsible for this change of the Late Cretaceous life was not abrupt but progressed gradually during the later part of the Maastrichtian in response to the above noted factors.

The disappearance pattern of the larger benthic foraminifera and planktic microfossils in the studied area indicates progressive deterioration of habitable environments which may have selectively removed organisms from the scene. Environment-sensitive ones (like the facies-dependent benthic groups) were first to disappear, while the plankton groups which are not facies dependent (in the sense in which benthic groups are) were last to depart when the crisis became intolerably severe.

The pattern of reappearance of the planktic species and the larger benthic foraminifera in the area of study also points to their selective and gradual recovery during Early Cenozoic. In the post-Cretaceous scenario of events, the evolution of marine organisms took several million years to restore their normal diversity (Keller, 1988). Like the environmental deterioration of the Late Maastrichtian, the environmental amelioration (regeneration of habitable environments) during Early Palaeogene was also a slow process in which less sensitive (facies independent), morphologically simple plankton groups and smaller benthic foraminifera (r-strategists) appeared and diversified first in the stressful environments of the Danian seas. The specialised animal groups with complex morphologies (k-strategists to which the larger benthic foraminifera belong) recovered and diversified later when stable, stress-free, oligotrophic environments were restored in the Thanetian seas.

The state of oligotrophy, once destroyed in the terminal Cretaceous event, could not recover soon. It was re-established only when primary production was revitalised to the levels capable of sustaining a large number of ecological niches for carbonate-precipitating organisms on shallow shelves. The oligotrophy is a complex and slow process because it is related to warming, high sea level, low influx of terrigenous (nutrient) supply, reduced upwelling, etc. It may have taken several million years to accelerate the recovery of shallow, neritic carbonate depositional regimes.

The beginning of oligotrophy, characterised in many Early Palaeogene Tethyan sections by the first appearance of larger benthic foraminifera comprising operculines, miscellaneids, etc., has been correlated with the zone P_{3b}. It is followed by an interval of extensive carbonate deposition (referred to as the period of "expanded oligotrophy", Hallock *et al.,* 1991) when the larger foraminifera began to become highly diversified and widely distributed geographically. This interval is considered equivalent of the zone P_4, in which *Glomalveolina primaeva* first appears, and is characterised by full diversity of larger foraminifera (Hottinger, 1994). In the Shillong

PLATE 1 ⟶

1. *Glomalveolina primaeva* (Reichel) (axial section), lumps of algae and skeletal debris (sample No. 86/Lkd/DR1), x 25.
2. *Miscellanea juliettae villattae* Leppig (equatorial section), algal lumps and fragments of foraminifera (sample No. 86/Lkd/DR5), x 30.
3. *Miscellanea juliettae villattae* Leppig (axial section) (sample No. 86/Lkd/DR2), x 30.
4. *Glomalveolina primaeva* (Reichel) (axial sections) and algal lumps (sample No. 86/Lkd/DR4), x 25.
5. Microfacies showing Orbitolites sp., fragments of other foraminifera, *Distichoplax biserialis* and algal lumps (sample No. 86/Lkd/DR4), x 20.
6. *Operculina* sp. (equatorial section), algal lumps, fragments of foraminifera (sample No. 86/Lkd/DR1), x 30.

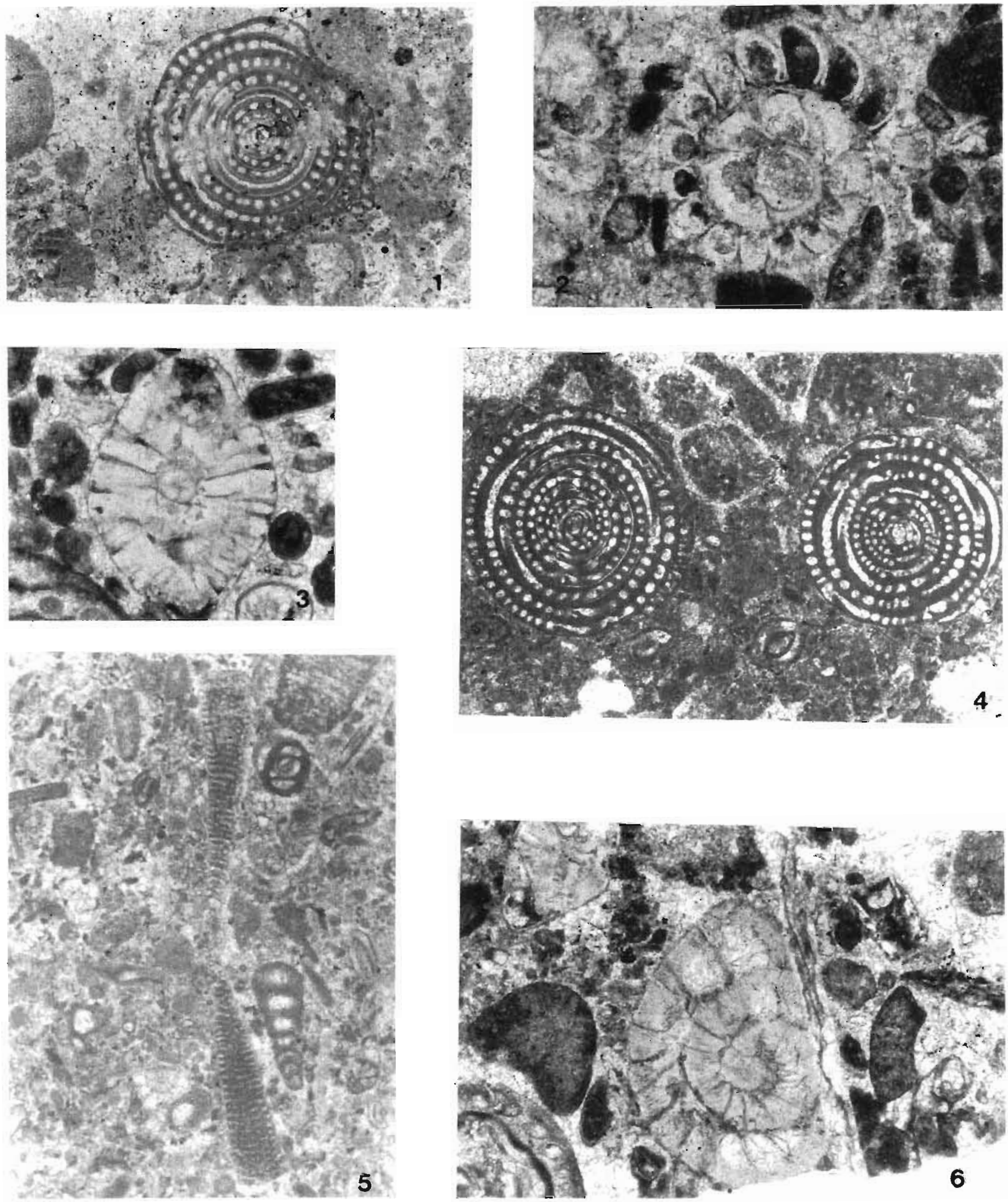


PLATE 1

area, the assemblage equivalent of the P_{3b} Zone is not developed and there is thus no indication of the early phase of oligotrophy. The Shillong assemblage of larger benthic foraminifera has been dated as the Thanetian (=P_4 Zone) by the presence of *G. primaeva* and is considered here to mark 'expanded oligotrophy' which seems to have created a large number of ecological niches for rapid evolution of larger foraminifera in the Shillong area.

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