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Dinoflagellate cysts from the Lakadong Sandstone, Cherrapunji area: biostratigraphical and palaeoenvironmental significance and relevance to sea level changes in the Upper Palaeocene of the Khasi Hills, South Shillong Plateau, India

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ABSTRACT

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The biostratigraphical and palaeoenvironmental significance of diagnostic Late Palaeocene (Thanetian) dinoflagellate cyst assemblages (dominated by *Apectodinium* and *Wilsonidinium* species) recovered from Lakadong Sandstone exposed around Cherrapunji, Khasi Hills (Meghalaya) is discussed. Based on the occurrence of the cosmopolitan markers, the dinoflagellate cyst assemblages are assigned to the combined *Apectodinium hyperacanthum* and *A. augustum* (Ahy-Aau) Biozones. Integration of dinoflagellate cyst evidence with larger foraminiferal data from the underlying Lakadong Limestone suggests close correspondence of the *Apectodinium* acme with the *Ranikothalia nuttalli- Miscellania miscella* Assemblage (SBZ 5-SBZ6). Estuarine and coastal swamp depositional setting is favoured for the coal-bearing Lakadong Sandstone which is considered to be the lateral facies equivalent of the upper Lakadong Limestone, developed during sea level highstand. TheTherria limestone/sandstone - Lakadong limestone/sandstone succession of the Khasi Hills is interpreted (to be deposits of transgressive and high stand system tracts) as representing a single depositional sequence between two minor sea level falls, possibly corresponding to the 3rd order cycles TA2·1-TA2·3 of the Global Sea Level Cycle Chart.

Key-words—Dinoflagellate cyst biostratigraphy, Palaeoenvironment, Sea level changes, Sequence stratigraphy, Late Palaeocene.

भारत के चेरापूँजी क्षेत्र के लाकाडोंग बालुकाश्म से प्राप्त घूर्णीकशाभ पुटियाँ : जैवस्तरिकीय एवं पुरापर्यावरणीय महत्त्व तथा दक्षिणी शिलांग पठार की उपरिपेलियोसीन युगीन खासी पर्वतश्रेणियों के समुद्र तलीय परिवर्तनों की प्रासंगिकता

राहुल गर्ग एवं ख्वाजा अतीकुज़्ज़माँ

सारांश

प्रस्तुत शोध पत्र में मेघालय की खासी पर्वतश्रेणियों में चेरापूँजी के आस-पास अनावरित लाकाडोंग बालुकाश्म से प्राप्त निदानसूचक अन्तिम पेलियोसीन (थैनेटियन) युगीन घूर्णीकशाभ पुटी समुच्चयों (जिनमें *एपेक्टोडीनियम* तथा *विल्सोनीडीनियम* प्रजातियों की प्रमुखता है) के महत्त्व के विषय में चर्चा की गयी है. विश्वव्यापी चिह्नकों की उपस्थिति के आधार पर घूर्णीकशाभ पुटीय समुच्चयों को संयुक्त रूप से *एपेक्टोडीनियम हाइपराकैन्थम* तथा *ए. ऑगस्टम* (आही-आउ) जैवमण्डलों में निर्धारित किया गया है. अधः शायी लाकाडोंग चूना पत्थर से प्राप्त वृहत्तर फ़ोरैमिनीफ़ेरीय आंकड़ों से पुष्ट घूर्णीकशाभ पुटी की एकान्विति *रानीकोथालिया नट्टाली-मिसलेनिया मिसेला* समुच्चय (एस.बी.ज़ेड. 5-एस.बी.ज़ेड. 6) से युक्त *एपेक्टोडीनियम* एक्मे के साथ गहन संगति प्रस्तावित करती है. लेखक कोयला धारी लाकाडोंग बालुकाश्म हेतु ज्वारनदमुखी एवं समुद्र तटीय अनूपीय निक्षेपणीय स्थितियों के पक्ष में हैं, जिसे समुद्र तलीय हाई स्टैण्ड के निर्मित होने के दौरान विकसित उपरि लाकाडोंग चूना पत्थर के समतुल्य क्षैतिज संलक्षणी माना जा सकता है. खासी पर्वत श्रेणियों के थीरिया चूना पत्थर/बालुकाश्म-लाकाडोंग चूना पत्थर/बालुकाश्म अनुक्रम को दो लघु समुद्र तलीय अधोगमनों को सम्भवतः भूमण्डलीय समुद्र तलीय चक्र तालिका के टी. ए. 2·1-टी.ए. 2·3 के तृतीय चक्र के मध्य एकमात्र निक्षेपणीय अनुक्रम का प्रतिनिधित्व करने वाले अनुक्रम के रूप में (संक्रामी एवं हाई स्टैण्ड सिस्टम वीथी के निक्षेपण हेतु) व्याख्यायित किया गया है.

संकेत शब्द—घूर्णीकशाभ पुटीय जैवस्तरिकी, पुरापर्यावरण, समुद्र तलीय परिवर्तन, अनुक्रम स्तरिकी, अन्तिम पेलियोसीन.

INTRODUCTION

THE Shillong Plateau is situated in Meghalaya, northeast India, bordering the plains of Bangladesh (Fig. 1). It lies on the southwestern edge of the Assam Shelf, which is considered to be the northeastern extension of the Indian Peninsular shield. The Assam Shelf includes the Shillong Plateau, Garo, Khasi, Jaintia and Mikir Hills and the Upper Assam Valley (Murty, 1983). The southern fringes of the Shillong Plateau, commonly referred to as the South Shillong Plateau, form the Khasi-Jaintia Hills. This is characterised by extensive development of carbonates alternating with sandstones ranging in age from Upper Palaeocene to Middle Eocene, belonging to the Sylhet Limestone Formation. The geology of the South Shillong Plateau has been dealt in detail by several workers (Medlicott, 1869; Evans, 1932; Ghosh, 1940; Wilson & Metre, 1953; Nagappa, 1959; Biswas, 1962; Mathur & Evans, 1964; Chakraborty, 1972; Murthy *et al.*, 1976; Dasgupta, 1977; Samanta & Raychaudhury, 1983).

The present paper deals with the dinoflagellate cyst assemblages recovered from the Lakadong Sandstone, the coal-bearing sandstone unit of the Sylhet Limestone Formation (Wilson & Metre, 1953; Raja Rao, 1981), exposed around Cherrapunji in the East Khasi Hills. It is sandwiched between well-dated larger foraminiferal-algal rich sediments of the Lakadong Limestone and the Umlatdoh Limestone. Although terrestrial palynofossils (spores and pollen) have been documented (Sah & Dutta, 1966; Dutta & Sah, 1970; Kar & Kumar, 1986), datable benthic or planktonic microfossils are yet to be recorded from the Lakadong Sandstone. In the absence of any direct evidence, age interpretations have been based primarily on its stratigraphical position and have ranged from Upper Palaeocene (Nagappa, 1959; Jauhri, 1994, 1996, 1998) to Lower Eocene (Pandey, 1972). The association of coal in the Lakadong Sandstone has also evinced keen interest for interpretations of its depositional environment. According to Raja Rao (1981) and Misra (1992), the coal-bearing Lakadong Sandstone was laid down in estuarine or lagoonal or coastal swampy conditions. However, Pandey and Ravindran (1988) favoured a fresh water origin for this unit considering it to be devoid of marine biota. Recovery of dinoflagellate cysts from Lakadong Sandstone, especially from horizons underlying and overlying the coal measures are, therefore, considered significant in this context.

The objectives of the present study are: (1) to investigate the dinoflagellate cyst assemblages for their stratigraphical and palaeoenvironmental significance, (2) to integrate the information with larger foraminiferal data for the purpose of stratigraphical precision and facies interpretation, and (3) to understand the microfossil evidence in terms of the depositional setting and changes in relative sea level. Interpretations of the depositional environment have been made with the support of data provided by Jauhri (1994, 1997) who made a detailed study of the larger foraminifera and the carbonate buildup in this region (Jauhri 1988, 1996, 1998). The inferred relative sea level changes, supplemented by dinoflagellate cyst and larger foraminiferal bioevents, are interpreted in a sequence stratigraphic context.

GEOLOGICAL SETTING

The stratigraphic framework of the Upper Cretaceous-Lower Tertiary shelf sediments exposed in the Khasi and Jaintia Hills has been the subject of intensive study by several workers. Evans (1932) redefined the "Nummulitic Series" of Medlicott (1869) as Sylhet Limestone stage. Wilson and Metre (1953) assigned separate names to the four limestone bands and three clastic interbands. The classification of Wilson and Metre

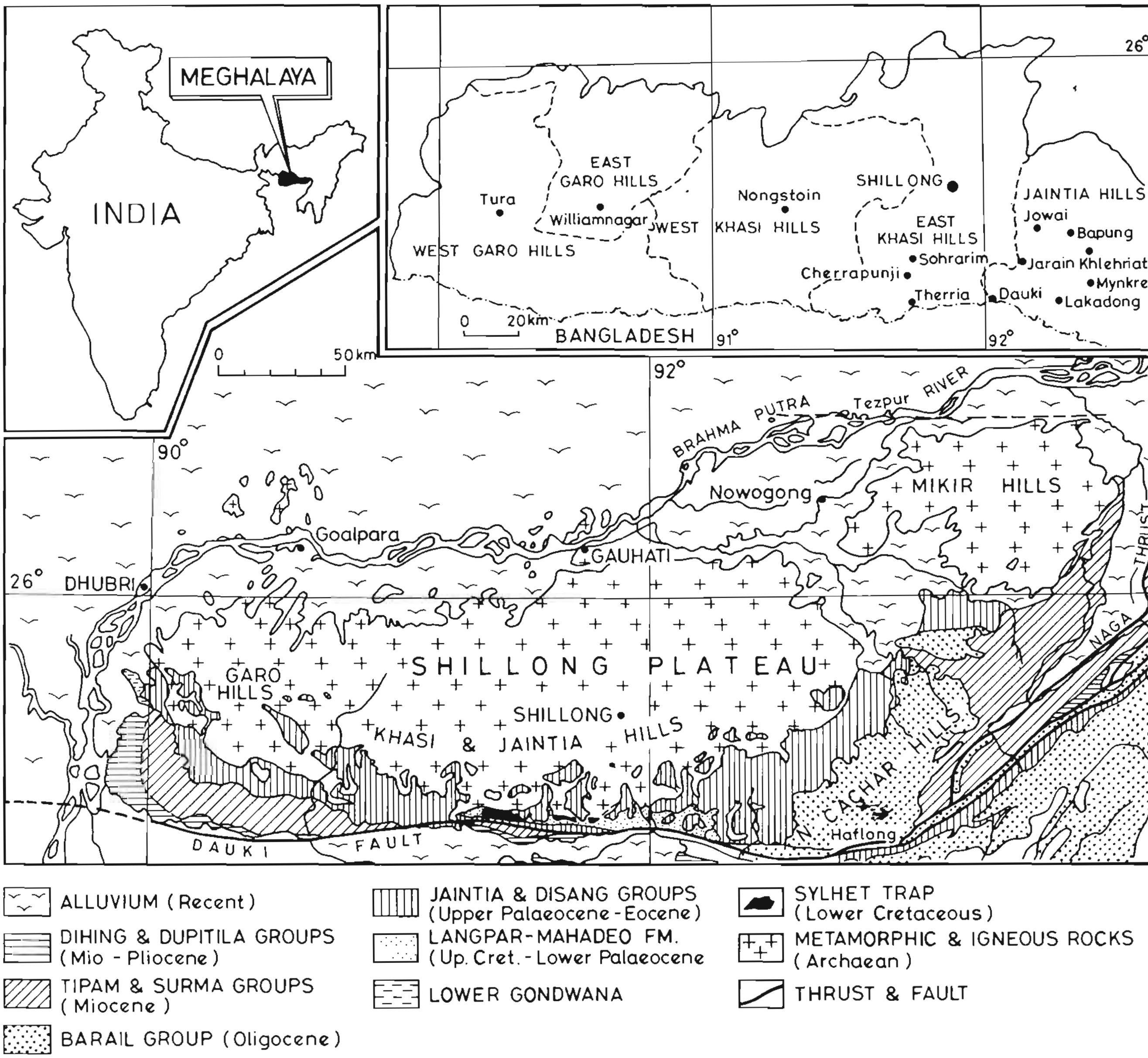

Fig. 1—Location Map showing main geological features of the South Shillong Plateau (after Mathur & Evans, 1964).

(1953) has been used widely with modifications by later workers (Nagappa, 1959; Biswas, 1962; Mathur & Evans, 1964; Murthy *et al.*, 1976; Dasgupta, 1977; Raja Rao, 1981). Biswas (1962) and Raja Rao (1981) subsequently gave the formal lithostratigraphical status to the chronostratigraphical nomenclature introduced by Wilson and Metre (1953). The lithostratigraphical classification followed in the present work is given in Fig. 2.

The Palaeogene carbonate succession exposed on the South Shillong Plateau belongs to the Sylhet Limestone Formation, which includes three foraminifera rich limestone units interbedded with thick sandstone - shales units (Wilson & Metre, 1953; Nagappa, 1959; Raja Rao, 1981). The Sylhet Limestone Formation ranges in age from Upper Palaeocene to Middle Eocene (Thanetian – Bartonian). All three limestone units contain characteristic and datable larger foraminiferal assemblages. The Lakadong Sandstone contains thin but workable coal seams in parts of the Khasi and Jaintia Hills.

The Sylhet Limestone Formation overlies the Upper Palaeocene Therria Formation which is characterised by hard, compact, well-bedded sandstones with an extensively bioturbated sandy horizon, rich in *Thallasinoides* burrows, towards the top. This ichno-horizon, which is termed as the *Therria Ichno-horizon*, is well exposed south of Cherrapunji

STAGE		AGE	FORMATION/ MEMBER		THICK-NESS M	LITHOLOGY
EOCENE	UPPER	PRIBONIAN	KOPILI FORMATION		500	Alternations of fine to coarse sandstones, grey siltstones and shales with few limestone bands
	MIDDLE	LUTETIAN-BARTONIAN	SYLHET LIMESTONE FORMATION	P RANG LIMESTONE	60-150	Bluish grey massive to thinly bedded foraminiferal limestones with marl earthy limestone
				NARPUH SANDSTONE	15-26	Coarse to medium grained ferruginous sandstones with pyrite nodules and thin calcareous and shaly bands
	LOWER	YPRESIAN		UMLATDOH LST	70-110	Grey to pinkish grey foraminiferal limestone with calcareous sandstone partings
PALAEOCENE	UPPER	THANETIAN		LAKADONG SST	35-150	Predominantly buff to whitish, soft, friable, medium to coarse grained arkosic sandstone, often pyriteous with thin grey-black, frequently burrowed, carbonaceous shales and siltstones and thin coal seams
				LAKADONG LST	10-60	Grey to brownish grey foraminiferal-algal limestone, dolomitic at the base with thin grey shale, silty shale partings in the upper part
		SELANDIAN	THERRIA FORMATION		20-80	Hard, buff to brownish, medium to coarse, ferruginous sandstones with thin bands of pyriteous siltstone & carbonaceous shale; '*Thalassinoides* Ichno' horizon near the top, thick limestone/calcareous sandstone at the base.
	LOWER	DANIAN	LANGPAR FORMATION		10-50	Grey to buff coloured earthy limestones and calcareous sandstones interbedded with calcareous silty shales and carbonaceous shales
UPPER CRETACEOUS		MAASTRICHTIAN	MAHADEO FORMATION		160-335	Massive, fine to coarse grained glauconitic sandstones containing grey shales, mudstones and calcareous sandstones in the upper part;conglomerates and pebbly sandstones at the base
? JURASSIC TO LOWER CRETACEOUS			SYLHET TRAP		250-400	Aa and pahoehoe type Basalts

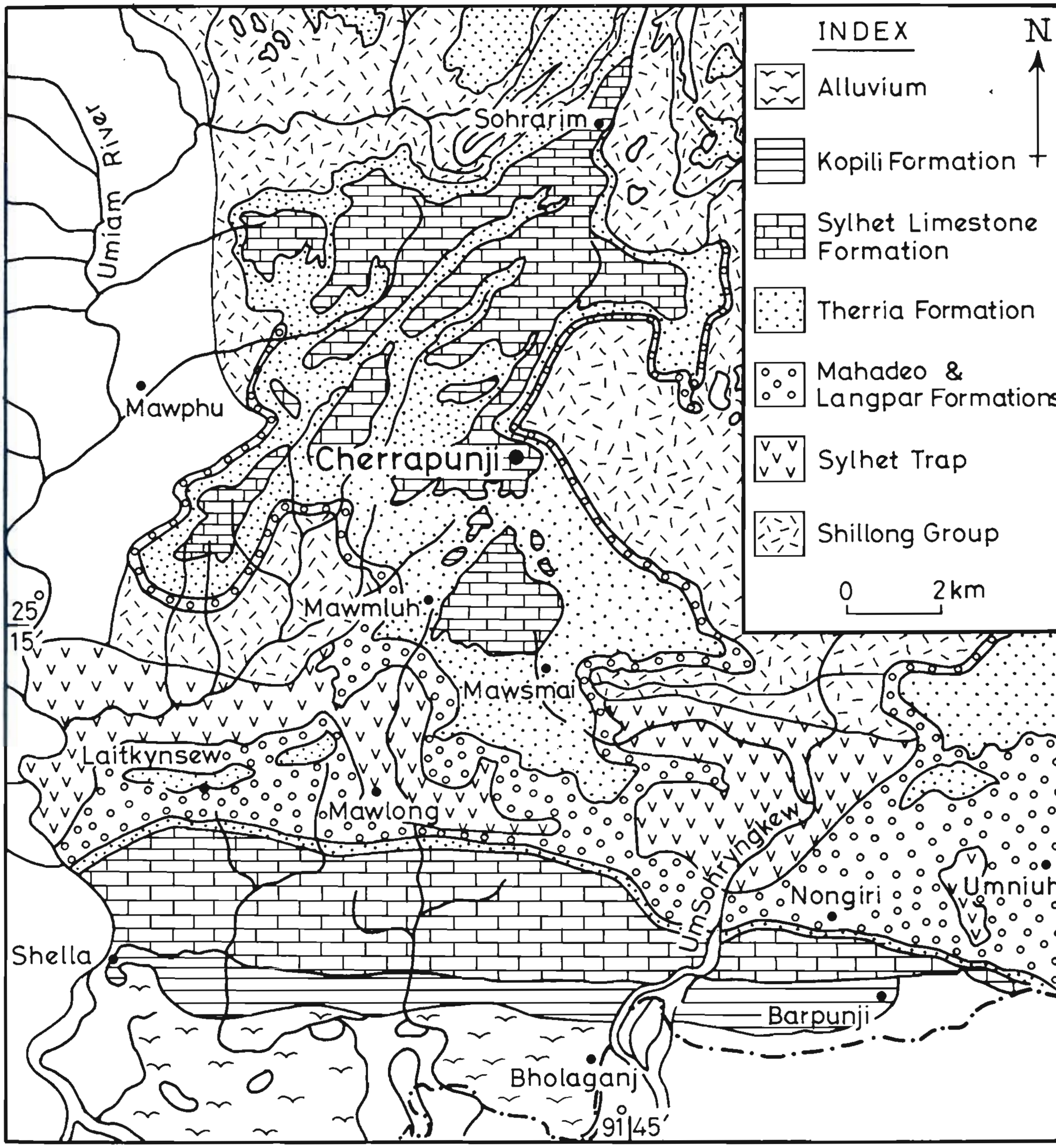

Fig. 3—Geological map of Cherrapunji area (Redrawn from Ghosh, 1940).

(e.g., near Cherra Circuit House and Naokalikai Falls picnic spot, and Mawsmai Gate on the Cherra-Shella road) in the Khasi Hills. It has been found to extend eastward to the south of Jowai near Jarain (Jowai-Muktapur track), southwards of Pynurkha (Rymbai-Borghat track) and on the hill slopes leading to Khadum (westwards of Jowai-Badarpur Road) in

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Fig. 2—Stratigraphical classification of Upper Cretaceous- Eocene rocks of the Khasi Hills (Modified after Raja Rao, 1981).

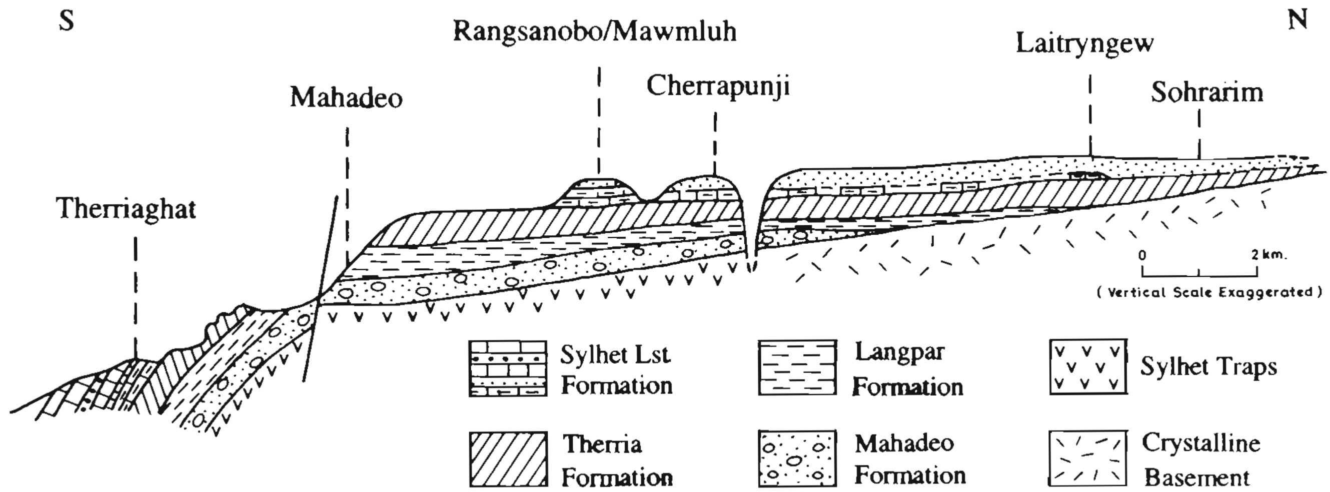

Fig. 4—Schematic cross-section of the Cherrapunji- Therriaghat area, South Shillong Plateau, showing distribution of Upper Cretaceous-Eocene rocks (Modified after Ghosh, 1940).

the Jaintia Hills (see Fig. 1). It is considered to represent a widespread regional transgressive event, which may serve as a good marker horizon. The Therria Formation is conformably overlain by the algal-foram rich Lakadong Limestone to be followed higher-up by coal-bearing Lakadong Sandstone.

The Lakadong Limestone and Lakadong Sandstone are exposed over a wide area around Cherrapunji. The overlying units of the Sylhet Limestone Formation are confined to the southern fringes of the plateau. Ghosh (1940) mapped the area in detail, which has provided the basis of subsequent studies in this area (Fig. 3).

The Lakadong Limestone and Lakadong Sandstone show a variable development on the Cherrapunji Plateau and along its southern slopes towards the plains of Bangladesh (Ghosh, 1940). Towards the south, the Lakadong Limestone has the thickest development as seen at the Therriaghat (Um Sohryngkew) section. It is attenuated northwards near Mawmluh, Rangsanobo and Nongthymmai with a considerably reduced thickness at Cherrapunji. North of Cherrapunji, the Lakadong Limestone rapidly pinches out towards Laitryngew (Medlicott, 1869). Near 29 MP (mile post) on Shillong – Cherrapunji Road section, Lakadong Limestone is completely absent and the Lakadong Sandstone directly overlies the Therria Formation. There is a corresponding increase in the thickness of the Lakadong Sandstone, which shows its thickest development near Laitryngew and Sohrarim, northwards of Cherrapunji, but becomes vastly attenuated towards the south in the Therriaghat section (Fig. 4). Only carbonaceous shales occur in the Lakadong Sandstone and no coal is found here.

These lateral facies changes, coupled by the juxtaposition nature of the two sandstone units (Medlicott, 1869; Ghosh, 1940), seem to have created a considerable confusion regarding the stratigraphical position of the coal-bearing sandstones exposed north of Cherrapunji, in the Khasi Hills and also in parts of the Jaintia Hills. The coal-bearing Lakadong Sandstone has often been misinterpreted as the Therria Formation (including the Cherra Sandstone of earlier workers) in the Cherrapunji Plateau (Sen, 1948 in Biswas, 1962; Sah & Dutta, 1966; Dutta & Sah, 1970, 1974). However, these coal-bearing sandstones of the Khasi-Jaintia Hills have long been considered to constitute the lower part of the Sylhet Limestone Formation (Medlicott, 1869; Ghosh, 1940; Wilson & Metre, 1953; Nagappa, 1959; Biswas, 1962; Das Gupta, 1977; Raja Rao, 1981; Samanta & Raychaudhuri, 1983). Biswas (1962) had categorically mentioned that there is no coal associated with the "Cherra Formation" (Therria Formation). In the Jaintia Hills, exposures of the coal-bearing Lakadong Sandstone around Bapung, north of Mynkre along the Jowai-Badarpur Road (see Fig. 1), have been mapped as the Therria Formation which has been mistaken as the main

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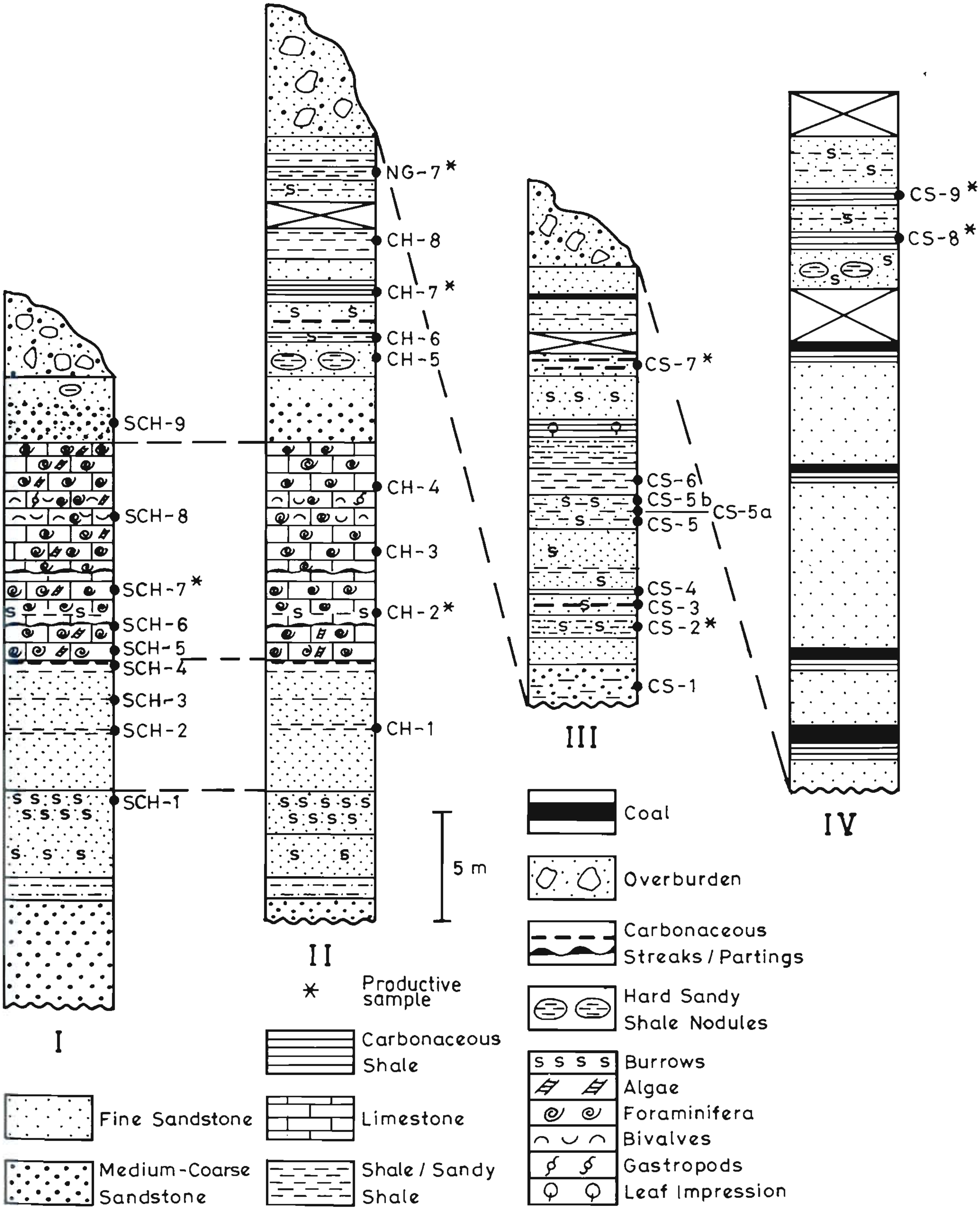
Fig. 5—Studied Sections exposed North of Cherrapunji along the Shillong-Cherrapunji Road (MP refers to 'milepost' as marked on the Survey of India toposheet no. 78 O/11).

I. Section ca 300 m west of road across a rivulet (31/2 MP).

II. Section on a hillock along the eastern side of the road between 31 & 32 MP (sample NG7 was collected from the other side of the hillock after a traverse to Nongpriang Valley. The upper part of the hillock exposing more than 30 m of the Lakadong Sandstone, containing a minor coal seam at the top, was not sampled due to slumping.)

III. Composite section along the road from north of Sohrarim up to Mawmithied (between 24 & 26 MP).

IV. Section near Laitryngew, samples CS8 & CS9 collected from the road side section just south of Laitryngew, overlying the thick succession of coal-bearing sandstone exposed in the coalfield.


NG-7 *
CH-8
CH-7 *
CH-6
CH-5
CH-4
CH-3
CH-2 *
CH-1
SCH-9
SCH-8
SCH-7 *
SCH-6
SCH-5
SCH-4
SCH-3
SCH-2
SCH-1
CS-7 *
CS-6
CS-5 b
CS-5a
CS-5
CS-4
CS-3
CS-2 *
CS-1
CS-9 *
CS-8 *
I
II
III
IV
5 m
Coal
Overburden
Carbonaceous Streaks / Partings
Hard Sandy Shale Nodules
Burrows
Algae
Foraminifera
Bivalves
Gastropods
Leaf Impression
* Productive sample
Carbonaceous Shale
Limestone
Shale / Sandy Shale
Fine Sandstone
Medium-Coarse Sandstone

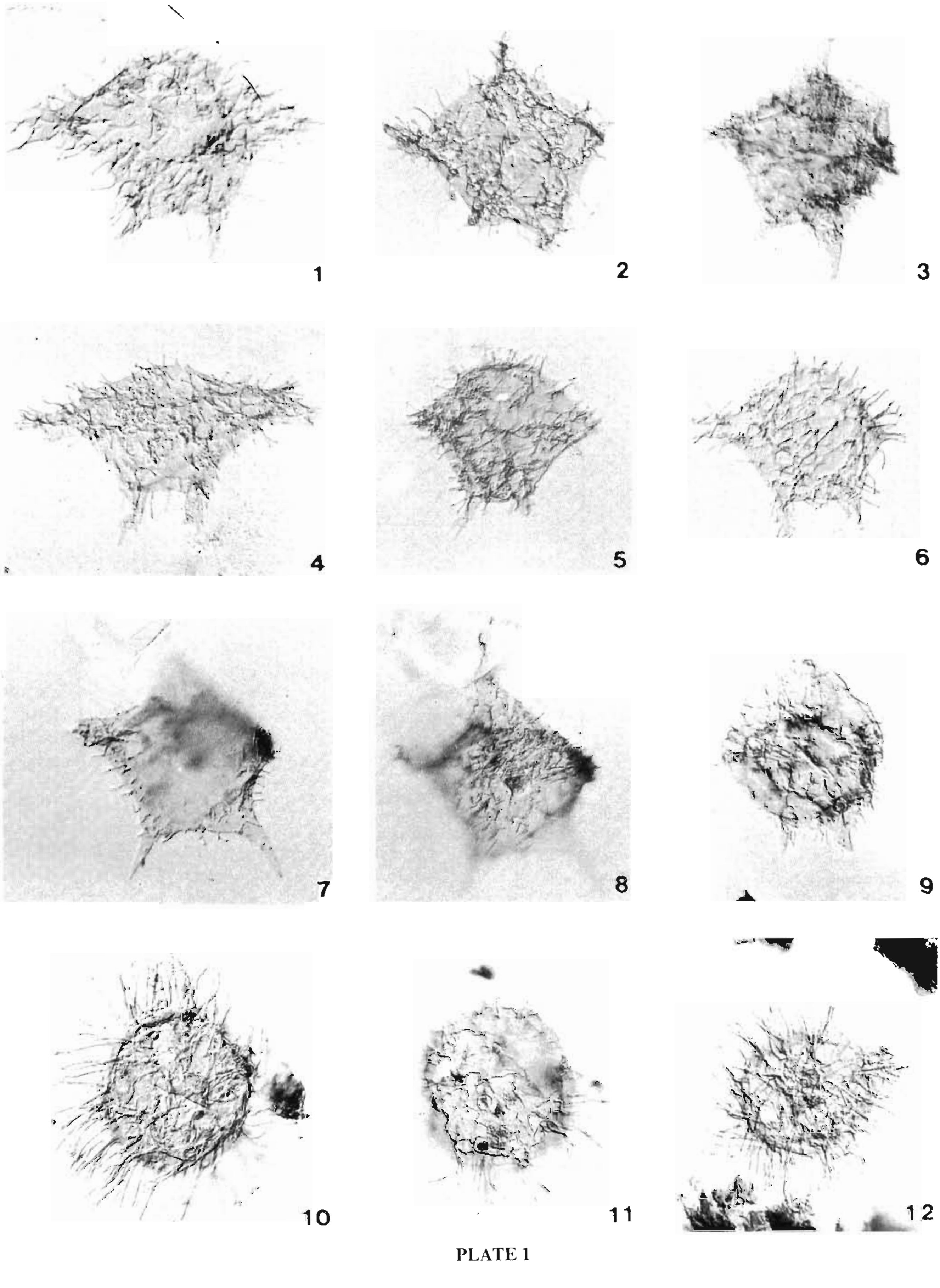


PLATE 1

coal measure unit in the area (Saxena & Tripathi, 1982). The Therria Formation is exposed near Mynkre (Dutta & Jain, 1980) and coal occurrences near Bapung and other areas in the Jaintia Hills have been found to be restricted to the Lakadong Sandstone (Raja Rao, 1981; Misra, 1992). The age significant findings of the dinoflagellate cyst assemblages reported from the supposedly Therria Formation (Tripathi & Singh, 1984; Singh & Tripathi, 1986; Tripathi, 1989) have, therefore, to be viewed in this context.

MATERIAL AND METHODS

Samples for the present study were collected from sections exposed north of Cherrapunji. The sections lie along the Cherrapunji-Shillong Road in vicinity of Cherrapunji, Laitryngew, Sohrarim and Mawmithied (Fig. 5). Out of 29 samples, 8 proved to be productive of dinoflagellate cysts and acritarchs. Additional material collected from the Um Sohryngkew (Therriaghat) section, Nongthymmai and Mawmluh limestone quarries (south of Cherrapunji) and from the Jowai-Badarpur Road section in Jaintia Hills has also been studied for comparison and correlation purposes.

For the recovery of dinoflagellate cysts, the samples were processed using standard palynological techniques. After HCl and HF treatment, the macerate was treated with 40% HNO_3 for oxidation and washed using 25 μm sieve. After staining with safranin, the water-free residue was mixed with polyvinyle alcohol and spread evenly on the glass cover slides. Permanent slides were prepared by fixing the oven dried cover slides using Canada balsam as the mounting medium. Study and photography was carried out on Olympus Vanox –AH2 microscope with Nomarski Interference Contrast and automatic photo attachments. The illustrated dinoflagellate cysts are provided with the England Finder positions on the respective slides. The slides have been registered and deposited in the repository of the Museum, Birbal Sahni Institute of Palaeobotany, Lucknow.

DINOFLAGELLATE CYST ASSEMBLAGES

The organic-walled phytoplankton assemblages recovered from the Lakadong Sandstone of Cherrapunji area are well preserved, and show low to moderate species richness with often-high numerical abundance of individual species. The assemblages contain 30 species of dinoflagellate cyst and 3 species of acritarch (see checklist; Plates 1-3). A preponderance of peridinioid dinoflagellate cysts (*Apectodinium* and *Wilsonidinium*) is strikingly evident over all the other species.

The assemblages contain many species of *Apectodinium* including A. *homomorphum, A. hyperacanthum, A. parvum, A. paniculatum, A. quinquelatum* and *Apectodinium* cf. *A. augustum*. Another species of *Apectodinium*, recorded here as *Apectodinium* sp. A, is also very common and is an important component of the assemblages. *Apectodinium* sp. A is characterised by a shorter than broad cyst lacking an apical horn, much reduced or absent antapical horns and long and broad lateral horns. Transitional forms between A. *paniculatum* and *A. augustum*, characterised by very well developed horns and much longer processes were also recorded and documented here as *Apectodinium* sp. B. The assemblages also show common *Wilsonidinium* species. Two of the most commonly occurring species of *Wilsonidinium* are documented here as *Wilsonidinium* sp. A and *Wilsonidinium* sp. B. *W. nigeriense* and W. *echinosuturatum* occur rarely. As detailed morphologic and taxonomic study of dinoflagellate cysts are not intended here, a taxonomic account of these significant morphotypes of *Apectodinium* and *Wilsonidinium* will be published elsewhere.

Some other important species occurring rarely in the assemblages include *Ifecysta pachyderma, Muratodinium fimbriatum* and *Lanternosphaeridium lanosum*. The remaining species in the assemblages (*Polysphaeridium subtile, Cordosphaeridium inodes, C. exilimurum, Achomosphaera* sp., *Spiniferites* spp., *Adnatosphaeridium multispinosum, Operculodinium* spp., *Thalassiphora pelagica* and *Amphorosphaeridium multispinosum*) are longer ranging and occur rarely.

Out of all the productive samples, richest dinoflagellate cyst assemblages are recorded from three levels (samples NG7, CS7 and CS8; see Fig. 5). Occurrence of dinoflagellate cysts above and below the coal measures is significant as it helps to date precisely the coal occurrences in this region. Assemblages below the coal measures display high frequencies of both *Apectodinium* and *Wilsonidinium*, while those overlying the coal measures (Sample CS8) show abundance of *Apectodinium*

PLATE 1

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(All figures in Nomarski Interference Contrast; magnified x 500)

1, 4. *Apectodinium paniculatum* (Costa & Downie) Lentin & Williams 1977, Slide nos. BSIP 12482 (W44/2); 12481(E46/1).

2, 3. *Apectodinium hyperacanthum* (Cookson & Eisenack) Lentin & Williams 1977, Slide nos. BSIP 12483 (K59); 12482 (Y52/3).

5, 6. *Apectodinium quinquelatum* (Williams & Downie) Costa & Downie 1979, Slide nos. BSIP 12480 (N45/4), 12481 (K56).

7, 8. *Apectodinium* cf *A. augustum* (Harland) Lentin & Williams 1977, Slide no. BSIP 12482 (V27/1).

9. *Apectodinium parvum* (Alberti) Lentin & Williams 1977, Slide no. 12482 (R60).

10–12. *Apectodinium homomorphum* (Deflandre & Cookson) Lentin & Williams 1977, Slide nos. BSIP 12487 (G60); 12490 (R51/1); 12481 (W52).

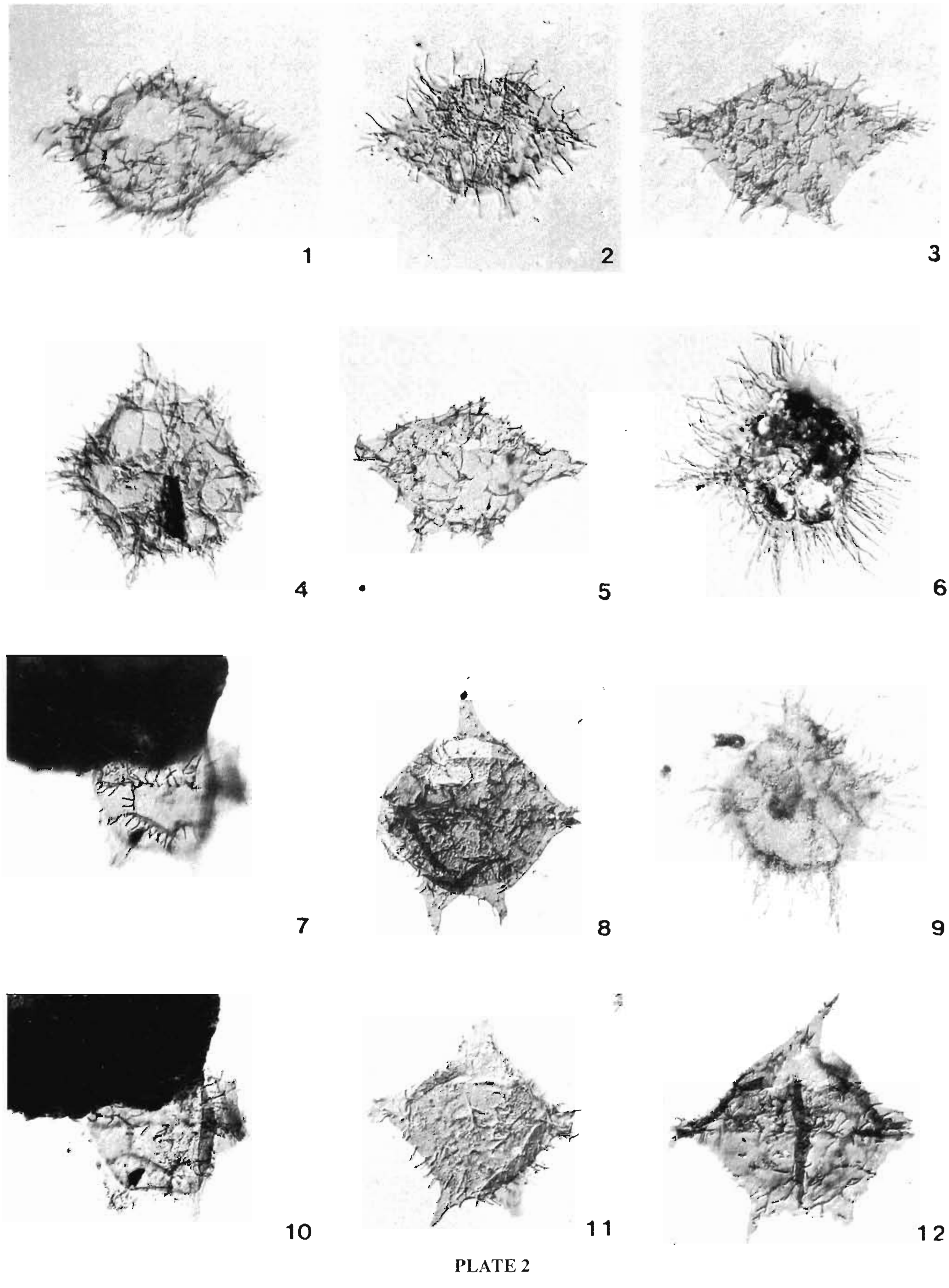

PLATE 2

only. *Wilsonidinium* was not recorded at this level but *Muratodinium fimbriatum* is rarely present. *Ifecysta pachyderma* and *Lanternosphaeridium lanosum* (solitary occurrences) are confined to lower levels (Sample NG7) only.

A few samples taken from the Lakadong Limestone also yielded dinoflagellate cyst assemblages represented only by rare *Operculodinium, Polysphaeridium* and *Adnatosphaeridium*. Samples of Lakadong Sandstone collected from southerly exposures at the Nongthymmai and Mawmluh limestone quarries and the Therriaghat section yielded rare unrecognisable dinoflagellate cysts and mainly contain acritarchs including *Collumosphaera* spp.

Checklist

For taxonomy of genera and species and complete bibliography, reference is made to that cited in Williams *et al.* (1998) for dinoflagellate cysts and Fensome *et al.* (1990) for acritarchs.

Dinoflagellate cysts:

1. *Achomosphaera* sp.
2. *Adnatosphaeridium multispinosum* Williams & Downie, 1966
3. *Amphorosphaeridium multispinosum* (Davey & Williams) Sarjeant, 1981
4. *Apectodinium* cf. *A. augustum* (Harland) Lentin & Williams, 1977
5. *A. homomorphum* (Deflandre & Cookson) Lentin & Williams, 1977
6. *A. hyperacanthum* (Cookson & Eisenack) Lentin & Williams, 1977
7. *A. paniculatum* (Costa & Downie) Lentin & Williams, 1977
8. *A. parvum* (Alberti) Lentin & Williams, 1977
9. *A. quinquelatum* (Williams & Downie) Costa & Downie, 1979
10. *A. longispinosum* (Wilson) Bujak & Davies, 1983
11. *Apectodinium* sp. A
12. *Apectodinium* sp. B
13. *Cordosphaeridium fibrospinosum* Davey & Williams, 1966
14. *C. gracile* (Eisenack) Davey & Williams, 1966
15. *C. inodes* (Klump) Eisenack, 1963
16. *Diphyes colligerum* (Deflandre & Cookson) Cookson 1965
17. *Eocladopyxis peniculata* Morgenroth, 1966
18. *Fibrocysta* sp.
19. *Ifecysta pachyderma* Jan du Chene & Aderidan, 1985
20. *Lanternosphaeridium lanosum* Morgenroth, 1966
21. *Muratodinium fimbriatum* (Cookson & Eisenack) Drugg, 1970
22. *Operculodinium* sp.
23. *Polysphaeridium subtile* Davey & Williams, 1966
24. *Spinidinium macmurdoensis* (Wilson) Lentin & Williams, 1977
25. *Spiniferites* sp.
26. *Thalassiphora pelagica* (Eisenack) Eisenack & Gocht 1960 emend. Benedeck & Gocht 1981
27. *Wilsonidinium echinosuturatum* (Wilson) Lentin & Williams, 1976
28. *Wilsonidinium* sp. cf. *W. nigeriense* Jan du Chene & Aderidan, 1985
29. *Wilsonidinium* sp. A
30. *Wilsonidinium* sp. B

Acritarchs:

1. *Collumosphaera* cf. *C. fruticosa* Jain & Dutta in Dutta & Jain, 1980
2. *Cyclopsiella* sp.
3. *Pterospermopsis* sp.

Previous dinoflagellate cyst records from South Shillong Plateau

In the South Shillong Plateau, Palaeocene dinoflagellate cysts have been recorded from the Cherrapunji-Therriaghat areas of the Khasi Hills and the Jowai-Badarpur Road section in the Jaintia Hills (Sah *et al.*, 1970; Jain *et al.*, 1975; Dutta & Jain, 1980; Jain & Garg, 1982; Tripathi & Singh, 1984; Singh & Tripathi, 1986; Garg, 1986; Tripathi, 1989; Garg & Jain, 1993, 1996). Upper Palaeocene assemblages are known only from the Jowai-Badarpur Road section (Dutta & Jain, 1980; Tripathi & Singh, 1984; Singh & Tripathi, 1986; Tripathi, 1989; authors' unpublished data) and contain species of *Apectodinium*.

Dutta & Jain (1980) recorded seven species of dinoflagellate cyst from the uppermost part of the Lakadong Sandstone near its contact with the overlying Umlatdoh Limestone and assigned Late Palaeocene age. Except for *Hystrichokolpoma rigaudae*, all the other species are common

←

PLATE 2

(All figures in Nomarski Interference Contrast; magnified x 500)

1–3, 5. *Apectodinium* sp. A , Slide nos. BSIP 12483 (F64); 12480 (U49 , M50); 12481 (W39/4).

4. *Apectodinium longispinosum* (Wilson) Bujak & Davies, 1983, Slide no. BSIP 12489 (V61).

6, 9. *Apectodinium* sp. B , Slide nos. BSIP 12487 (J60/2); 12488 (N39/1).

7, 10. *Wilsonidium echinosuturatum* (Wilson) Lentin Williams 1976. Slide no. BSIP 12486 (N34/4).

8, 11, 12. *Wilsonidium* sp. A, Slide nos. BSIP 12480 (K41/4); 12485 (J43/1); 12483 (U51/1).

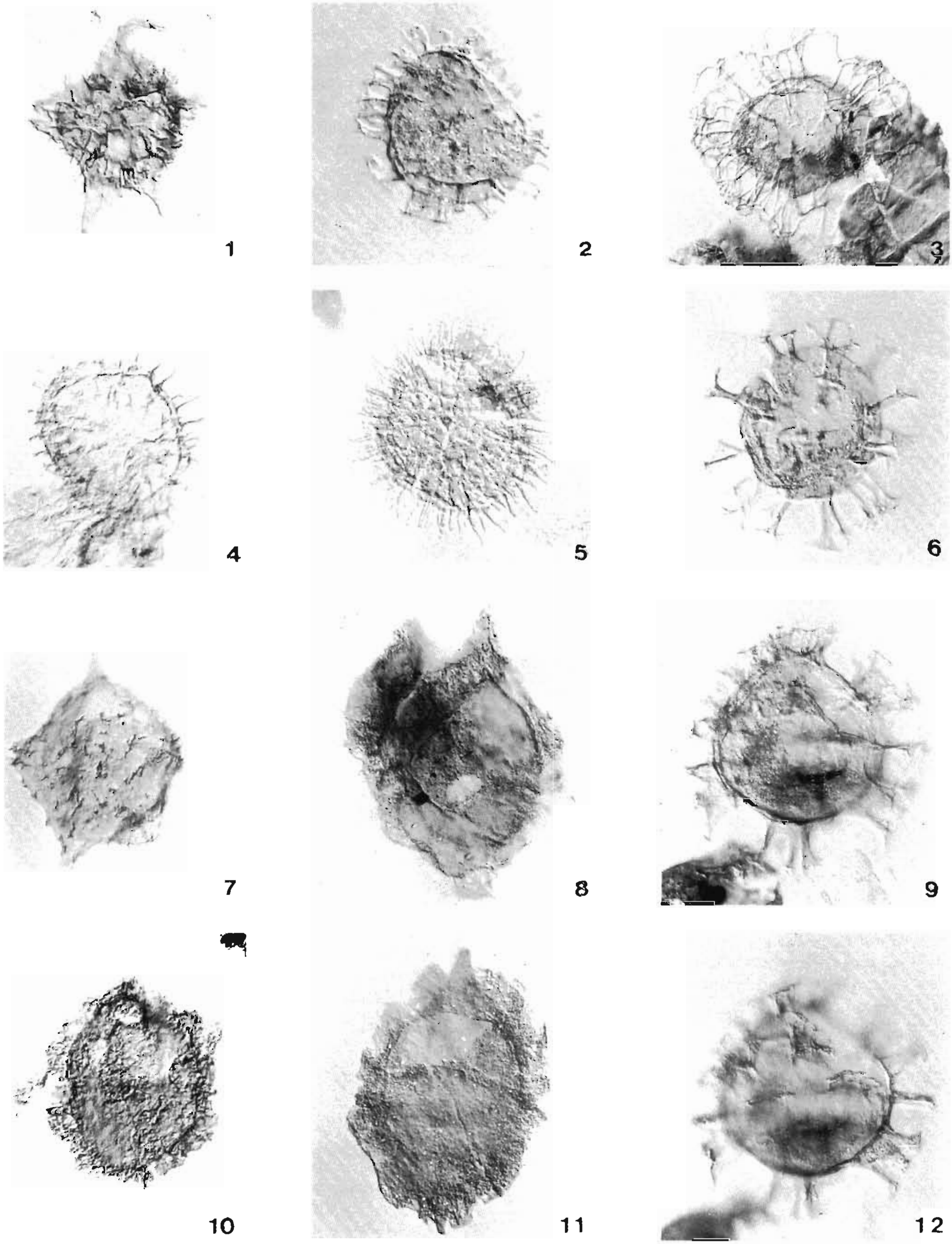

PLATE 3

to the Cherrapunji area also. *Apectodinium parvum* is found to be the most abundant species while *A. homomorphum* and *A. hyperacanthum* are only rarely recorded.

Tripathi & Singh (1984), Singh & Tripathi (1986) and Tripathi (1989) documented dinoflagellate cyst assemblages from the so-called Therria Formation (Lakadong Sandstone as discussed elsewhere in this paper). These studies are significant as datable dinoflagellate cysts assemblages were reported from strata associated with coal seams in this area. The assemblages contain 13 species and show dominance of *Apectodinium,* represented by *A. homomorphum* and *A. parvum* only. Other species belong to *Adnatosphaeridium, Homotryblium, Cordosphaeridium, Operculodinium, Polysphaeridium* and *Thalassiphora* (recorded as *Codoniella langparensis* by Tripathi, 1989) and show a close similarity with the Cherrapunji assemblages. This has been aptly corroborated by dinoflagellate cyst evidence from the Lakadong Sandstone exposed between Bapung and Lumshnong in the Jowai-Badarpur Road section (authors' unpublished data). However, no dinoflagellate cysts were recovered from upper levels of the Therria Formation underlying the Lakadong Limestone, during the course of the present study.

Comparable assemblages dominated by *Apectodinium* are widely recorded from India including Vriddhachalam (Jain & Garg, 1986) and subsurface of Karaikal (Jain & Garg, unpublished data) in the Cauvery Basin, subsurface of the Krishna-Godavari Basin (Garg *et al*., 1995) and subsurface of the Kutch Basin (authors' unpublished data). Direct calibration of these assemblages with the Late Palaeocene nannofossil *Discoaster multiradiatus* Zone (NP9) has also been established in the Gopurapuram area, Vriddhachalam in the Cauvery Basin (Jain *et al*., 1983; Jain & Garg, 1986). Recent findings of *Apectodinium* and *Wilsonidinium* assemblages, closely comparable to those recorded in this report, from the subsurface of the Upper Assam Valley (authors' unpublished data) may be extremely useful in identification of equivalent sediments in the subsurface of the Assam Shelf.

DISCUSSION

Stratigraphic Significance

The genus *Apectodinium* is the oldest representative of the sub family Wetzelielloideae (Family Peridiniaceae), and is one of the most characteristic and stratigraphically important genera in the Palaeogene dinoflagellate cyst assemblages worldwide. Standard biozonation schemes based on their species have been proposed and precisely calibrated with Standard planktonic foraminifera and calcareous nannofossil biozonation schemes. Powell (1992, pp. 176-178) re-defined two Late Thanetian biozones *Apectodinium hyperacanthum* (Ahy) and *A. augustum* (Aau) for the Palaeocene of NW Europe. The older Ahy Biozone is defined between the FAD of *A. homomorphum* and FAD of *A. augustum* whereas the younger Aau Biozone covers the interval between the FAD of *A. augustum* and that of *P. magnificum*. However, Brinkhuis *et al*. (1994) reported *A. hyperacanthum* from the early part of Late Palaeocene close to the Danian – Selandian boundary corresponding to the base of the planktonic foraminifer Zone P3 in the low – latitude El Kef Section. It represents the earliest stratigraphic occurrence of the genus *Apectodinium*. This is agreed with our unpublished investigations as part of a wider study encompassing Late Maastrichtian to Palaeocene dinoflagellate cysts from Meghalaya. In these studies, *A. hyperacanthum* has been recorded in the uppermost part of the Langpar Formation, containing P3 Zone planktonic foraminifera. A worldwide *Apectodinium* Acme nevertheless occurs close to the Palaeocene-Eocene Boundary (Harland, 1979; Powell, 1992; Brinkhuis *et al*., 1994).

The Aau biozone is characterised by the presence of *Apectodinium augustum, A. hyperacanthum, A. paniculatum, A. parvum, A. quinquelatum* and *A. summissum,* besides the rather long ranging *A. homomorphum*. It has been calibrated with calcareous nannofossil Zone NP9 (pars) of Martini (1971), planktonic foraminifera Zones P5 (pars) plus P6a (Berggren, 1969; Berggren & Miller, 1988) equivalent to Zone P5 of Berggren *et al*. (1995), and the dinoflagellate cyst sub-Biozone D5a of Costa & Manum (1988). The age of the Aau

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PLATE 3

(All figures in Nomarski Interference Contrast; magnified x 500)

1 *Wilsonidium* sp. B, Slide no BSIP 12480 (Q63/1).

2. *Amphorosphaeridium? multispinosum* (Davey & Williams) Sarjeant 1981. Slide no. BSIP 12482 (V23).

3. *Adnatosphaeridium multispinosum* Willams & Downie 1966. Slide no. BSIP 12483 (K58/1).

4 *Polysphaeridium subtile* Davey & Williams 1966 emend. Bujak *et al*., Slide no. BSIP 12491 (T60).

5. *Eocladopyxis peniculata* Morgenroth 1966, Slide no. BSIP 12484 (Q62/2).

6. *Cordosphaeridium gracile* (Eisenack) Davey & Williams 1966, Slide no. BSIP 12484 (H61/2).

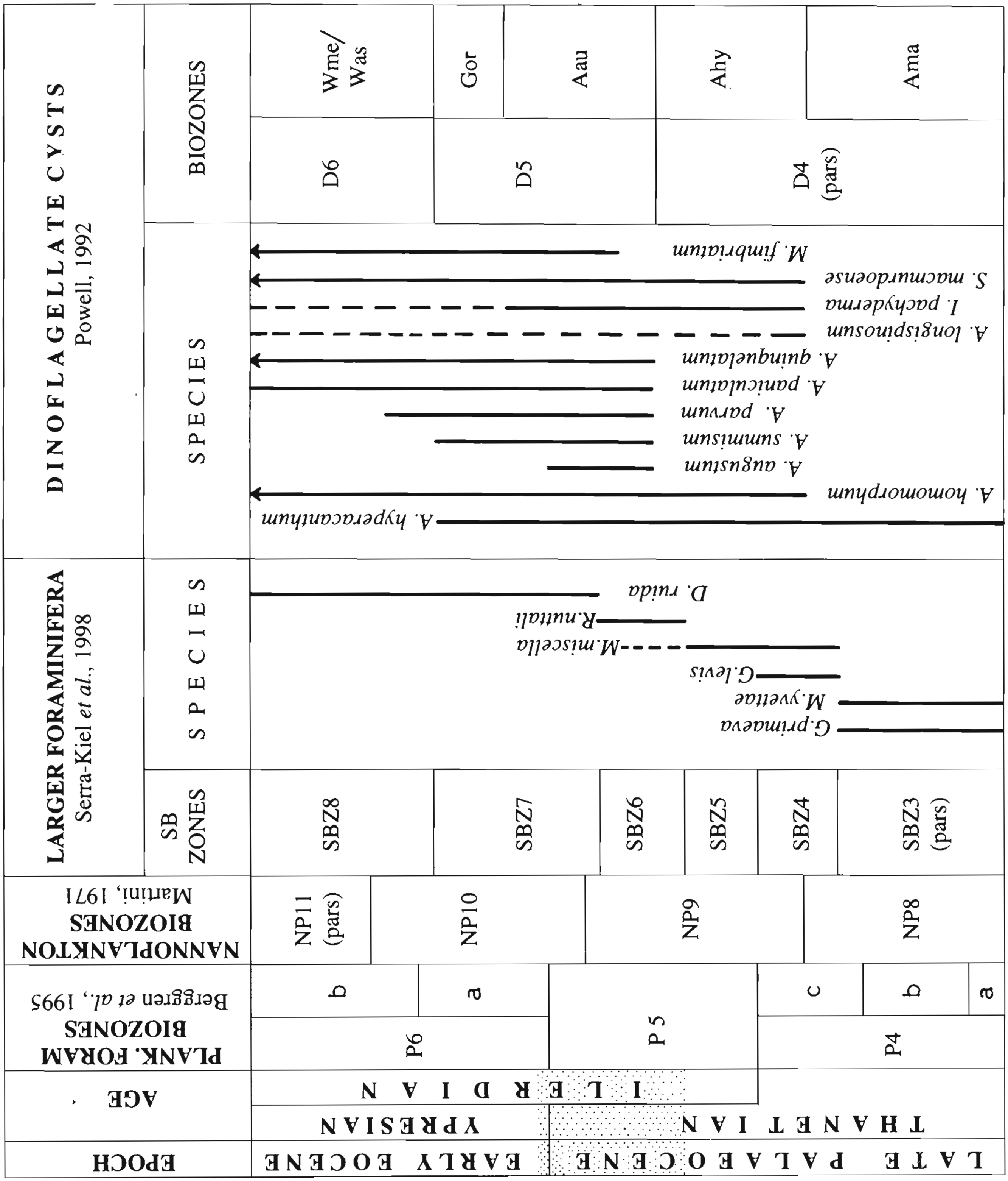
7. *Spinidinium macmurdoense* (Wilson) Lentin & Williams1977, Slide no. BSIP 12483 (T25).

8. *Lanternosphaeridium lanosum* Morgenroth 1966, Slide no. BSIP 12484 (V60).

9, 12. *Cordosphaeridium fibrospinosum* Davey & Williams 1966, Slide no. BSIP 12484 (O39).

10. *Cullunosphaera* cf. *C. fruticosa* Jain & Dutta in Dutta & Jain 1980, Slide no. BSIP 12492 (V45/3).

11 *Ifecysta pachyderma* Jan du Chene & Aderidan 1985. Slide no. BSIP 12485 (W64/1).


EPOCH
LATE PALAEOCENE
EARLY EOCENE
AGE
THANETIAN
YPRESIAN
ILERDIAN
PLANK. FORAM BIOZONES
Berggren et al., 1995
P4
P 5
P6
a
b
c
NANNOPLANKTON BIOZONES
Martini, 1971
NP8
NP9
NP10
NP11 (pars)
LARGER FORAMINIFERA
Serra-Kiel et al., 1998
SB ZONES
SBZ3 (pars)
SBZ4
SBZ5
SBZ6
SBZ7
SBZ8
SPECIES
G.primaeva
M.yvettae
G.levis
M.miscella
R.nuttali
D. ruida
DINOFLAGELLATE CYSTS
Powell, 1992
SPECIES
A. hyperacanthum
A. homomorphum
A. augustum
A. summissum
A. parvum
A. paniculatum
A. quinquelatum
A. longispinosum
I. pachyderma
S. macmurdoense
M. fimbriatum
BIOZONES
D4 (pars)
D5
D6
Ama
Ahy
Aau
Gor
Wme/Was

Biozone ranges from Latest Thanetian to base Ypresian (Powell, 1988, 1992). *A. augustum* has its LAD at the Palaeocene-Eocene Boundary (Powell, 1988; Williams *et al.*, 1993).

The presence of rich and diverse *Apectodinium* assemblages in the Lakadong Sandstone exposed in the Cherrapunji area suggests its placement in the Aau Biozone indicating Late Thanetian age. Occurrence of *Wilsonidinium nigeriense* and *Ifecysta pachyderma*, known from Late Thanetian-Early Ypresian (NP9 or NP9 – NP10 zones) of Nigeria (Jan du Chene & Adediran, 1985), further supports assignment of the Lakadong Sandstone assemblages to the Late Thanetian, close to the Thanetian-Ypresian Boundary. The Cherrapunji assemblages also contain *Spinidinium macmurdoense*, *Wilsonidinium echinosuturatum* and *Apectodinium longispinosum* in common with New Zealand Late Palaeocene assemblages (Wilson, 1968, 1988). However, in the basal part of the Lakadong Sandstone, immediately above the Lakadong Limestone but below sample NG7, a slightly older age (possibly equivalent to Ahy Zone) is preferred due to the occurrence of a meagre assemblage containing only *A. homomorphum* and *Apectodinium* sp. A.

The dinoflagellate cyst assemblages assigned to the Ahy/ Aau biozones are found to overlie directly the *Glomalveolina primaeva* Assemblage Zone (SBZ3 = Late P4) within the Lakadong Limestone dated on the evidence of *Miscellania yvettae* and *M. juliettae* from the Cherrapunji section (Jauhri, 1994, 1998; Serra-Kiel *et al.*, 1998). Dinoflagellate cyst assemblages from levels overlying the coal measures, although less diverse, are still quite rich in *Apectodinium*, and in addition contain *M. fimbriatum* and *A. longispinosum*. This is indicative of a slightly younger age assignable to the upper part of the Aau Biozone.

In the Therriaghat section, the interval overlying the SBZ3-SBZ4 assemblage, is represented by the *Ranikothalia nuttalli-Miscellania miscella* Assemblage (SBZ 5 to SBZ6), corresponding to the planktonic foraminiferal Zone P5. It extends from the upper part of the underlying Lakadong Limestone to the base of overlying Umlatdoh Limestone and is dated as "Early Ilerdian / Late Thanetian" (Jauhri, 1994).

The combined evidence of dinoflagellate cysts and larger foraminifera from Cherrapunji and Therriaghat areas are not only useful in terms of integrated biostratigraphical resolution, but also permit inferences to be drawn upon lateral facies development and interrelationship of Lakadong Limestone and Lakadong Sandstone. A comparative range chart of selected dinoflagellate cyst and larger foraminiferal species is presented in Figure 6. The evidence indicates that a major part of the Lakadong Sandstone (including the coal measures), at Cherrapunji is coeval and the lateral facies equivalent of the upper part of the Lakadong Limestone which was laid down in more basinal areas to the south. It is interesting to note that Biswas (1962) had suggested that coal-bearing sandstones in areas north of Cherrapunji were most likely deposited at the time of limestone deposition (Sylhet Limestone Formation) of the southerly sections. However, interpretations regarding their precise age and correspondence with any specific unit of the Sylhet Limestone Formation were left unresolved by Biswas (1962).

A suggested correlation of the Cherrapunji Plateau sections with the Therriaghat section, based on integration of dinoflagellate cyst and larger foraminifera (Jauhri, 1994, 1996, 1998), is presented in Figure 7. The *Glomalveolina primaeva* Zone (SBZ3), identified on the evidence of *Miscellanea yvettae* and *M. juliettae* in the Cherrapunji section, is correlated to the lower part of the combined *G. primaeva- G. levis* Zone (SBZ3-SBZ4) of the Therriaghat section (corresponding to the upper part of the planktonic foraminifera P4 Zone). The upper part of the *G. primaeva-G. levis* Zone (latest P4 Zone), characterised by total range of *G. levis* in the Therriaghat section, is equated with the lower part of Ahy-Aau Zone at the base of the Lakadong Sandstone in Cherrapunji section (which directly overlies the *G. primaeva* Zone). *G. levis* is not recorded from the Cherrapunji section. The *Apectodinium* acme in the Cherrapunji section is tentatively correlated to the first appearance of *Ranikothalia nuttalli* in the lower part of *R. nuttalli-M. miscella* Zone (SBZ5-SBZ6) corresponding to the P5 Zone. Occurrence of *Muratodinium fimbriatum,* supporting a comparatively younger age in the assemblage overlying the coal measures, is probably correlatable with the uppermost part of the combined SBZ5-SBZ6 Zones identified at Therriaghat. Overlying strata, equivalent to the Lakadong Sandstone exposed in the Therriaghat section, are apparently not present in the Cherrapunji section or may have been eroded away. Samples from this part in Therriaghat section show a preponderance of acritarchs (*Collumosphaera* spp.), observed in the Mawmluh Limestone quarry section also which lies between Therriaghat and Cherrapunji (see Fig. 4). The larger foraminifera from the basal part of the overlying Umlatdoh Limestone at Therriaghat show the appearance of *Daviesina ruida* in association with *R. nuttalli,* indicative of an 'early Ilerdian'/Late Thanetian age, corresponding to late P5 Zone

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Fig. 6—Comparative Range Chart of selected species of dinoflagellate cysts and larger benthic foraminifera recorded in Cherrapunji- Therriaghat area.
(i) The Dinoflagellate Cyst Zones and Shallow Benthic Zones (SBZ) are directly integrated with Standard Foraminifera/ Nannofossil Zones by respective authors; their correlation shown here is by implication;
(ii) The Planktonic Foraminifer P5 Zone of Berggren *et al.* 1995 incorporates Subzone P6a of Berggren 1969 and Berggren & Miller, 1988.
(iii) Shaded part in the Epoch/ Age column shows the Palaeocene/ Eocene "Boundary Time Span" in Shallow Tethys Region indicated by Molina *et al.* (1992) spanning the interval between ~ 54.6 to 55.5 Ma according to Serra-Kiel *et al.* (1998) & Berggren *et al.* (2000, p. 45, fig. 3);
(iv) In Dinocyst Bizonation Scheme of Powell (1992), the top of NP9 Zone is placed in the basal Early Eocene following Haq *et al.* (1987a).

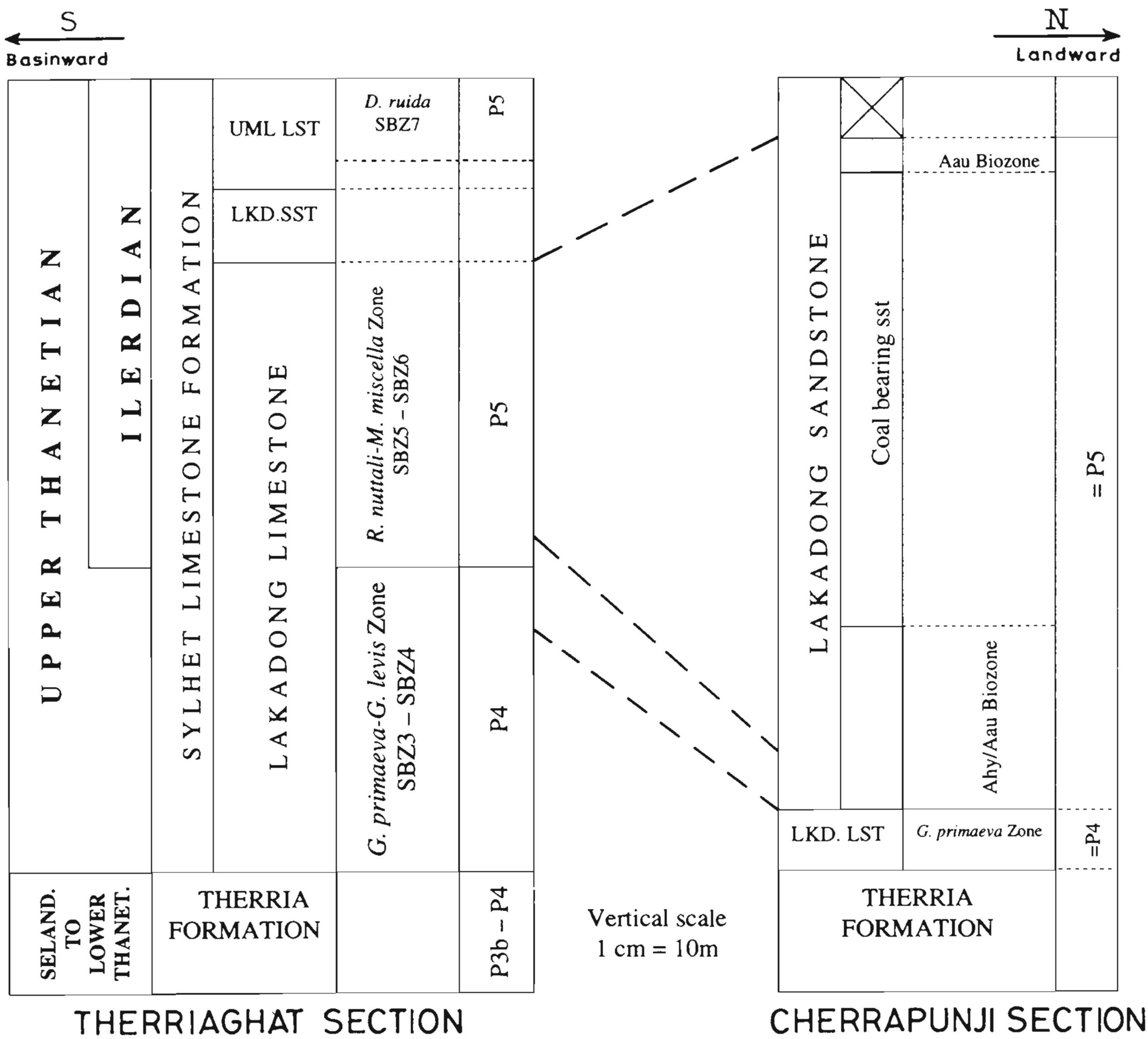


Fig. 7—Correlation of Therriaghat and Cherrapunji Plateau section.

(Jauhri, 1998). Significantly, the occurrence of *Apectodinium hyperacanthum* is noted in the basal part of the Umlatdoh Limestone, (overlying the *Apectodinium* acme horizon in the upper levels of the Lakadong Sandstone), in the Thangski Coffee Garden section, Jowai-Badarpur Road in the Jaintia Hills. The evidence from Meghalaya allows integration between larger foraminifera and dinoflagellate cysts (as Ahy-Aau Biozones are found to closely calibrate with SBZ4 to lower part of SBZ7). The close stratigraphic correspondence of the *Apectodinium* Acme with the *Ranikothalia nuttalli–Miscellanea miscella* Assemblage Zone is suggested. It is noteworthy that correspondence of the lower part of the *A. hyperacanthum* Zone (equivalent to the combined Ahy-Aau Biozones) with *G. levis* Zone has also been noted in the North Pyrenees of Europe (Tambareau, 1994).

Palaeoenvironmental aspects

A predominance of *Apectodinium* is considered to be indicative of low salinity, estuarine or near shore environments (Downie *et al.*, 1971; Costa & Downie, 1976). Its acme in NW Europe represents reduced salinity in a depositional setting below wave base with anoxic bottom conditions

(Heilmann-Clausen, 1985). The occurrence of bacterial infestation and pyrite relic structures (sensu Neves & Sullivan, 1964) on cyst walls of *Apectodinium* (pl. 1, fig. 11; pl. 2, fig. 6) is suggestive of post depositional biodegradation of cysts in a reducing environment. Similar conditions have been noted in the *Apectodinium* suite reported from the Krishna-Godavari Basin (Garg *et al.*, 1995). The association of *Apectodinium* rich assemblages with NP9 Zone calcareous nannofossils (dominated by tiny Braarudosphaerids) has been attributed to near shore, low salinity, restricted marine conditions (Jain & Garg, 1986).

The occurrence of *Apectodinium* rich levels in the Lakadong Sandstone, therefore, suggests low salinity, reducing bottom conditions probably below wave base. The association of pyrite relic structures with dinoflagellate cysts in the upper part points towards anoxic bottom conditions. The occurrence of iron sulphide has been noted in the upper horizons of Lakadong Sandstone near its contact with the Umlatdoh Limestone in the Cherrapunji- Shella Road section, Khasi Hills and the Thangski Coffee Garden section (Jowai-Badarpur Road) in Jaintia Hills. In the Therriaghat and Mawmluh sections, the predominance of almost monospecific assemblage of acritarchs and rarity of dinoflagellate cysts in the uppermost Lakadong Sandstone may indicate stressful conditions (see Tyson, 1995).

In a study based on larger benthic foraminifera from the Lakadong Limestone in South Shillong Plateau, Jauhri (1994, 1996) related the foraminifera-algal rich carbonate buildups to the phase of "Expanded Oligotrophy" in a shallow neritic setting that began to develop during P4 (Thanetian) times in the Shillong region. This phase is characterised by the emergence of carbonate platform environments during the deposition of the Lakadong Limestone and continued up to the deposition of the Umlatdoh Limestone. The oligotrophic setting, however, seems to have been interrupted for a while when limestone deposition was hampered and the coal-bearing Lakadong Sandstone was laid down.

According to Brasier (1995), the marine ecosystem is under prolonged influence of oceanic control which operates through the interaction of several factors including climate, sea level fluctuations, nutrient influx, terrigenous input, upwelling, ocean mixing, etc. A state of Oligotrophy is generated during high stands of sea level when the climate is warmer and sea waters are depth stratified with low nutrient supply (Brasier, 1995). Because of decreased terrigenous flux and increased production of carbonate precipitating organisms, oligotrophy enhances carbonate buildups on shallow shelves (Hottinger, 1987). During low stands of sea level, with relatively cooler climates and highly connective seawaters, eutrophic conditions are likely to develop. Such conditions lead to considerable mixing of water masses and thereby enriched nutrient supply. This is also accompanied by increased terrigenous flux giving rise to stressed environments and often accompanied by reduced salinity. In such an environment, carbonate precipitation is hampered resulting in considerable loss of carbonate platform environments and the destruction of larger foraminiferal populations (Caron & Homewood, 1983; Jauhri, 1997).

Phytoplanktons, especially dinoflagellate cysts, are important (palaeo) biological indicators of upwelling and eutrophication events. A predominance of Peridiniacean cysts (P) over Gonyaulacacean cysts (G) have been used as marker for palaeo-upwelling based on the studies of the Late Miocene to Holocene succession of the Bering Sea and North Pacific (Bujak, 1984), and Quaternary sediments off Peruvian Coast (Powell *et al.*, 1992). An increase in phytoplankton biomass typically takes place during eutrophication events caused by coastal upwelling (Powell *et al.*, 1992) or river discharge (Malone, 1991).

In the context of a prolonged phase of "Expanded Oligotrophy", in the Shillong Shelf, it may be possible to record a short-lived phase of eutrophic conditions developed as a consequence of changes in the depositional environment. The overall predominance of P-cysts and the rarity of G-cysts in the Lakadong Sandstone points towards stressful conditions due to the onset of deposition in estuarine-coastal swamp environments. Lowered salinity caused by very high terrestrial runoff is indicated by the abundance of land derived plant debris, which tends to accompany increased terrigenous flux. Sudden replacement of the dinoflagellate cyst assemblages by an almost monospecific assemblage of the acritarch *Collumosphaera* in the thin Lakadong Sandstone wedge (between thick foram-rich limestones in Therriaghat section) may have taken place due to shallowing accompanied by increased fresh water flux. Carbonate precipitation was hampered for a short period. These conditions seem to be indicative of a short-lived eutrophication event associated with a sea level low stand towards the top of the Lakadong Sandstone sandwiched between a major phase of "Expanded Oligotrophy" towards the end of the Palaeocene.

DEPOSITIONAL SETTING AND SEQUENCE STRATIGRAPHIC CONSIDERATIONS

A comprehensive study of larger foraminifera and facies development of the carbonate buildup in the Cherrapunji-Therriaghat area by Jauhri (1988, 1994, 1996, 1998) has provided the basic depositional framework of the studied succession. According to Jauhri (1994; personal communication), the Lakadong Limestone represents deposits of a progradational cycle of the carbonate platform laid down during sea level high stand. This began after the Late Palaeocene marine flooding event, correlative to the *Therria Ichno-horizon*, possibly before the *G. primaeva* Zone

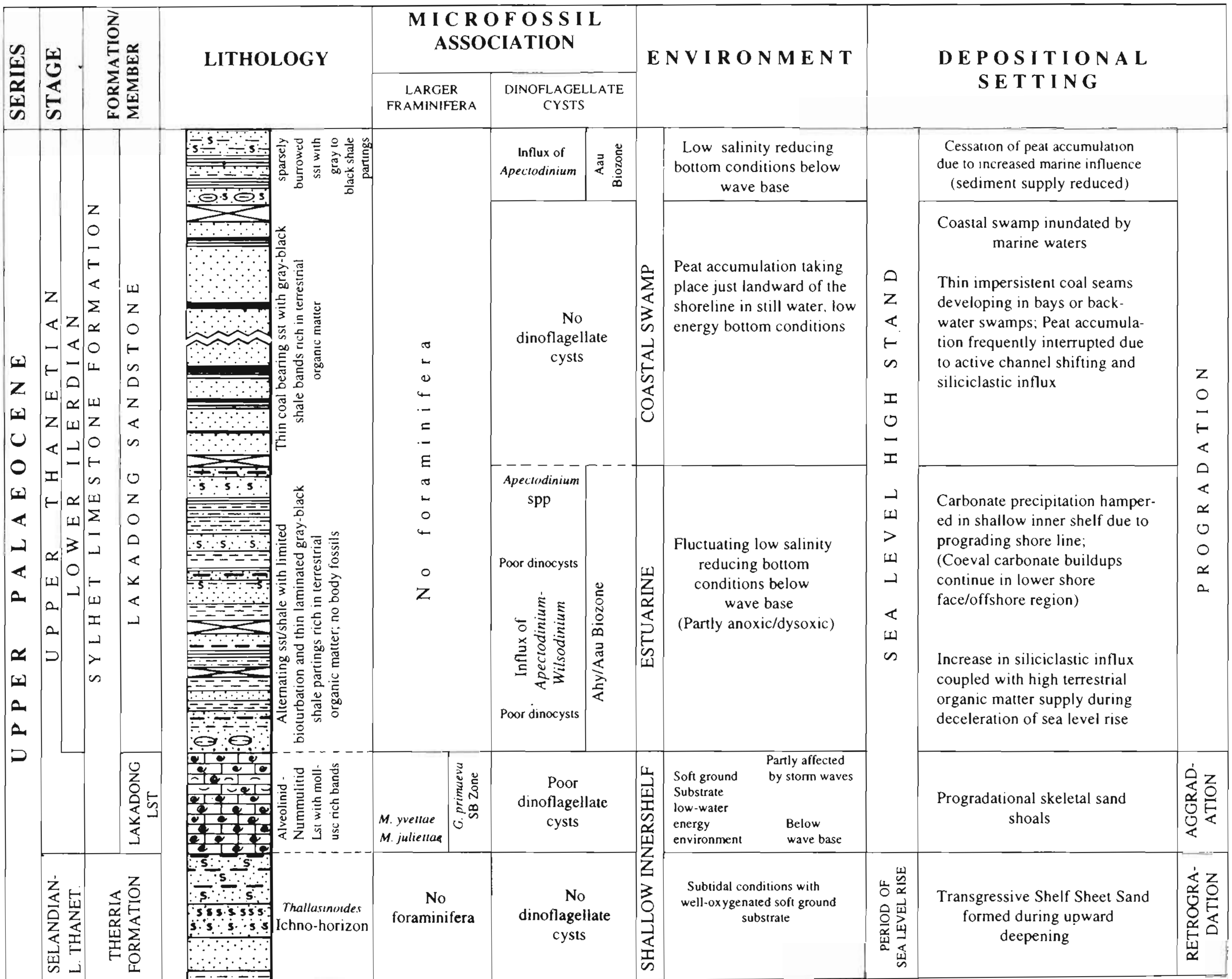


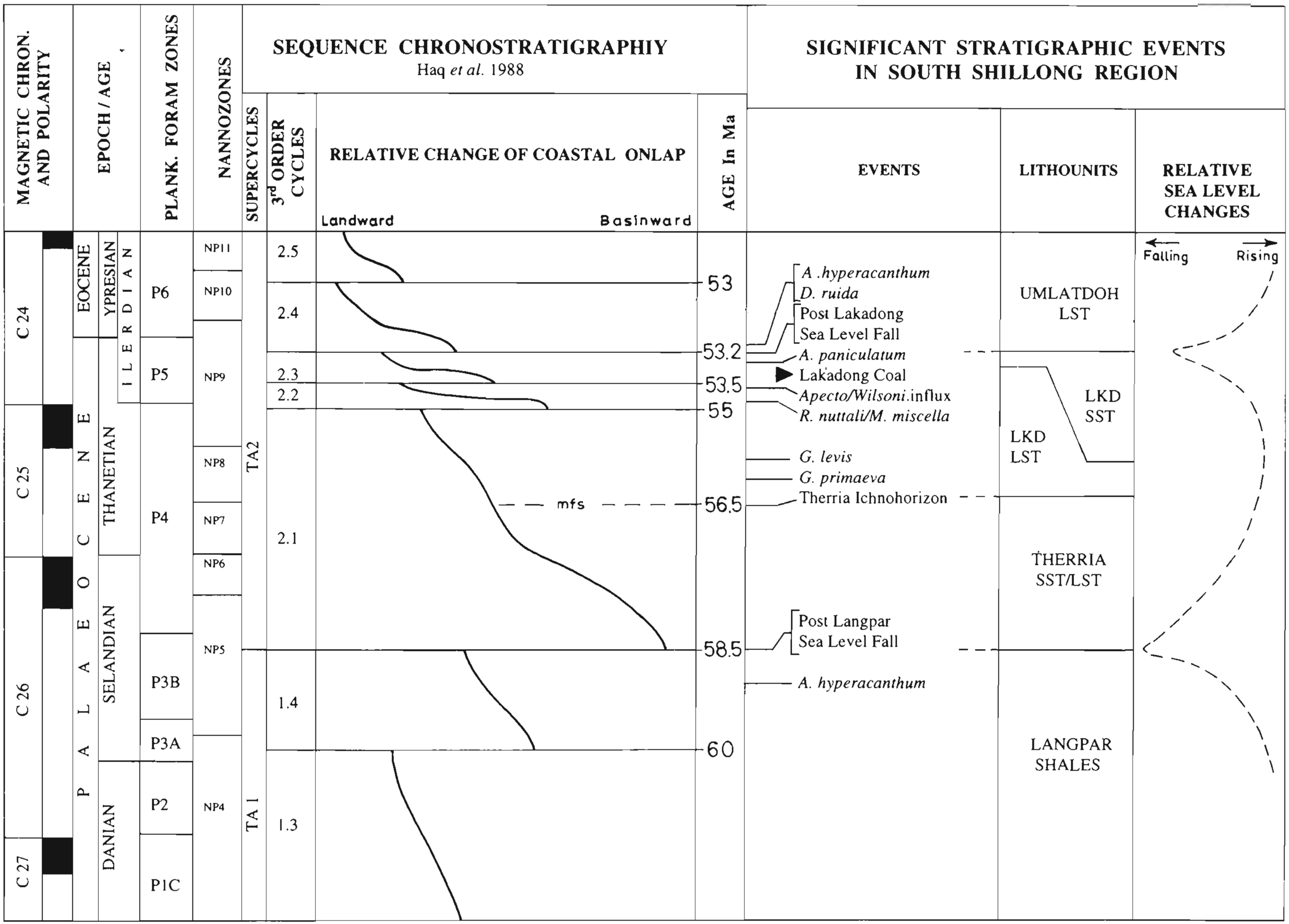
Fig. 8—Palaeoenvironment. Depositional setting and Stratigraphic development of the lower part of the Sylhet Limestone Formation in the Cherrapunji Plateau.

(equivalent to early P4 Zone). Evidence from dinoflagellate cysts and other related data have now made it possible to understand the depositional setting of the Lakadong Sandstone and associated strata and interpret the Upper Palaeocene succession of Khasi Hills in a sequence stratigraphic context (Figs. 8-9).

The *Thallasinoides* -rich Ichno-horizon towards the top of the Therria Formation represents a transgressive shelf sheet sand body formed during upward deepening as a consequence of the rise in relative sea level after the post-Langpar sea level fall. It is a widespread planar deposit of regional extent, albeit with some variations in the burrowing intensity (in the Khasi-Jaintia Hills) and may serve as a marker bed within the Therria Formation. Reduced sediment supply during the transgression favoured the prolific growth of burrowing organisms and extensive bioturbation under subtidal conditions with a well-oxygenated soft ground substrate. This Ichno-horizon represents a marine flooding event of regional extent and indicates the most landward position of the shoreline extending farthest northward onto the Cherrapunji Plateau (see Fig.4). The overlying strata of the Therria Formation are relatively thin bedded, finer sandstones/siltstones containing thin black carbonaceous organic-rich partings and burrowed horizons. The Therria Ichno-horizon could be interpreted as a maximum flooding surface (mfs) or else, together with the overlying strata, may either represent a maximum flooding zone (sensu Emery & Meyers, 1996).

Continued decrease in sediment supply supported the growth of algal-foram rich carbonate buildups that began to aggrade during the period of sea level high stand on the shallow shelves in lower shoreface/offshore region. This occurred mainly under low-water energy conditions, possibly below fair-weather wave base, with depths ranging between 10-20 m or even less (Jauhri, 1994). Sudden increase in terrigenous flux during a further deceleration of sea level rise resulted in rapid progradation of the shoreline. Carbonate buildups on the innermost part of the shelf in Cherrapunji Plateau region were obliterated giving rise to estuarine conditions. Alternating sandstone/shale, showing limited burrowing activity (mostly thin horizontal tubes), and laminated carbonaceous shale partings (rich in terrestrial organic matter and low diversity but rich peridinioid dinoflagellate cyst assemblages, and a total lack of body fossils) is indicative of fluctuating low salinity reducing bottom (?partly anoxic/ dysoxic) conditions below wave base. Coeval with this, carbonate deposition continued uninterrupted under well-oxygenated normal marine conditions in more basinal areas at Therriaghat. Continuation of the progradational cycle during sea level high stand gave rise to coastal swamp conditions leading to the development of thin impersistent coal seams in bays or back water swamps (Misra, 1992) enhanced by periodic cutoff of clastic supply. Occurrence of mangrove pollen in associated sediments (Kar & Kumar, 1986) also favours proximity to the shoreline. Mangroves grow along tropical coasts and estuaries under tidal influence with ability to root in an anoxic substratum (Chapman, 1977 in Van Campo, 1986). A wet and humid climate is postulated on palynomorph evidence (Misra, 1992). The peat accumulation that was taking place just landward of the shoreline in still water, low energy bottom conditions was frequently interrupted by active channel shifting (Misra, 1992) and intermittently increased terrigenous supply which is suggested by relatively high ash content of these coals (Raja Rao, 1981). The progradational cycle seems to have culminated with cessation of peat accumulation during late high stand possibly due to a change in sediment supply (which caused inundation of the peat mires by estuarine waters and cessation of coal formation before final withdrawal of the sea). Although the overlying sedimentary succession is missing from Cherrapunji area, the thin wedge of Lakadong Sandstone overlying the Lakadong Limestone in Therriaghat section provides evidence of a short-lived relative sea level fall. The common occurrence of acritarchs and lack of recognisable dinoflagellate cysts, with high influx of terrestrial organic matter, in this unit is indicative of a general shallowing trend. Consequent upward shallowing in the upper part of the Lakadong Limestone in the basinal Therriaghat section is also reflected by the transition from dominantly wackestone facies to packstone/ boundstone facies (Jauhri, 1994; Nichols, 1999). That the shelf area was not exposed completely (as a consequence of the withdrawal of the sea) is indicated by the lack of fluvial sediments or an erosional contact at the top of Lakadong Sandstone. This Late Thanetian relative sea level fall seems to have lasted only for a short period and was followed soon after by a relatively rapid sea level rise during latest Thanetian- early Ypresian times as evidenced by thick carbonate buildups of the overlying Umlatdoh Limestone. The inferred relative sea level changes in South Shillong are indicated in Fig. 9.

The identification of these short term sea level fluctuations during the Late Thanetian (close to the Palaeocene-Eocene boundary) supplemented by dinoflagellate cysts and foraminifer bioevents facilitates correlation of the Upper Palaeocene sequences of Khasi-Jaintia Hills with the Haq *et al.* (1988) Sea Level Cycle Chart (see Fig. 9). The Langpar Formation exposed in the Um Sohryngkew (Therriaghat) section presents one of the most complete Upper Maastrichtian-Danian dinoflagellate cyst (Garg & Jain, 1993; authors' unpublished data), calcareous nannofossil (Garg & Jain, 1995; Garg, unpublished data) and planktonic foraminifer (Pandey, 1981; Pandey & Ravindran, 1988) records in the Indian region. The dinoflagellate cyst and planktonic foraminiferal rich Danian shales/limestones of the Langpar Formation in Therriaghat area are overlain by a sandy-shaly succession (the uppermost part of which contains *A. hyperacanthum* along with a sudden flux of terrestrial plant debris but lacks planktonic foraminifera). It overlies the *P.*


MAGNETIC CHRON. AND POLARITY
EPOCH / AGE
PLANK. FORAM ZONES
NANNOZONES
SEQUENCE CHRONOSTRATIGRAPHIY
Haq et al. 1988
SUPERCYCLES
3rd ORDER CYCLES
RELATIVE CHANGE OF COASTAL ONLAP
Landward
Basinward
AGE In Ma
SIGNIFICANT STRATIGRAPHIC EVENTS IN SOUTH SHILLONG REGION
EVENTS
LITHOUNITS
RELATIVE SEA LEVEL CHANGES
Falling
Rising
C 24
C 25
C 26
C 27
EOCENE
YPRESIAN
ILERDIAN
PALAEOCENE
THANETIAN
SELANDIAN
DANIAN
P6
P5
P4
P3B
P3A
P2
P1C
NP11
NP10
NP9
NP8
NP7
NP6
NP5
NP4
TA2
TA1
2.5
2.4
2.3
2.2
2.1
1.4
1.3
mfs
53
53.2
53.5
55
56.5
58.5
60
A. hyperacanthum
D. ruida
Post Lakadong
Sea Level Fall
A. paniculatum
Lakadong Coal
Apecto/Wilsoni.influx
R. nuttali/M. miscella
G. levis
G. primaeva
Therria Ichnohorizon
Post Langpar
Sea Level Fall
A. hyperacanthum
UMLATDOH LST
LKD SST
LKD LST
THERRIA SST/LST
LANGPAR SHALES

pussila bearing calcareous shales/limestones, indicating P3 Zone (Pandey, 1981). The shallowing upward trend at the top of the Langpar Formation is indicative of a fall in relative sea level. The hard sandy limestones (recrystallised and dolomitic at places) at the base of the Therria Formation, containing porcellaneous and arenaceous foraminifers, with a few calcareous perforate forms (Nagappa, 1959), represents a marine flooding event and deposits of the early transgressive phase. The relative sea level rise subsequent to the post-Langpar sea level fall in the late Selandian (late P3Zone) matches with the base of the 3rd order cycle TA 2.1. The *Therria Ichno-horizon* that predates the *G. primaeva* Zone (late P4) may correspond with the maximum flooding surface within TA 2·1 at 56·5 Ma (although precise age control is missing). The Therria Formation represents transgressive deposits while the aggradational-progradational succession of the Lakadong Limestone and Lakadong Sandstone are representatives of highstand system tract deposits (with extremely short-lived period for coal formation). This brief phase of coal formation seems to be a widespread coeval event during a sea level highstand in the entire Garo-Khasi-Jaintia hilly tract. The sea level fall at the top of Lakadong Sandstone apparently corresponds to the top of TA2·3 on the evidence of dinoflagellate cysts (Aau Biozone) and larger foraminifera (SBZ 6) that may be calibrated with the late P5 Zone of planktonic foraminifera. Thus, the combined Therria Limestone/Sandstone-Lakadong Limestone/Sandstone succession of Khasi Hills represents a single retrogradational-progradational depositional sequence, that possibly corresponds to combined 3rd order cycles TA2·1-2·3 (despite the lack of more precise plankton dating). With the available data, it is not yet possible to find signatures of sea level changes that may have been associated with the cycles TA2·2 and TA2·3. A detailed analysis involving sedimentological and biostratigraphical data from additional sections may considerably enhance our understanding of the Upper Palaeocene sequences of the South Shillong Plateau.

CONCLUSIONS

1. Dinoflagellate cyst assemblages from Lakadong Sandstone indicate a Late Thanetian age (Ahy-Aau Biozones), close to the Palaeocene - Eocene boundary.
2. Dinoflagellate cyst evidence suggests that the deposition of coal-bearing sediments in the Lakadong Sandstone was an extremely short-lived event.
3. The predominance of *Apectodinium* indicates reduced salinity in a depositional setting (below wave base with anoxic bottom conditions) supporting estuarine to coastal swamp depositional environments for the coal-bearing Lakadong Sandstone.
4. The close stratigraphical correspondence of the *Apectodinium* Acme (Aau Biozone) with the *Ranikothalia nuttalli - Miscellanea miscella* Assemblage Zone of Larger Foraminifera (SBZ 5 - SBZ6) is suggested.
5. The Lakadong Sandstone on the Cherrapunji Plateau region is the lateral facies equivalent of the upper part of Lakadong Limestone in the more basinal areas of Therriaghat area.
6. The Therria Limestone/Sandstone-Lakadong Limestone/Sandstone sequence of Khasi hills represents deposits of transgressive and highstand system tracts, representing a single depositional sequence between post-Langpar and post-Lakadong sea level falls corresponding broadly to the 3rd order cycles TA2·1-TA2·3.

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Fig. 9—Significant Stratigraphic events and relative Sea Level changes in Late Palaeocene of East Khasi Hills, South Shillong Plateau tentatively correlated with Sea Level Cycle Chart of Haq *et al.* (1987b, 1988). The Larger Foraminiferal data is taken from Jauhri (1994, 1997, 1998).

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