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PALYNOLOGY OF THE EOCENE SEDIMENTS OF THE WEST GARO HILLS, MEGHALAYA, NE INDIA: BIOSTRATIGRAPHIC AND PALAEOENVIRONMENTAL IMPLICATIONS

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ABSTRACT

The present paper deals with the palynofloral assemblages recovered from the Tura, Siju and Rewak Formations (early to late Eocene) exposed along the Tura–Dalu road, West Garo Hills, Meghalaya. The palynoflora recorded from the Tura Formation is qualitatively poor and consists mainly of pteridophyte spores, gymnospermous pollen and fungal remains. The overlying Siju Formation is dominated by dinoflagellate cysts, whereas the topmost Rewak Formation is mainly represented by pteridophytic spores and angiosperm pollen. Four distinct palynozones have been recognized on the basis of abundance and distribution of stratigraphically significant palynofossils, in ascending order. The present palynofloral data supported by benthic foraminiferal record suggest that the Siju Formation was deposited in a transgressive phase of a shallow sea. The dominance of terrestrial elements and decrease in dinocyst and benthic foraminifera populations in the overlying Rewak Formation clearly indicate the onset of a regressive phase during the sedimentation of the Rewak Formation. The Siju Formation is predominantly marine, whereas the Rewak Formation represents sediments deposited in a coastal swamp environment. The palynoflora has been compared with the Eocene assemblages recorded from other sedimentary basins of India, and based on the characteristic pollen, middle and late Eocene age have been assigned for the Siju and Rewak Formations respectively. The modern distribution of the extant counterparts of the palynotaxa indicates the prevalence of a tropical (warm-humid) climate during deposition of the Eocene rocks in the area of investigation.

Keywords: Palynofossils, Palaeoenvironment, Benthic Foraminifera, Eocene, Meghalaya, India

INTRODUCTION

A thick sedimentary sequence, unconformably overlying the Precambrian basement complex and ranging from Palaeocene to Recent in age, occupies the southern part of the Garo Hills, Meghalaya. These sediments mainly comprise sandstones and shales with several fossiliferous limestone bands. Several lithostratigraphic classifications have been proposed by earlier workers for the Cretaceous-Tertiary rock sequences of this region (Evans, 1932; Chakraborty, 1972; Chakraborty and Baksi, 1972; Murthy *et al*., 1976 etc.). Fox (in Heron, 1937) for the first time used the term "Siju Limestone" for the Nummulite-bearing limestone of the Garo Hills, which overlies the Tura Sandstone. The Rewak Formation conformably overlies the Siju Formation with a marker bed at the base (Chakraborty and Baksi, 1972).

Extensive palynological investigation has been done on the Tura Formation (Biswas, 1962; Chatterjee and Ghosh, 1963; Banerjee, 1964; Ghosh, 1969; Kar *et al*., 1972; Singh *et al*., 1976; Singh, 1977a, b; Sah and Singh, 1974, 1977; Singh and Singh, 1978; Tewari and Singh, 1984; Ambwani, 1993; Saxena *et al*., 1996 and Tripathi *et al*., 2000) and its equivalents (Cherra, Therria and Mikir Formations). However, only a few papers have been published on the palynology of the overlying Siju and Rewak formations (Baksi, 1962, 1974; Salujha *et al*., 1972, 1974; Saxena and Sarkar, 2000). The present palynological study has been carried out mainly on the Eocene rocks exposed along a part of Tura-Dalu road, west of the Garo Hills. Palynological data are supplemented by the recorded benthic foraminifera from the Siju Formation. The objectives of the present work are: 1) To determine the qualitative as well as quantitative distributional patterns of the significant palynofloral assemblages within the Eocene sediments of the Garo Hills as related to the changing environmental conditions of deposition, and 2) To apply the palynodata in inferring age and palaeoclimate of the studied sequences.

STRATIGRAPHY

A Precambrian Basement complex made up of granite and granite gneisses, is the oldest stratigraphic unit of the major part of the Garo Hills. Its upper part is highly weathered and altered into kaolinitic clays. The basement is unconformably overlain by the Tura Formation which is composed of medium to coarse grained and gritty, clayey, dirty white, yellow and reddish, clayey, non-feldspathic, frequently current-bedded sandstone intercalated with grey shale, carbonaceous shale, lithomargic clay, siltstone and coal seams. This formation is extensively developed in the north and south of the Tura Range. The fact that sedimentation of this formation took place over the uneven surface of the basement is evident by its patchy development in the marginal part of the basin. The base of the Tura Formation is marked by a pebble bed. The Tura Formation is conformably succeeded by the Siju Formation in the Tura-Dalu road Section and is well exposed in a stream cutting at about 10 km from Tura on Tura-Dalu road. It is made up of hard, greyish yellow to yellow, arenaceous and fossiliferous limestone, with thin beds of highly calcareous shales. The Siju Formation exhibits high degree of lateral variation. In the Tura-Dalu Section, it is only a few metres thick containing thin arenaceous limestone with alternations of shale, whereas to the east of Rongra it is represented by massive limestone of about 250 metres thickness. The Siju Formation is overlain by the predominantly argillaceous Rewak Formation. The Rewak Formation is composed of thinly bedded, splintery, grey and carbonaceous shales intercalated with fine-grained, ferruginous, current-bedded sandstones and black shale with phosphatic nodules and pebbles at the base.

The Rewak Formation is overlain by the Kherapara Formation. Further down dip, the Kherapara Formation is followed by Boldamgiri, Angartoli, Bilkona and Dalu formations. The stratigraphic succession along the Tura-Dalu road in West Garo Hills, Meghalaya is summarized in Table 1.

MATERIAL AND METHODS

The rock samples for the present palynological investigation were collected mainly from the Siju and Rewak Formations exposed between 10 km and 28 km from Tura, along the Tura-Dalu Road in the West Garo Hills, Meghalaya (Fig. 1). Thirty samples were collected from the grey shales, carbonaceous shales, arenaceous shelly limestone and yellowish fossiliferous limestone, etc. belonging to the Siju Formation exposed in a stream near Jenggitchakgre (10 kilometre milestone). Of these, 21 samples yielded palynofossils. On the other hand, 31 samples were collected from the grey and carbonaceous shales of the Rewak Formation exposed along the Tura-Dalu road (between 11.5 and 28 km milestones). Of these, 24 samples proved to be palynologically productive. 10 samples were also collected from the Tura Formation near the base of the Siju Formation. However, only 2 samples have yielded palynofossils. During collection of samples, special care was taken to avoid contamination or mixing. Only bigger pieces and chips of sediments were collected. Stratigraphic positions of the samples are shown in the composite section (Fig. 2).

To obtain the palynofossils, samples were treated with HCl followed by HF and HNO_3. After acid treatment, the samples were thoroughly washed with water and then treated with 5% KOH solution for 5-10 minutes, followed by repeated washing with water through 400 mesh sieve to remove all traces of alkali. The residue was then mixed with polyvinyl alcohol, spread uniformly over cover glasses and dried in oven. The cover glasses were mounted upon slides, using canada balsam. The benthic foraminifera were studied by thin section analysis of the collected limestones from the Siju and Rewak Formations. The percentage of each palynotaxon was calculated by counting 200 specimens per sample. All slides and negatives of the figured specimens are stored in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow, India.

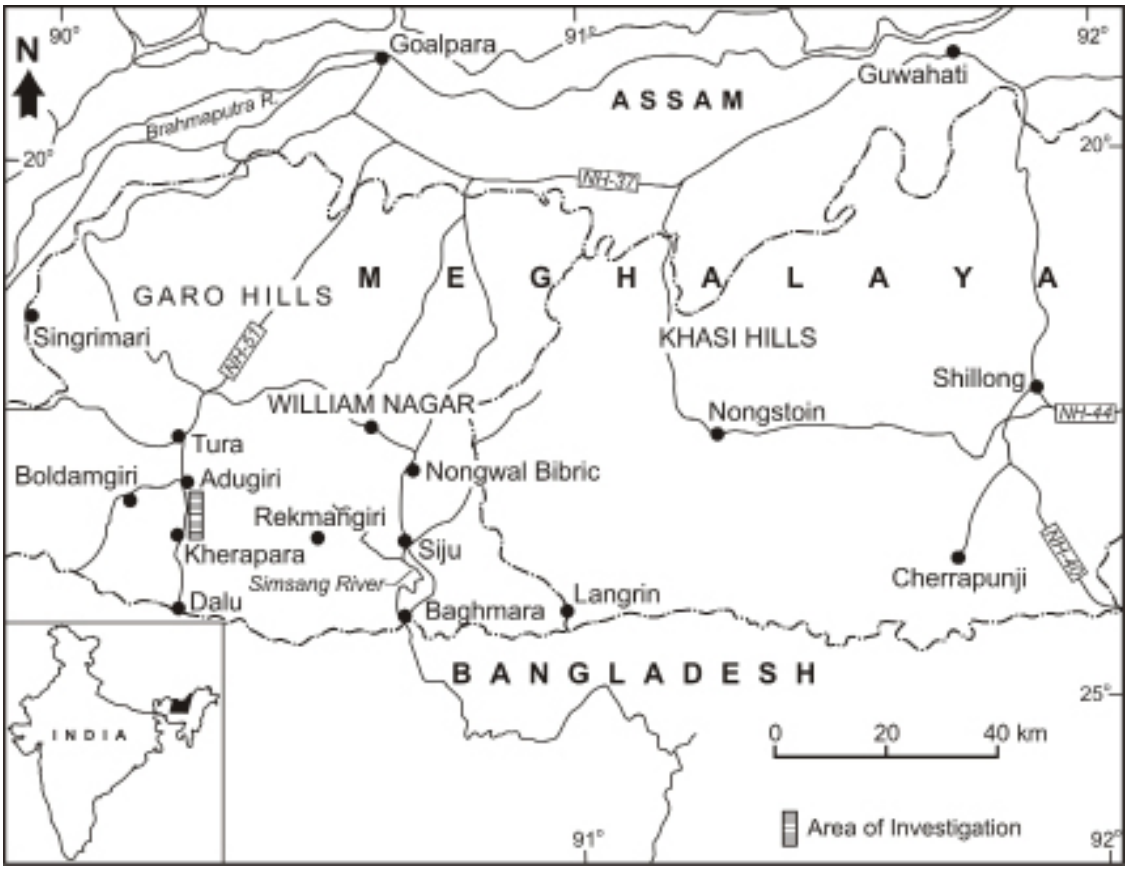

Fig. 1. Location map of the study area between Adugiri and Kherapera in the West Garo Hills, Meghalaya, N.E. India.

EXPLANATION OF PLATE I

(All photomicrographs are magnified ca x 500 and the microscope co-ordinates are with in the parenthesis)

1&2 ***Achomosphaera ramulifera*** (Deflandre) Evitt Slide nos. BSIP 12795 (45 x 97); BSIP 12794 (40 x 103); 3&4 ***Areoligera senonensis*** Lejeune-Carpentier, Slide nos. BSIP 12793 (59 x 109); BSIP 12792 (27 x 97.5); 5 ***Pentadinium laticinctum*** Gerlach, Slide no. BSIP 12791 (40 x 113); 6 ***Homotryblium floripes*** (Deflandre and Cookson) Stover, Slide no. BSIP 12790 (32 x 101); 7. ***Cordosphaeridium inodes*** (Klumpp) Eisenack, Slide no. BSIP 12793 (46 x 113); 8. ***Achomosphaera sagena*** Davey and Williams, Slide no. BSIP 12789 (27 x 96); 9. ***Cordosphaeridium gracilis*** (Eisenack) Davey and Williams, Slide no. BSIP 12788 (61 x 105); 10 ***Operculodinum centrocarpum*** (Deflandre and Cookson) Wall, Slide no. BSIP 12793 (37 x 105); 11. ***Tectatodinium*** sp. Slide no. BSIP 12787 (34 x 105); 12. ***Operculodinium major*** Jain and Dutta, Slide no. BSIP 12778 (48 x 100); 13. ***Glaphyrocysta exuberans*** (Deflandre and Cookson) Stover and Evitt, Slide no. BSIP 12793 (32 x 96).

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Plate I

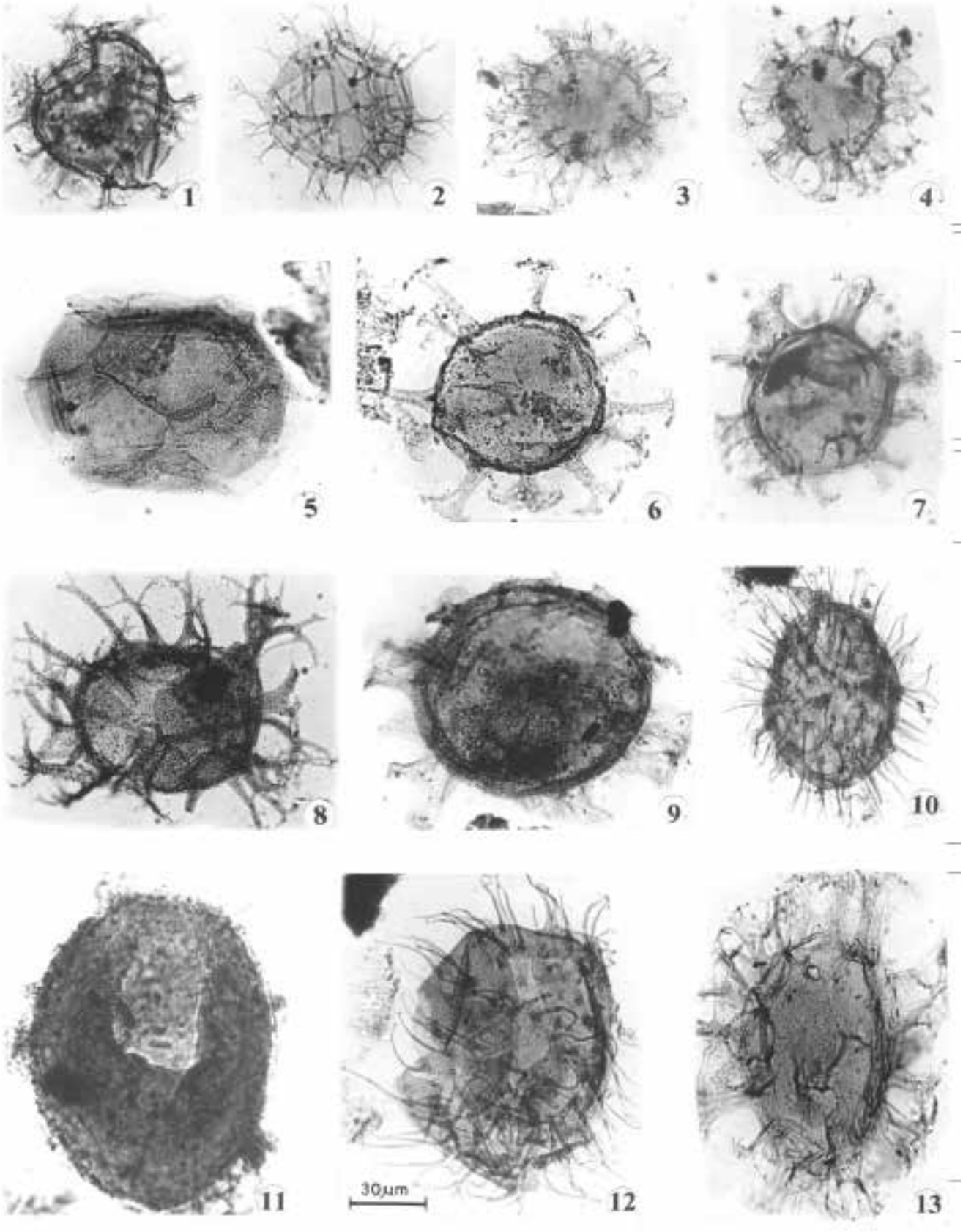


Table 1: Showing the stratigraphic succession in the Garo Hills (after Chakraborty and Baksi, 1972).

Age	Stratigraphic Unit	Lithology	Remarks
Post-Eocene	Post-Rewak (Kherapara,Boldamgiri, Angartoli, Bilkona Rangapani and Dalu Formations)	-	
Late Eocene	Rewak Formation	Thinly bedded, splintery, grey shales and carbonaceous shales with interbeds of fine grained, ferruginous, current bedded sandstones and coal streaks. Thin foraminiferal limestone beds occur in the upper part.	Exposed between 10 km and 28 km on Tura-Dalu Road
Middle Eocene	Siju Formation	Banded alternations of hard, greyish yellow and yellow, arenaceous foraminiferal limestone and calcareous shales or marl. Hard, massive limestone occurs in the upper part.	Exposed in a stream cutting at 10 km from Tura on Tura –Dalu Road
	----------Unconformity----------		
Palaeocene Early Eocene	Tura Formation	Medium to coarse grained and gritty, clayey, dirty white, yellow and reddish, nonfeldspathic, frequently current bedded sandstones intercalated with thin argillaceous beds and coal seams.	Exposed between Tura and 10 km from Tura on Tura –Dalu Road
	----------Unconformity----------		
Precambrian	Basement Complex	Granite and granite gneisses	

CHECKLIST OF PALYNOFOSSILS AND BENTHIC FORAMINIFERA

A checklist of the recorded palynotaxa and benthic foraminifera is given below. Well preserved palynofossils/ benthic foraminifera have been illustrated (Plates I-V). Palynotaxa are arranged alphabetically within the categories, i.e. dinoflagellate cysts, fungal remains, pteridophyte spores, gymnosperm and angiosperm pollen.

Dinoflagellate cysts

Achomosphaera ramulifera (Deflandre) Evitt, 1963
Achomosphaera sagena Davey & Williams, 1966
Adnatosphaeridium vittatum Williams & Downie, 1966
Areoligera senonensis Eaton, 1976
Cordosphaeridium inodes (Klumpp) Eisenack, 1963 Morgenroth,1968
Cordosphaeridium gracile (Eisenack) Davey & Williams, 1966
Cordosphaeridium exilimurium Davey & Williams, 1966
Distatodinium ellipticum (Cookson) Eaton, 1976
Glaphyrocysta exuberans (Deflandre & Cookson) Stover & Evitt, 1978
Homotryblium floripes (Deflandre & Cookson) Stover, 1975
Homotryblium oceanicum Eaton, 1976
Homotryblium plectilum Drugg & Loeblich, 1967
Melitasphaeridium choanophorum (Deflandre & Cookson) Harland & Hill,1979
Operculodinium centrocarpum (Deflandre & Cookson) Wall, 1967
Operculodinium major Jain & Dutta in Dutta & Jain, 1980
Pentadinium laticinctum Gerlach, 1961
Tectatodinium sp.

Fungal remains

Inapertisporites kedvesii Elsik, 1968
Frasnacrititrus taugourdeaui Saxena & Sarkar, 1994
Monoporisporites sp.
Polycellaesporites bellus Chandra *et al*., 1984
Trichothyrites amorphous (Kar & Saxena) Saxena & Mishra, 1990
Callimothalus assamicus Kar *et al*., 1972
Callimothalus.pertusus Dilcher, 1965

Pteridophyte spores

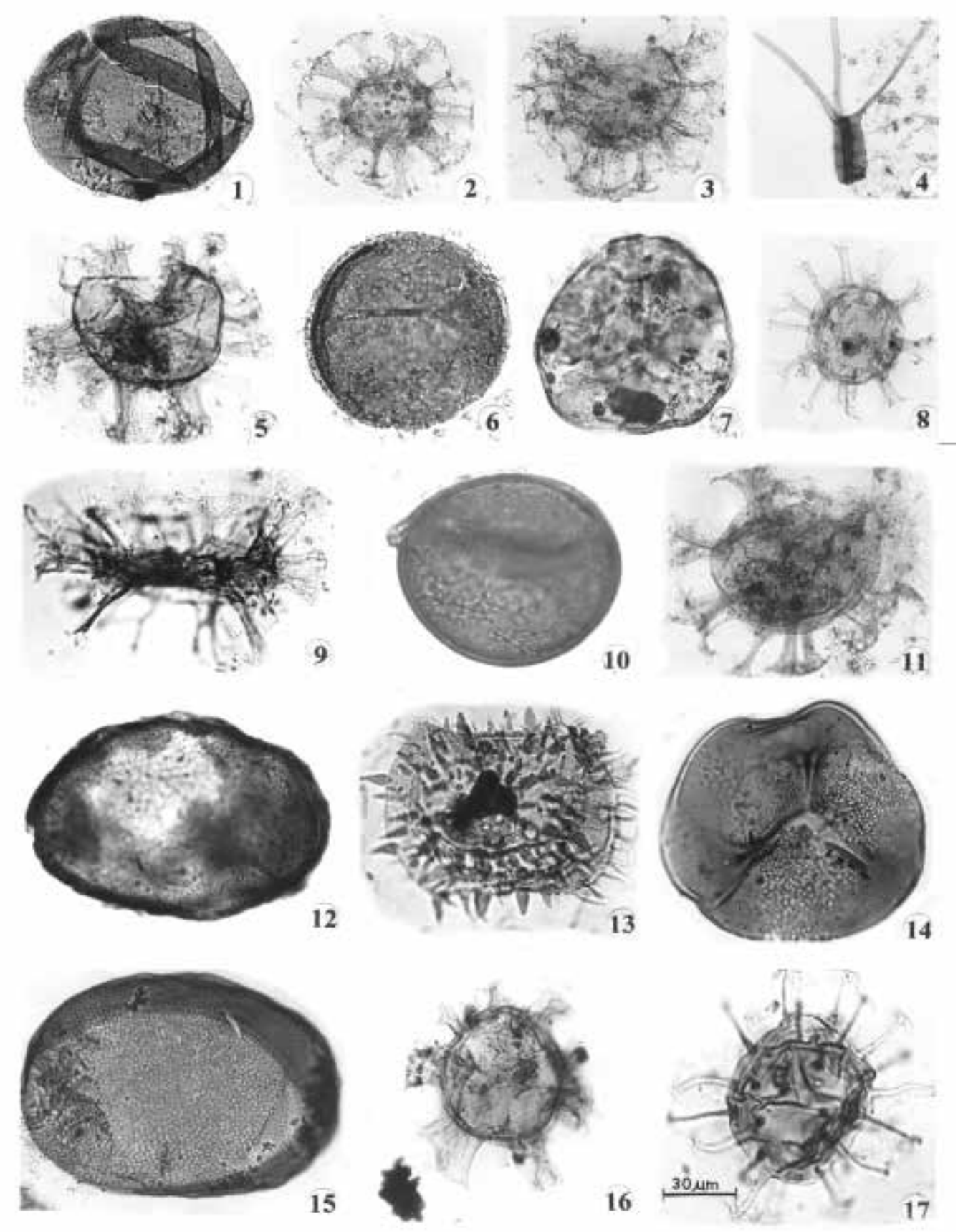
Biretisporites convexus (Sah & Kar) Kar,1978
Cyathidites australis Couper, 1958
Intrapunctisporis intrapunctis Krutzsch, 1959
Lycopodiumsporites sp.
Lygodiumsporites eocenicus Dutta & Sah,1970
Lygodiumsporites lakiensis Sah & Kar, 1969
Monolites discordatus (Pflug in Thomson & Pflug) Potonie' 1960
Monolites sp.
Polypodiaceasporites meghalayensis Saxena, 1992

EXPLANATION OF PLATE II

(All photomicrographs are magnified ca x 500 and the microscope co-ordinates are with in the parenthesis)

1. ***Inapertisporites kedvesii*** Elsik, Slide no. BSIP 12779 (40x98); 2. ***Homotryblium oceanicum*** Eaton, Slide no. BSIP 12790 (32x101); 3. ***Adnatosphaeridium vittatum*** Williams and Downie, Slide no. BSIP 12793 (58 x 109); 4. ***Frasnacritetrus taugourdeaui*** Saxena and Sarkar, Slide no. BSIP 12780 (33 x 98); 5. ***Cordosphaeridium exilimurium*** Davey & Williams, Slide no. BSIP 12781 (44 x 105); 6. ***Monolites discordatus*** (Pflug in Thomson and Pflug) Potonie' Slide no. BSIP 12782 (58 x 104); 7. ***Lygodiumsporites eocaenicus*** Dutta and Sah, Slide no. BSIP 12783 (39 x 103); 8. ***Homotryblium plectilum*** Drugg and Loeblich, Slide no. BSIP 12784 (50 x 102); 9. ***Distatodinium ellipticum*** (Cookson) Eaton, Slide no. BSIP 12784 (20 x 108); 10. ***Monolites*** sp. Slide no. BSIP 12786 (27 x 98); 11. *Incertae sedis* type 1, Slide no. BSIP 12816 (45 x 112); 12. Pollen type-I, Slide no. BSIP 12804 (38 x 95); 13. Angiosperm Pollen type 1, Slide no. BSIP12784 (15 x 85) 14. ***Biretisporites convexus*** Sah and Kar, Slide no. BSIP 12805 (31 x 95); 15. ***Matanomadhiasulcites microreticulatus*** (Dutta & Sah) Kar & Kumar, Slide no. BSIP 12806 (58 x 99); 16. ***Cordosphaeridium inodes*** (Klumpp) Eisenack, Slide no. BSIP 12784 (35 x 95); 17. ***Melitasphaeridium choanophorum*** Deflandre and Cookson, Slide no. BSIP 12784 (3 x 101).

Plate II



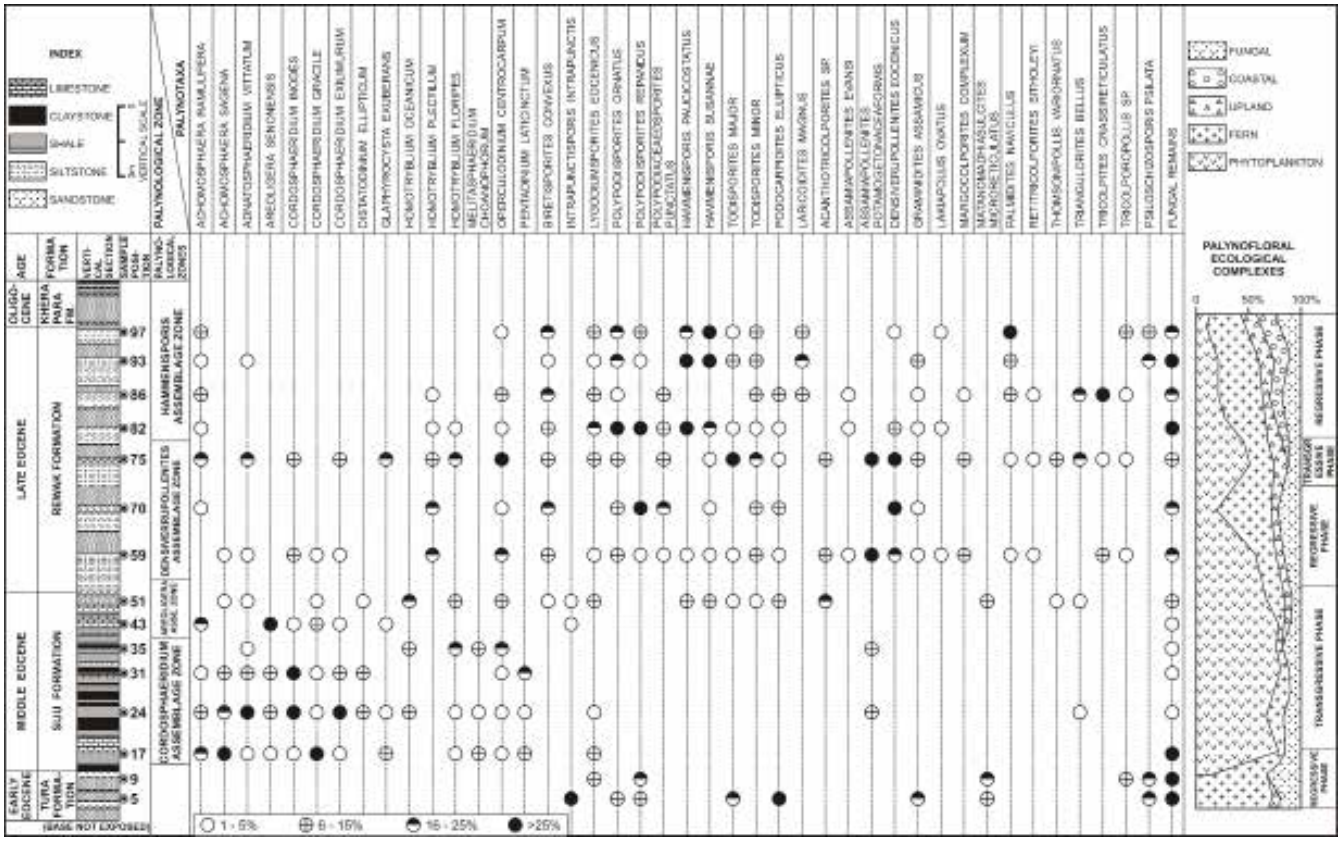


Fig. 2. Showing lithocolumn with position of samples, distribution and frequency of palynotaxa along with palynofloral ecological complexes.

Polypodiaceasporites punctatus Singh *et al*., 1985
Polypodiisporites ornatus (Sah) Saxena & Trivedi, 2009
Polypodiisporites repandus (Takahashi) Saxena & Khare, 2009
Hammenisporis paucicostatus (Kar) Saxena & Trivedi, 2009
Hammenisporis sussannae (Van der Hammen) Saxena & Trivedi, 2009
Todisporites major Couper 1958
Todisporites minor Couper, 1958
Verrutriletes sp.

Gymnosperm pollen

Inaperturopollenites punctatus (Saxena, 1978) Saxena & Bhattacharya, 1987
Laricoidites magnus (Potonie') Potonie' *et al*. ex. Potonie'1960
Podocarpidites ellipticus Cookson, 1947 ex. Couper, 1953

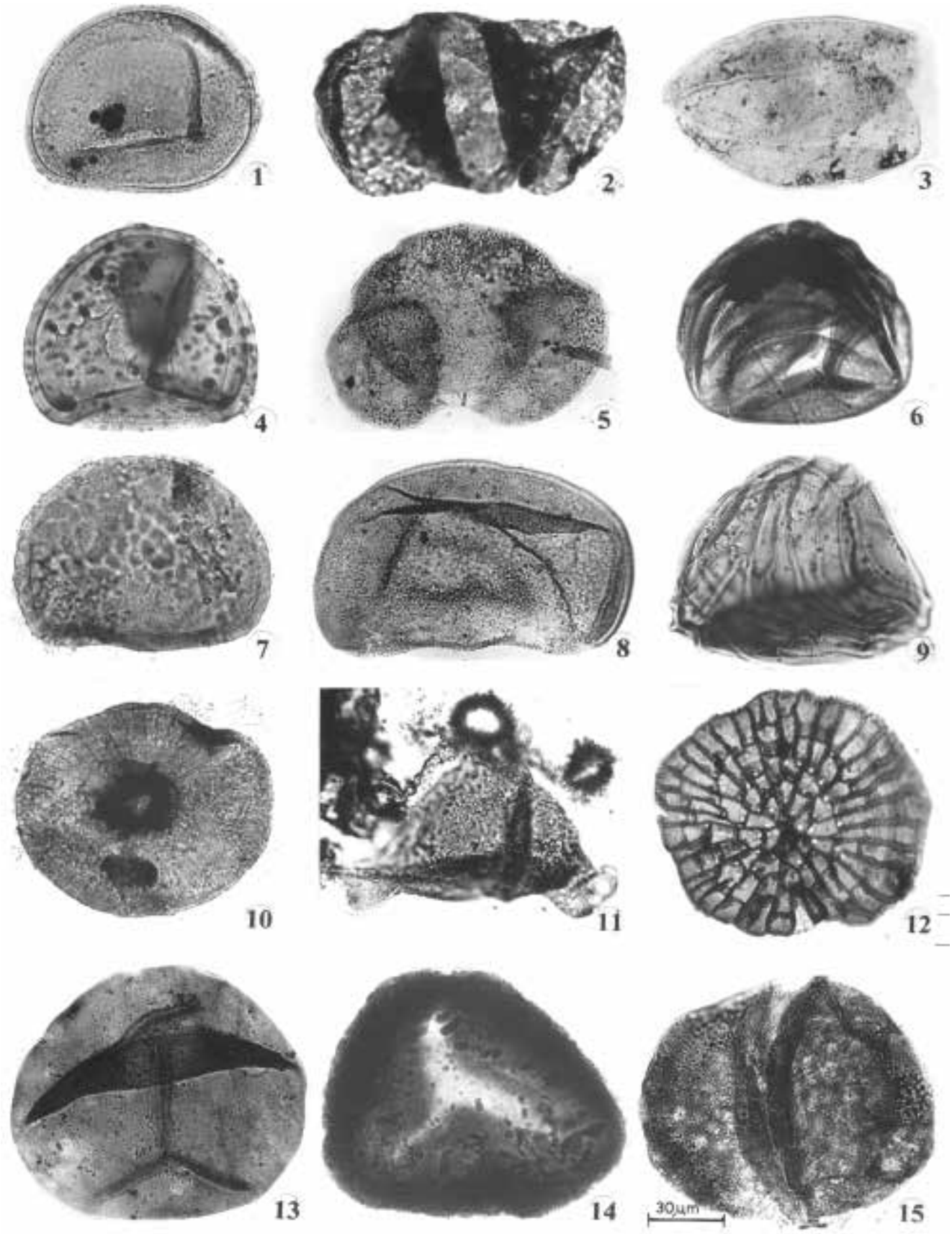
Angiosperm pollen

Acanthotricolporites sp.
Assamiapollenites evansii (Biswas) Singh, 1975
Assamiapollenites potamogetonaceaeformis (Biswas) Singh & Saxena,1984
Densiverrupollenites eoceanicus Tripathi & Singh, 1984
Graminidites assamicus Sah & Dutta, 1968
Thomsonipollis variornatus Venkatachala & Rawat, 1974
Impatientidites sp.
Lakiapollis ovatus Venkatachala & Kar, 1969
Margocolporites complexum (Ramanujam) Varma *et al*., 1986
Matanomadhiasulcites microreticulatus (Dutta & Sah) Kar & Kumar,1986
Neocouperipollis kutchensis (Venkatachala & Kar) Kar & Kumar, 1986
Palmidites naviculus Kar & Saxena, 1981
Retitricolporites sitholeyi (Ramanujam) Varma *et al*., 1986
Triangulorites bellus (Sah and Kar) Kar, 1985
Tricolpites crassireticulatus Dutta &Sah, 1974
Tricolpites sp.
Tricolporopollis sp.
Triporopollenites sp.
Angiosperm Pollen type 1
Angiosperm Pollen type 2
Angiosperm Pollen type 3
Angiosperm Pollen type 4

EXPLANATION OF PLATE III

(All photomicrographs are magnified ca x 500 and the microscope co-ordinates are with in the parenthesis); 1. ***Polypodiaceaesporites punctatus*** Singh *et al*., Slide No. BSIP 12806 (40 x 113); 2. ***Podocarpidites ellipticus*** Cookson ex. Couper, Slide No. BSIP 12807 (24 x 103); 3. ***Psiloschizosporis*** sp. Slide No. BSIP 12807 (35 x 97); 4. ***Verrutriletes*** sp. Slide No. BSIP 12808 (44 x 99); 5. ***Podocarpidites khasiensis*** Dutta and Sah, Slide No. BSIP 12809 (48 x 105) 6. ***Striatriletes paucicostatus*** Kar, Slide No. BSIP 12810 (55 x 108); 7. ***Polypodiisporites ornatus*** Sah, Slide No. BSIP 12807 (25 x 97); 8. ***Polypodiaceaesporites punctatus*** Singh *et al*., Slide No. BSIP12811 (23 x 103); 9. ***Hammenisporis sussannae*** (Van der Hammen) Saxena & Trivedi, Slide No. BSIP 12811 (16x106) 10. ***Notothyrites amorphous*** (Sah and Kar) Kar, Slide No BSIP12812 (14x103); 11. ***Triangulorites bellus*** (Sah and Kar) Kar, Slide No. BSIP 12793 (50 x 98) 12. ***Callimothalus assamicus*** Kar *et al*., Slide No. BSIP 12779 (18 x 98.5); 13. ***Todisporites major*** Couper Slide No. BSIP 12813 (26 x 99); 14. ***Lygodiumsporites eocaenicus*** Dutta and Sah, Slide No. BSIP 12812 (52 x 103); 15. ***Podocarpidites ellipticus*** Cookson ex Couper, Slide No BSIP 12799 (30 x 108).

Plate III



Incertaesedis

Psiloschizosporis psilata Kar & Saxena, 1981
Heliospermopsis sp.
Incertaesedis type-1

Benthic Foraminifera

Assilina spinosa Davies & Pinfold, 1937
Assilina sp.
Lockhartia conditi Smout, 1954
Nummulites beaumonti d'Archiac & Haime, 1853
Nummulites incrassatus de la Harpe, 1883
Nummulites mamillatus Fichtel & Moll, 1798
Nummulites sp. 1
Nummulites sp. 2
Nummulites sp. 3
Operculina subformai Provale, 1908

DISCUSSION

The recovered palynofloral assemblages from the Eocene sediments of the Tura-Dalu road section are very rich, diversified and represented by dinoflagellate cysts, fungal spores, ascostromata, pteridophyte spores, gymnosperm and angiosperm pollen. The palynoflora recorded from the Tura Formation is qualitatively poor. The recorded palynoflora mainly consists of *Intrapunctisporis intrapunctis, Polypodiisporites repandus, Podocarpidites ellipticus*, *Matanomadhiasulcites microreticulatus* followed by *Psiloschizosporis psilata* and fungal remains. Palynofloral assemblage recovered from the overlying Siju Formation is dominated by dinoflagellate cysts, i.e. *Achomosphaera ramulifera*, *A. sagena, Areoligera senonensis, Cordosphaeridiun inodes, C. gracile, Homotryblium floripes, H. plectilum* and *Operculodinium centrocarpum,* whereas the Rewak palynoflora is mainly represented by spores, pollen and fungal remains. Some of the important constituents of the Rewak palynofloral assemblages are *Lygodiumsporites eocenicus, Polypodiisporites ornatus, Densiverrupollenites eocaenicus* and *Hammenisporis susannae.* On the basis of quantitative analysis of the palynoflora, the studied sequence of Siju and Rewak is divided into four distinct assemblage zones, i.e. *Cleistosphaeridium* Assemblage Zone, *Areoligera* Assemblage Zone, *Densiverrupollenites* Assemblage Zone and *Hammenisporis* Assemblage Zone in ascending order of stratigraphy. The distribution and frequency of stratigraphically significant palynotaxa are given in Fig. 2. Only two samples of the Tura Formation have yielded palynofossils dominated mainly by fungal spores and microthyriaceous ascostromata, pteridophyte spores and gymnosperm pollen.

The Siju assemblage is dominated by dinoflagellate cysts followed by fungal remains but spores and pollen are rare. On the basis of frequency and distribution of palynotaxa, the Siju succession has been divided into two assemblage zones i.e., *Cordosphaeridium* Assemblage Zone and *Areoligera* Assemblage Zone. The assemblage zones are recognised on the basis of abundance, decline, restricted occurrence and absence of palynotaxa. The Rewak palynofloral assemblage of the present succession is dominated by pteridophyte spores followed by angiospermous pollen. Dinoflagellate cysts are poorly represented in the upper horizons. Fungal spores and microthyraceous ascostromata are quite abundant throughout the succession. The Rewak succession is divided into two distinct assemblage zones, i.e. *Densiverrupollenites* Assemblage Zone and *Hammenisporis* Assemblage Zone. The lower zone is dominated by *Densiverrupollenites eocaenicus* and *Assamiapollenites potamogetonacaeformis* along with pteridophyte spore *Todisporites major*. Dinoflagellate cysts, i.e. *Operculodinium centrocarpum, Achomosphaera ramulifera* and *Adnatosphaeridium vittatum* are frequent in some samples. The upper zone is characterized by the dominance of *Hammenisporis susannae* and *H. paucicostatus* together with angiosperm pollen *Palmidites naviculatus* and *Tricolpites crassireticulatus*. Dinoflagellate cysts are poorly represented in this assemblage zone. Fungal spores and microthyriaceous ascostromata are frequent throughout the succession. The occurrence of *Psiloschizosporis psilata* in some samples is also noteworthy. Apart from palynofossils, several species of *Nummulites* (*N. beaumonti*, *N. incrassatus* and *N. mamillatus*), *Lockhartia conditi, Operculina subformai* and *Assilina spinosa* have been recorded from the limestone samples (Nos.17, 31 and 43) of the Siju Formation. In the present area of investigation, the Rewak Formation did not yield any benthic foraminifera. The brief characteristics of the palynofloral assemblages are discussed below.

PALYNOLOGICAL ZONES

Cordosphaeridium Assemblage Zone

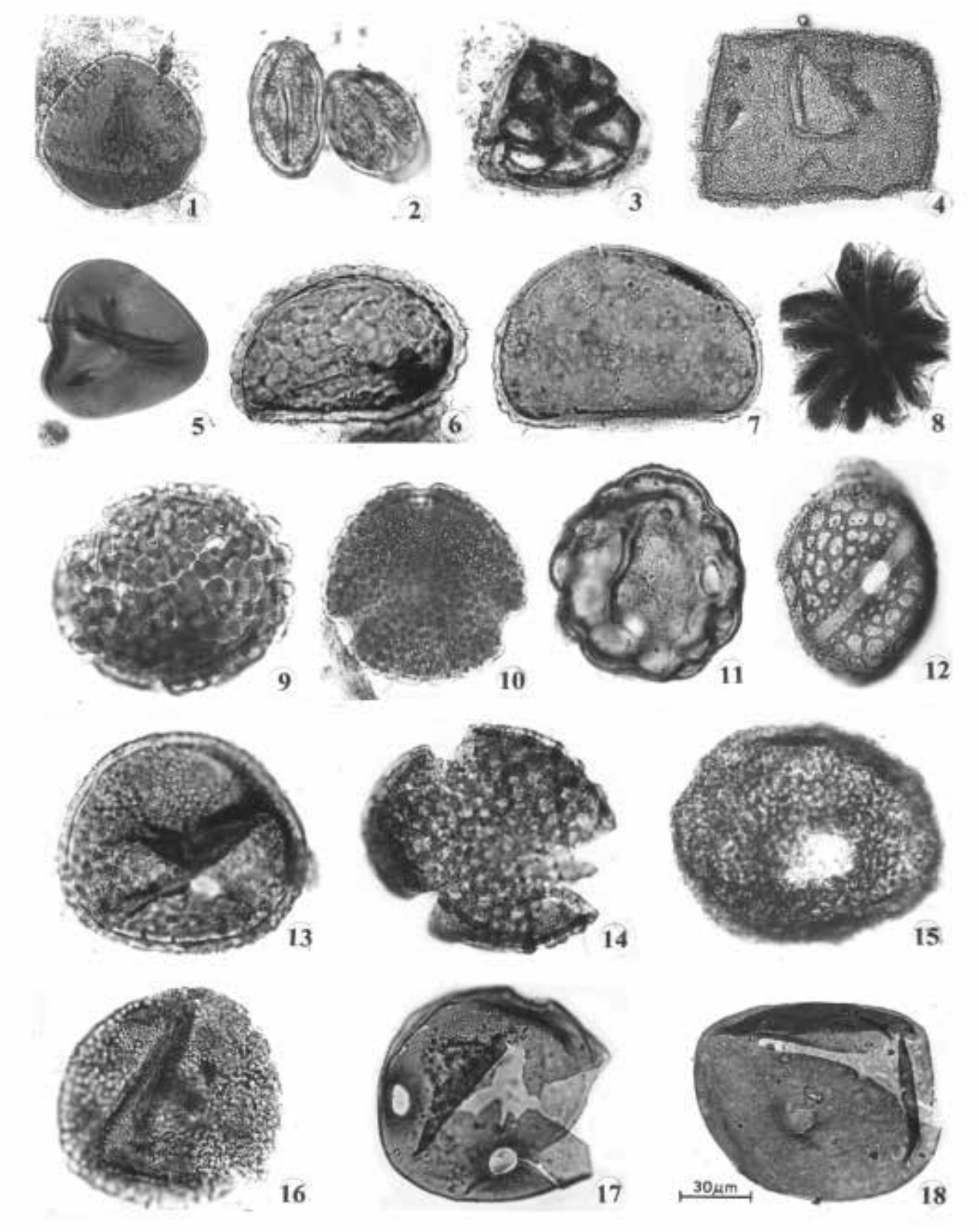
Cordosphaeridium Assemblage Zone covers a thickness of 11 m running from 6 m to 17 m of the Siju succession in the present stratigraphic section. The palynoflora in this zone is highly diversified. Dinoflagellate cysts (*Achomosphaera sagena*, *Adnatosphaeridium vittatum*, *Cordosphaeridium inodes* and *Cordosphaeridium gracile)* are the major elements of the assemblage. The other dinocyst taxa represented in this assemblage are *Achomosphaera ramulifera, Homotryblium floripes, Operculodinium centrocarpum, Pentadinium laticinctum, Areoligera senonensis, Distatodinium ellipticum, Glaphyrocysta exuberans Homotryblium oceanicum and Melitasphaeridium choanophorum.* Fungal spores and conidia are present at all levels. *Cordosphaeridium inodes* and *Cordosphaeridium gracile* constitute more than 50% of the total assemblage.

EXPLANATION OF PLATE IV

(All photomicrographs are magnified ca x 500 and the microscope co-ordinates are with in the parenthesis)

1. ***Todisporites minor*** Couper, Slide No. BSIP 12797 (57 x 103); 2. ***Tricolpites*** sp. Slide No. BSIP 12787 (47 x 106); 3. ***Lycopodiumsporites*** sp. Slide No. BSIP 12798 (50 x 107); 4. ***Impatientidites*** sp., Slide No. BSIP 12797 (19 x 95); 5. ***Cyathidites australis*** Couper, Slide No. BSIP 12799 (39 x 96); 6. ***Polypodiisporites ornatus*** Sah, Slide No. BSIP 12800 (67 x 102); 7. ***Polypodiisporites repandus*** Takahashi, BSIP Slide No. 12801 (50 x 109); 8. ***Heliospermopsis*** sp. BSIP Slide No. 12802 (43 x 103); 9. ***Densiverupollenite eocaenicus*** Tripathi and Singh, Slide Nos. BSIP 12802 (50 x 110); 10. ***Acanthotricolporites*** sp., Slide No. BSIP 12806 (46 x 108); 11. ***Tricolporopollis*** sp., Slide No. BSIP 12782 (30 x 95); 12. Angiosperm Pollen type 3, Slide No. BSIP 12803 (53 x 103); 14. ***Tricolpites crassireticulatus*** Dutta and Sah, BSIP Slide No. 12814(28x100); 15. Angiosperm Pollen type- 4, BSIP Slide No.12815 (36 x 98); 13&16. ***Thomsonipollis variornatus***, Venkatachala and Rawat, BSIP Slide No.12782, (52 x 112); Slide No. BSIP 12779 (62 x 99); 17. ***Lakiapollis ovatus*** Venkatachala and Kar, Slide No. BSIP 12798 (58 x 103); 18. ***Graminidites*** sp., Slide No. BSIP 12801 (36 x 99)

Plate IV



***Areoligera* Assemblage Zone**

This palynological zone covers the 17 m to 21 m interval of the section. The assemblage is characterised by the presence of dinoflagellate taxa, i.e. *Areoligera senonensis, Achomosphaera ramulifera* and *Homotryblium oceanicum*. Land derived palynofossils, i.e. *Biretisporites convexus, Intrapunctisporis intrapunctis, Todisporites major, Todisporites minor, Triangulorites bellus and Thomsonipollis variornatus* in low percentages have been encountered in some of the samples. This assemblage zone can be demarcated from the overlying and underlying assemblage zone by overwhelming dominance of *Areoligera senonensis.*

***Densiverrupollenites* Assemblage Zone**

This palynofloral assemblage zone covers the 21 m to 30 m interval of the succession belonging to the Rewak Formation. The most dominant taxa in this assemblage are *Densiverrupollenites eoceanicus, Polypodiisporites repandus* , *Todisporites major* and *Operculodinium centrocarpum.* The other taxa recorded in this assemblage are *Achomosphaera ramulifera*, *Adnatosphaeridium vittatum, Homotryblium floripes, H. plectilum, Polypodiaceasporites punctatus, Glaphyrocysta exuberans, Biretisporites convexus, Margocolporites complexum* and *Polypodiisporites ornatus.* This assemblage zone can be easily recognised by the dominance of land-derived elements, i.e. *Densiverrupollenites eoceanicus* and *Polypodiisporites repandus.* Sudden decrease of dinocyst taxa in this assemblge zone is also noteworthy.

***Hammenisporis* Assemblage Zone**

This zone covers the top 8 m thickness of the Rewak succession. Most dominant forms in this assemblage are *Hammenisporis paucicostatus, H. sussannae, Polypodiisporites ornatus, P. repandus, Palmidites naviculus* and *Tricolpites crassireticulatus.* Quantitatively land derived elements increased sharply in this assemblage zone. Other taxa recorded in this assemblage zone are *Biretisporites convexus, Lygodiumsporites eocaenicus, Laricoidites magnus, Triangulorites bellus and Psiloschizosporis psilata.* This assemblage zone can be demarcated from the underlying assemblage zone by the occurrences of high percentage (>60%) of *Hammenisporis sussannae* and *Hammenisporis paucicostatus* as well as sudden decrease of dinoflagellate cysts in the assemblage.

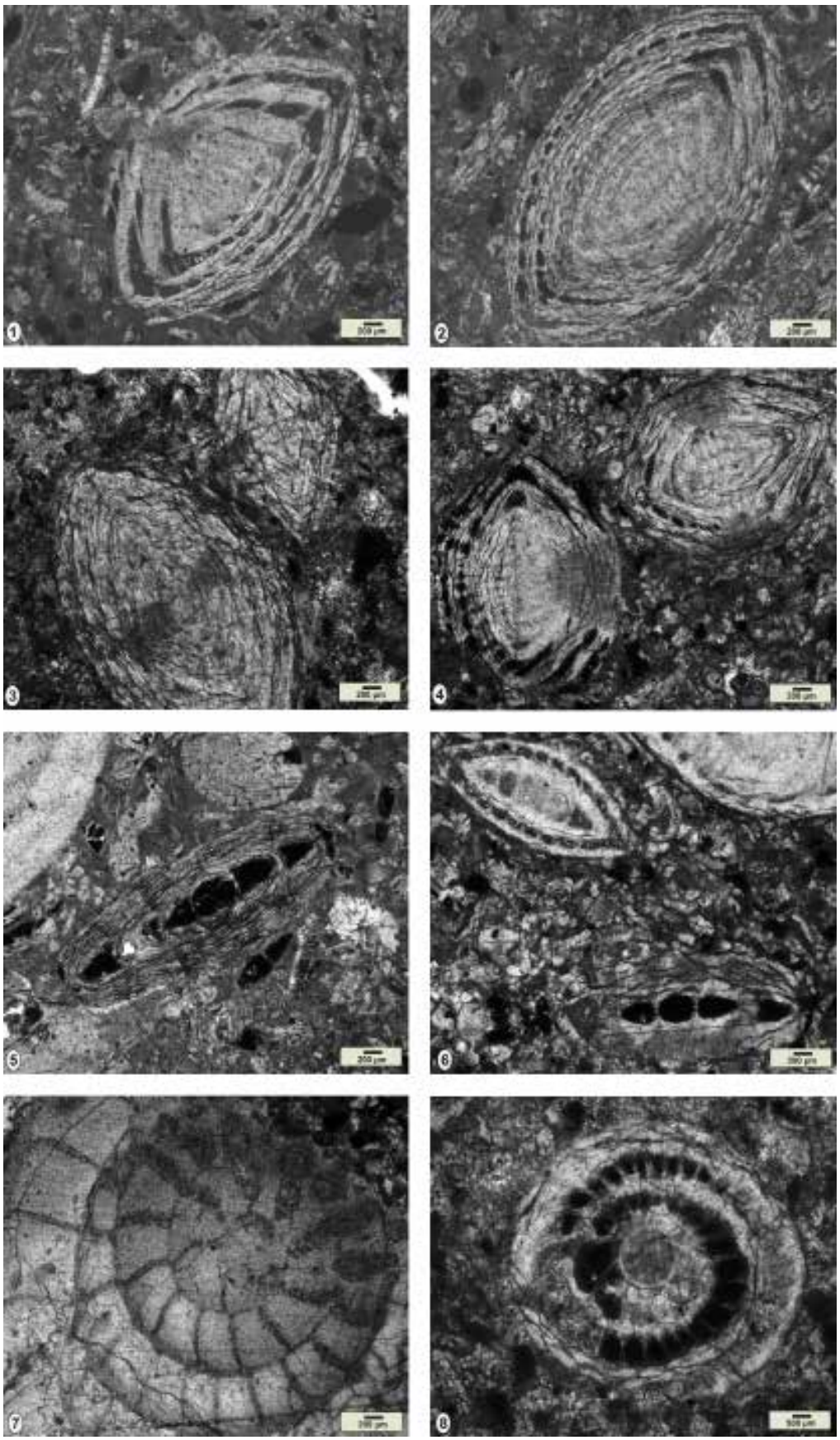
BIOSTRATIGRAPHIC CORRELATION

Palynological investigation of the Palaeogene rocks of Meghalaya and Assam has been extensively carried out by several workers. Most of the studies are from the lowermost Tura Formation of the Garo Hills (Biswas, 1962; Sah and Singh, 1974; Tripathi *et al*., 2000), the Cherra Formation and Lakadong Sandstone in the Khasi Hills (Dutta and Sah, 1970; Kar and Kumar, 1986), the Therria Formation in the Jaintia Hills (Tripathy and Singh, 1984) and the Mikir Formation in the North Cachar Hills (Mehrotra and Sah, 1982). Due to lack of sufficient pollen spectra, the Tura palynofloral assemblage could not be compared very well with other recorded palynofloral asemblages. Palynofloras from the overlying Siju/Sylhet Formations have been recorded by Baksi (1962) and Sah and Singh (1977) from the Garo Hills and by Dutta and Jain (1980), Tripathi and Singh (1984) and Kar (1992) from the Jaintia Hills. The present assemblage is closely comparable to the Simsang Palynological Zone I of the Simsang River Section because it contains dinoflagellate cysts and arecaceous pollen (Baksi, 1962). Dutta and Jain (1980) recorded dinoflagellate cysts from the Sylhet Limestone (Lakadong Limestone, Lakadong Sandstone and Prang Limestone) and Kopili Formation exposed near Lumshnong in Jaintia Hills. Several dinoflagellate taxa, i.e. *Cordosphaeridium, Distatodinium, Homotryblium, Hystrichokolpoma, Operculodinium, Spiniferites* and *Thalassiphora* are found common in the two assemblages. It is striking that dinoflagellate cysts, which are abundant in the studied assemblage, have not been found in the palynofloral assemblage of the Siju Formation of the Garo Hills recorded by Sah and Singh (1977) as well as in the Prang assemblage (top member of the Sylhet Limestone Group) reported by Kar (1992). Abundance of *Nummulites beaumonti* has also been reported by Jauhri and Agarwal (2001) from the Prang Formation of South Shillong Plateau, Meghalaya belonging to middle Eocene which corresponds well with the presently studied benthic foraminiferal assemblage. The present assemblage is very similar to palynofloral assemblage recorded from the Subathu Formation of Himachal Pradesh (Singh *et al*., 1978; Sarkar and Singh, 1988; Singh and Sarkar, 1992; Sarkar, 1997; Sarkar and Prasad, 2000). Singh *et al*. (1978) proposed eight cenozones and two subzones in the Subathu Formation (late Palaeocene to late Eocene) of Kalka-Shimla area of Himachal Pradesh. The palynofloral assemblage closely corresponds to the lower horizons of *Cordosphaeridium multispinosum* Cenozone (early Lutetian).The middle Eocene palynofloral assemblages (Singh and Sarkar, 1992; Sarkar, 1997; Sarkar and Prasad, 2000) of the Subathu Formation contain abundant *Operculodinium* spp., *Lingulodinium machaerophorum*, *Spiniferites* spp. and *Achomosphaera* spp. The same trend has also been noticed in the Siju assemblage. Palynological information from the Eocene sediments of Jammu is rare. Khanna *et al*. (1985) described 17 genera and 23 species of dinoflagellate cysts from the Subathu sediments of Kalakot and adjoining areas. The Siju dinocyst assemblage is closely comparable with the top of *Cordosphaeridium multispinosum* Assemblage Zone and base of *Homotryblium* spp. Assemblage Zone. The palynofloral assemblages from the Eocene sediments of Kutch have been recorded by Mathur (1963, 1966), Sah and Kar (1969, 1970), Venkatachala and Kar (1969a, b), Kar (1978) and Jain and Tandon (1981). Of these, only the middle Eocene palynoflora from Jhadwa and Baranda in southwestern Kutch (Jain and Tandon, 1981) are similar with the Siju palynofloral assemblage. Of the five informal microplankton zones proposed by Jain and Tandon (1981), only Zone IV resembles the present palynofloral assemblage. The Siju palynofloral assemblage is characterized by the presence of *Cordosphaeridium inodes*, *Areoligera senonensis* and *Distatodinium ellipticum.* These forms were

EXPLANATION OF PLATE V

1. ***Lockhartia. conditi*** Smout axial section; 2. ***Nummulites*** sp. 1; 3. ***Nummulites beaumonti*** d'Archiac and Haime (left), centered oblique section and ***Nummulites incrassatus*** De La Harpe (right) transverse section; 4. ***Nummulites*** sp. 2 (left) and ***Nummulites mamillatus*** Fichtel and Moll (right); 5. ***Assilina spinosa*** Davies and Pinfold; 6. ***Nummulites*** sp. 3 (top) and ***Assilina*** sp. (bottom); 7. ***Operculina subformai*** Provale oblique section; 8. ***Nummulites beaumonti*** d'Archiac and Haime equatorial section

Plate V



abundant in the middle Eocene sediments throughout the globe. Moreover, the present assemblage is closely comparable to the middle Eocene assemblage known from Meghalaya, Himachal Pradesh, Haryana, Jammu and Kutch. The Siju palynofloral assemblage is therefore assigned to the middle Eocene age. The occurrences of benthic foraminifera, i.e. *Nummulites beaumonti*, *N. incrassatus*, *N. mamillatus* and *Operculina subformai* in the Siju Limestone also indicate a middle to late middle Eocene age. The palynofloral assemblage from the overlying Rewak Formation is closely comparable to the late Eocene palynofloral assemblages of the Kopili Formation recovered from the Garo, Khasi and Jaintia Hills (Baksi, 1962, 1974; Salujha *et al*., 1972, 1974; Sein and Sah, 1974; Tripathi and Singh 1984a, b, 1985; Singh and Tripathi, 1987). Late Eocene dinoflagellate cyst assemblage recorded from the base of the Kopili Formation in the Lumshnong area of Jaintia Hills, Meghalaya (Dutta and Jain, 1980) shows close similarity with the assemblage due to the domination of *Homotryblium plectilum*. The occurrence of *Densiverrupollenites eocaenicus, Hammenisporis susannae, Podocarpidites ellipticus, Tricolporopollis* and others, are characteristic for late Eocene age of the overlying Rewak Formation.

PALAEOCLIMATE AND ENVIRONMENT

Qualitatively, the Tura palynofloral assemblage from the study area is very poor. Only the abundance of pteridophyte spores assignable to Lygodiaceae (*Lygodiumsporites, Todisporites*) and Polypodiaceae (*Polypodiaceasporites*, *Polypodiisporites*), together with angiosperm pollen assignable to Poaceae (*Graminidites*) and Arecaceae (*Matanomadhiasulcites*) indicates that these plants were growing nearby in moist and shady habitats of coastal areas. Occurrence of epiphyllous fungi, e.g. *Phragmothyrites eocaenicus* and *Trichothyrites amorphous* in the palynoflora suggests prevalence of characteristic warm and humid conditions during deposition of these sediments. Dominance of taxa of Podocarpaceae (*Podocarpidites*) also characterises tropical, warm, humid climate during late phase of the sedimentation of the Tura Formation.

Dinoflagellate cysts, i.e. *Homotryblium, Cordosphaeridium* and *Cleistosphaeridium* are the major constituents of the Siju palynofloral assemblage. The distribution pattern of these dinocysts clearly shows the changes in the environment from older to younger horizons. The lower part of the sequence represented by *Achomosphaera sagena, Cordosphaerdium* spp., *Adnatosphaeridium vittatum* and *Homotryblium* spp., are deposited in the nearshore shallow marine environment where open marine forms appear. Recorded benthic foraminifera from this horizon also indicate a middle-proximal outer shelf environment. Quantitatively, *Glaphyrocysta exuberans, Cordosphaeridium gracile* and *Achomosphaera sagena* decline considerably in the upper part of the sequence and are replaced by *Achomosphaera ramulifera, Areologera senonensis, Homotryblium oceanicum* and *Operculodinium centrocarpum.* The presence of *Operculodinium* and frequent terrestrial palynomorphs in *Areoligera* assemblage zone indicates onset of brackish water environment in proximity to the shore line. This change in the dinocyst content may be due to the fluctuating environment in an unstable shelf. The palynofloral assemblage recovered from the Rewak Formation consists of algal and fungal remains, pteridophyte spores, gymnosperm and angiosperm pollen. Of these, *Biretisporites convexus*, *Lygodiumsporites eocenicus*, *Polypodiisporites ornatus*, *P. repundus*, *Hammenisporis susannae, H. paucicostatus* and *Densiverrupollenites eocenicus* dominate. The gymnosperm pollen occurs rarely. The frequency of algal remains (zygospores of Zygnemataceae) is low in the lower part of the section and increases in the upper section contrary to fungal remains. Pteridophyte spores and angiosperm pollen are comparatively less common in the lower part of the succession but their occurrence increases gradually at the top of the section. Modern analogue study of the families represented in the assemblage clearly points towards a tropical to subtropical climate. The occurrence of freshwater swamps and ponds in close proximity is indicated by the presence of several palynotaxa, i.e. *Lygodiumsporites, Hammenisporites,* etc. The presence of dinoflagellate cysts and arecaceous pollen grains in certain levels of the Rewak Formation indicates the marine influence during the deposition. The absence of benthic foraminifera in the Rewak Formation of the present investigation is also noteworthy. It is to be mentioned here that the upper part of the Kopili Formation (late Eocene) is rich in terrestrial palynofossils but no foraminiferal specimens are found (Samanta, 1971; Trivedi, 2009; Saxena and Trivedi, 2009).

CONCLUSIONS

Based on the quantitative analysis of the palynoflora, the studied sequence of the Tura-Dalu road section has been divided into four formal palynological assemblage zones in ascending order of stratigraphy, i.e. *Cordosphaeridium* Assemblage Zone, *Areoligera* Assemblage Zone, *Densiverrupollenites* Assemblage Zone and *Hammenisporis* Assemblage Zone.

Palynological data suggest that the Siju Formation was deposited in a transgressive phase of shallow sea. The increase of terrestrial elements and decrease in dinocyst and benthic foraminiferal population in the overlying Rewak Formation clearly indicate regressive phase during the sedimentation of the Rewak Formation. However, a minor transgressive phase has also been recognised in the Rewak Formation which may be due to sea-level fluctuations in an unstable shelf.

The lower part of the studied sequence was deposited in a near-shore, shallow marine environment with some open marine influence. The upper part was deposited in a brackish environment.

Modern distribution of the extant counterparts of the palynotaxa indicates prevalence of a tropical, warm-humid climate during the sedimentation of the Siju and Rewak Formations.

The studied sequence of the Siju Formation is dated as middle Eocene because the recovered palynoflora is closely comparable with the middle Eocene assemblages of Meghalaya, Himachal Pradesh, Haryana, Jammu and Kutch. The Rewak palynofloral assemblage corresponds well to the Kopili Formation palynofloral assemblages recorded from the Jaintia Hills, Meghalaya and belongs to the late Eocene.

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