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Palynostratigraphy of the Tertiary sediments of Meghalaya, Northeastern India – Present status and gaps

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ABSTRACT

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Thick and extensive Tertiary sediments, belonging to both shelf and geosynclinal facies, occupy the southern part of the Meghalaya Plateau. The basal part of these sediments is represented by the Langpar Formation which is followed by Jaintia (Therria, Sylhet Limestone and Kopili formations), Barail (Laisong, Jenam and Renji formations), Surma (Bhuban and Bokabil formations), Tipam (Tipam Sandstone and Girujan Clay formations), Dupitila and Dihing groups. In Garo Hills, these sediments are classified into various other differently named formations. A considerable amount of palynological information has so far been published from these sediments, which provides useful data for biostratigraphic zonation, correlation and age determination and for interpreting palaeoclimate, palaeogeography and environment of deposition. An effort has been made, in the present paper, to synthesize the published palynological work on these sediments in order to understand the present status of the Tertiary palynostratigraphy of Meghalaya. It has been noticed that the various palynozones established in the Tertiary sequence of Meghalaya can be rccognized by their peculiar palynofossil assemblages. This is particularly useful in the correlation of homotaxial stratigraphic units in Garo, Khasi and Jaintia Hills and in the interbasinal correlation. In spite of a good deal of palynodata available, there are plenty of gaps in our knowledge regarding Tertiary palynostratigraphy of Meghalaya that deserve attention of palynologists. These gaps have been identified for the future studies.

Key-words—Palynology, Palynostratigraphy, Tertiary, Meghalaya, Northeastern India.

पूर्वोत्तर भारत के मेघालय प्रान्त के टर्शियरी अवसादों की परागाणुस्तरिकी – वर्तमान अवस्था एवं अल्पज्ञता

रमेश कुमार सक्सेना

सारांश

मेघालय के पठार के दक्षिणी अंश में उपतटीय तथा भूअभिनतिक दोनों से सम्बन्धित स्थूल एवं विस्तृत टर्शियरी अवसाद उपस्थित हैं. इन अवसादों का आधारीय अंश लांगपार शैलसमूह द्वारा निरूपित है, जिसके पश्चात क्रमशः जयन्तिया (थीरिया, सिलहट चूना पत्थर तथा कोपिली शैलसमूहों), बरेल (लैसांग, जेनिम एवं रीन्ज़ी शैलसमूहों), सूरमा (भुवन एवं बोकाबिल शैलसमूहों), टीपम (टीपम बालुकाश्म एवं गिरूजान मृत्तिका शैलसमूहों), दुपीटीला एवं डिहिंग समूह आते हैं. गारो पहाडियों में इन अवसादों को विभिन्न अन्य शैलसमूहों के नामों से वर्गीकृत किया गया है. इन अवसादों से काफी मात्रा में परागाणविक सूचनाएँ अभी तक प्रकाशित की गई हैं, जिनसे जैवस्तरिकीय अनुक्षेत्र वर्गीकरण, सहसम्बन्धन एवं आयु निर्धारण

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तथा पुरापर्यावरण हेतु महत्वपूर्ण आंकड़े प्राप्त हुए हैं. मेघालय की टर्शियरी युगीन परागाणुस्तरिकी के वर्तमान स्तर को समझने के क्रम में इन अवसादों पर आधारित प्रकाशित परागाणुविज्ञान सम्बन्धी अनुसन्धान कार्यों को संश्लेषित करने का प्रयत्न प्रस्तुत शोध पत्र में हुआ है. मेघालय की टर्शियरी युगीन परागाणुस्तरिकी से सम्बन्धित परागाणविक आंकड़ों की अच्छी मात्रा में जानकारी होने के बावजूद ऐसे अनेक क्षेत्र हैं, जहाँ पर सूचनाओं का अभाव है तथा जिस ओर परागाणु वैज्ञानिकों को ध्यान देना है. इन न्यूनताओं की पहचान कर ली गई है तथा प्रस्तावित किया जाता है कि इन न्यूनताओं की पूर्ति करना भविष्य के अनुसन्धान कार्यों का उद्देश्य होना चाहिये.

संकेत शब्द—परागाणुविज्ञान, परागाणुस्तरिकी, टर्शियरी, मेघालय, पूर्वोत्तर भारत.

INTRODUCTION

THE state of Meghalaya, comprising Garo, Khasi and Jaintia Hills, covers an area of approximately 23,000 sq km. It is bordered to its northwest, north, east and southwest by the state of Assam and to its southwest and south by Bangla Desh. The southern portion of Meghalaya is occupied by a thick sequence of Cretaceous-Tertiary sediments, which remained a centre of attraction for geologists because of rich deposits of limestone, clay, glass sand and coal. Pioneering geological studies and mapping of this region have been done by Bedford (1842, in Medlicott 1868), Oldham (1859), Medlicott (1868, 1869, 1874), LaTouche (1882, 1883a, b, 1884, 1887, 1889, 1890a, b), Hayden (1897), Pinfold (1919), Palmer (1923), Fox (in Heron 1937), etc. Raja Rao (1981) published an account of the coalfields of Northeastern India.

Evans (1932) published a detailed study of the Tertiary sediments of Northeast India and proposed a stratigraphic classification, which received a wide acceptance. He opined that the Tertiary succession of this region is developed in two distinct facies, the shelf and the geosynclinal. Chakraborty (1972) and Chakraborty and Baksi (1972) realized that Evans' stratigraphic units are not applicable to the sediments developed in Garo Hills and western Khasi Hills of Meghalaya and proposed another lithostratigraphic classification for the Cretaceous-Tertiary sequence of this region. Director General, Geological Survey of India (1974) and Murthy *et al.* (1976) proposed yet another classification. They redefined some of the earlier stratigraphic units and also proposed a few new ones.

STRATIGRAPHIC SUCCESSION IN MEGHALAYA

The oldest rocks, represented by the Gneissic Complex (Archaean), are exposed in the central and northern parts of Meghalaya. These are believed to be the northeastern extension of the Indian Peninsular Block, separated from it by the Garo-Rajmahal Trough Fault. The Gneissic Complex is unconformably succeeded by the Shillong Group (Precambrian), which is exposed in the central and eastern parts of the Meghalaya Plateau. The Shillong Group is mainly composed of quartzite with subordinate phyllite, quartz-sericite schist, conglomerate, etc. These rocks are intruded by ultramafic and acidic sills and dykes. A patch of Lower Gondwana (Permian) sediments, containing streaks and lenses of coal and impressions of *Vertebraria indica,* is exposed at Singrimari in West Garo Hills. Along the southern border of Meghalaya Plateau are exposed Sylhet Traps (?Jurassic) which form a narrow, east-west strip, about 80 km long and 4 km wide. They unconformably overlie the Precambrian rocks and are unconformably overlain by the Late Cretaceous-Palaeogene sediments. The Late Cretaceous sediments are represented by Gumaghat and Mahadeo formations.

The basal unit of the Tertiary succession of Meghalaya is represented by the Langpar Formation (Danian). This formation overlies the Mahadeo Formation (Late Cretaceous) in the Umsohryngkew River Section in Cherrapunji area. The deposition of these sediments marks the beginning of the table shelf conditions. The Langpar Formation is succeeded by the Therria Formation (Palaeocene). Equivalents of the Therria Formation are known as Tura Formation (in part) in Garo Hills and Cherra Formation in Khasi Hills. Singh R.Y. (1982) observed that the Cherra Formation merges laterally into the Langpar Formation in Therriaghat area and that the former may be a lateral equivalent of the latter. The lithological difference between the two may merely be an expression of facies change. The Therria Formation is overlain by the Sylhet Limestone Formation (Early-Middle Eocene), which is made up of alternations of limestones and sandstones and is divided into five members, viz., Lakadong Limestone, Lakadong Sandstone, Umlatadoh Limestone, Nurpuh Sandstone and Prang Limestone. The lower two members of this formation may be equivalent to the upper part of the Tura Formation. In Garo Hills, the limestone, overlying the Tura Formation, is much reduced and is known as Siju Formation. Director General, Geological Survey of India (1974) and Murthy *et al.* (1976) included both Therria and Sylhet Limestone/Siju formations together into the Shella Formation. Overlying the Sylhet Limestone/Shella Formation is Kopili Formation (Late Eocene). In Garo Hills, equivalent of the Kopili Formation is known as Rewak Formation. The Langapr, Therria, Sylhet Limestone and Kopili formations together constitute the Jaintia

Age	Evans, 1932		Director General, Geological Survey of India, 1974; Murthy *et al.*, 1976	Chakraborty & Baksi, 1972 (Garo Hills and West Khasi Hills)
	Geosynclinal Facies	Shelf facies		
Pleistocene and Recent	Alluvium with high level terraces		Older and Newer Alluvia	Alluvium
-----	Unconformity		Unconformity	Unconformity
Pliocene	Dihing Group	Dihing Group		Dalu and Rangapani formations
Mio-Pliocene	Dupitila Group	Dupitila Group	Dupitila Group	Bilkona Formation
Miocene	Tipam Group: Girujan Clay; Tipam Sandstone	Tipam Group: Girujan Clay; Tipam Sandstone		
	Surma Group: Bokabil Formation; Bhuban Formation	Surma Group (not subdivided)	Surma Group: Chengapara Formation; Baghmara Formation	Angartoli Formation; Boldamgiri Formation
Oligocene	Barail Group: Renji Formation; Jenam Formation; Laisong Formation	Barail Group (not subdivided)	Simsang Formation	Kherapara Formation
Palaeocene-Eocene	Disang Group	Jaintia Group: Kopili Formation; Sylhet Limestone Formation; Therria Formation	Jaintia Group: Kopili Formation; Shella Formation; Langpar Formation	Rewak Formation; Siju Formation; Tura Formation

Fig. 1—Tertiary stratigraphy of Meghalaya.

Group. The equivalent of this group in geosynclinal facies is known as the Disang Group (in part). The Kopili Formation is overlain by the Barail Group (= Simsang Formation/Kherapara Formation) of Oligocene age. The Meghalaya Plateau witnessed considerable sinking during Oligocene resulting into thick deposition of the Barail Group. The Barail Group of geosynclinal facies is divided into three formations, viz., Laisong Formation (2400 m). Jenam Formation (1200 m) and Renji Formation (1000 m) whereas the same belonging to the shelf facies, exposed in the western part of the Shillong Plateau, is comparatively much thinner (1200 m). Chakraborty and Baksi (1972) introduced a new name - Kherapara Formation - for the Barail Group sediments of Garo Hills. These are nearly 1000 m thick and are divisible into a lower, mainly arenaceous Darik Member and an upper, more argillaceous Inolgiri Member. The close of Barail sedimentation in this region witnessed a period of uplift, nondeposition and erosion. The Barail Group is unconformably overlain by the Surma Group (Early Miocene) which is divisible into two formations, viz., Bhuban and Bokabil. The lower and upper parts of the Bhuban Formation (= Baghmara Formation/Boldamgiri Formation) are arenaceous with subordinate shales whereas the middle part is mainly argillaceous with thinly bedded sandstones. In Garo Hills, equivalent of the Bhuban Formation is known as Boldamgiri Formation. The Bhuban Formation is overlain by the Bokabil Formation (= Chengapara Formation/Angartoli Formation). The Surma Group is overlain by the Tipam Group, which is divisible into two formations, viz., Tipam Sandstone and Girujan Clay. This group is poorly exposed in the eastern part of Meghalaya. In Garo Hills, the Angartoli (=Bokabil) Formation is unconformably overlain by the Bilkona (= Dupitila) Formation. The Dupitila Group (Mio-Pliocene) is composed of mottled clays and siltstones, gritty sandstones and conglomerates. In Garo Hills, the Bilkona (= Dupitila)

Formation is unconformably overlain by the isolated outcrops of Dalu and Rangapani formations. Both these formations are equivalents of the Dihing Group and are overlain by the Older and Newer Alluvia of Pleistocene and Recent ages respectively (Fig. 1).

TERTIARY PALYNOSTRATIGRAPHY

A considerable amount of palynological information is known from the Tertiary sediments of Meghalaya, which has been successfully applied in biostratigraphy and in deducing palaeoclimate and environment of deposition. The Tertiary palynofossil localities in Meghalaya are shown in Fig. 2. A synthesis of the palynological work done on these sediments is presented below with the objectives to understand the present status of the Tertiary palynostratigraphy of Meghalaya and to identify gaps in our knowledge that need be bridged in the future studies.

Garo Hills

Palaeocene—Early Eocene

The Tura Formation (Palaeocene-Early Eocene), unconformably overlying the Precambrian rocks, constitutes the oldest stratigraphic unit of the Tertiary sequence of Garo Hils. This formation has been palynologically investigated by Biswas (1962), Chatterjee and Ghosh (1963), Banerjee (1964b), Ghosh (1969), Kar *et al.* (1972), Singh H.P. *et al.* (1976), Singh R.Y. (1977a, b), Sah and Singh R.Y. (1974, 1977a), Singh R.Y. and Singh H.P. (1978), Tewari and Singh R.Y. (1984), Ambwani (1993), Saxena *et al.* (1996) and Tripathi *et al.* (2000). Sah and Singh R.Y. (1974) divided the Tura Formation into four zones, viz., *Assamialetes emendatus* Cenozone, *Dandotiaspora telonata* Cenozone, *Palmidites plicatus* Cenozone and *Proxapertites assamicus* Cenozone. The *Assamialetes emendatus* Cenozone is characterized by *Assamialetes emendatus, Proxapertites crassimurus, Dandotiaspora dilata, Triorites communis, Droseridites parvus, Tricolporopollis matanomadhensis* and *Liliacidites major.* The important palynotaxa of the *Dandotiaspora telonata* Cenozone are *Dandotiaspora dilata, D. telonata, D. densicarpa, Lycopodiumsporites palaeocenicus, L. speciosus, Polycolpites speciosus* and *P. cooksoniae.* The *Palmidites plicatus* Cenozone is characterized by *Palmidites plicatus, P. maximus, Laricoidites magnus* and *Neocouperipollis brevispinosus.* The *Proxapertites assamicus* Cenozone is characterized by *Proxapertites assamicus, Margocolporites complexum, Cicatricosisporites macrocostatus, Stephanocolpites tertiarus, Meliapollis ramanujamii* and *Polypodiisporites speciosus.* Based on palynofossils, an estuarine to near-shore depositional environment has been suggested for the Tura Formation.

Singh R.Y. and Singh H.P. (1978) studied palynoflora from the subsurface Palaeocene sediments (= Tura Formation) in Nongwal Bibra (= Nangwalbibra) area of Darranggiri Coalfield. This assemblage closely compares with that recorded from the Tura Formation in type area by Singh (R.Y. 1977a). Singh H.P. *et al.* (1976) recognized *Dandotiaspora telonata* Cenozone in borehole NS-1 and *Dandotiaspora telonata* Cenozone and *Palmidites plicatus* Cenozone in borehole NS-5. In these boreholes, *Dandotiaspora telonata* Cenozone is better developed than that of the type area and is divisible into finer units. In borehole NS-1, Singh *et al.* (1976) recognized four subzones, viz., *Polycolpites cooksoniae* Subzone, *Palmaepollenites communis* Subzone, *Lycopodiumsporites palaeocenicus* Subzone and *Dandotiaspora telonata telonata* Subzone. In borehole NS-5, the lower two subzones are not traceable because of the poor recovery of spores and pollen grains. However, this part is rich in fungal remains and has been termed as 'Zone of fungal elements'. Overlying this zone, the upper two subzones encountered in borehole NS-1 were clearly recognized.

Ambwani (1993) recorded a palynoflora from the three coal seams of Rekmangiri Coal Mine of Garo Hills. Based on palynofloral assemblage, he concluded that the lower two coal seams are of Palaeocene age and the top coal seam is of Early Eocene age.

Saxena *et al.* (1996) also studied palynoflora from the Tura Formation of Nangwalbibra area in East Garo Hills and recognized two informal palynozones. The lower zone, characterized by the dominance of *Proxapertites* spp., *Tricolporopollis* spp., *Granustephanocolpites cooksoniae, Palmidites* spp., *Tricolpites matanomadhensis*, etc., corresponds to the *Assamialetes emendatus* Cenozone whereas the upper zone, characterized by *Lycopodiumsporites* spp. *Dandotiaspora* spp., *Foveosporites triangulus, Todisporites* spp., etc., corresponds to the *Dandotiaspora telonata* Cenozone.

Tripathi *et al.* (2000) studied palynoflora from the Tura Formation exposed along Tura-Dalu Road in West Garo Hills and recognized three palynozones, viz., *Lanagiopollis* spp. Assemblage-zone, *Palmidites* spp. Assemblage-zone and *Tricolporopilites* spp. Assemblage-zone. The *Lanagiopollis* spp. Assemblage-zone is characterized by *Lanagiopollis emarginatus, L. nanggulaensis, L. retismae, Dandotiaspora telonata* and *Paleocaesalpiniaceaepites eocenica.* The *Palmidites* spp. Assemblage-zone is character-ized by the dominance of dinoflagellate cysts along with *Palmidites plicatus, P. naviculus, P. granulatus* and *P. punctatus.* The *Tricolporopilites* spp. Assemblage-zone is characterized by the dominance of *Tricolporopilites uniformis, T. tectatus* and *T. robustus.*

Middle-Late Eocene

The Middle Eocene sediments in Garo Hills are represented by the Siju Formation. Baksi (1962) designated Simsang Palynological Zone-I as representing the palynoflora of the Sylhet Limestone (= Siju Formation) of Simsang River Section. Its main elements are pollen of Palmae and Caesalpiniaceae together with inaperturate and polycolpate/polycolporate pollen and a large number of hystrichosphaerids. Sah and Singh R.Y. (1977a) recorded a scanty spores-pollen assemblage from the Siju Limestone, which includes *Retipilonapites* sp., *Neocouperipollis brevispinosus, Cyathidites minor, Palmidites plicatus* and *Polycolpites cooksoniae. Polycolpites-Monosulcites (Colocasioideaepites)* assemblage Zone designated by Baksi (1974) from the Simsang River Section represents the Early-Middle Eocene palynoflora.

Baksi (1962) recognized Simsang Palynological Zone II in the Rewak Formation exposed along Simsang River Section. The principal constituents of this zone are *Laevigatosporites kopilia, Ginkgopites dubia, Simsangia trispinosa, Monocolpopites broadcolpusi* and *Acolporopites spinulosa* and dinoflagellate cysts. Salujha *et al.* (1972) described palynoflora from the Palaeogene sediments (Tura, Siju, Rewak and Darik formations) of Garo Hills. However, they did not mention occurrence of palynotaxa formation-wise.

Oligocene

Baksi (1962) established Simsang Palynological Zone III in the Barail Group (Kherapara Formation) exposed along Simsang River Section. This zone is characterized by the abundant occurrence of *Meyeripollis naharkotensis*, appearance of *Bauhinia burdwanensis*, frequent occurrence of *Polypodiisporites tuberculensis, Leiotriletes garoensis, Spinosopites acolporata, Tricolpopites spinosa, T. prolati, T. shorti, Tricolporipites minima, Schizaeaceaesporites knoxii*, etc.

Mishra *et al.* (1996) studied palynoflora and animal fossils from the post-Kopili succession of the Tura-Dalu Road Section, West Garo Hills. He recognized Biostratigraphic Zone 1 in the Simsang (=Kherapara) Formation which is characterized by *Meyeripollis naharkotensis, Polypodiisporites tuberculensis, Schizaeaceaesporites knoxi, Spinosopites acolporata, Polypodiaceaesporites* sp., *Lycopodiumsporites* sp., *Corrugatisporites* sp., *Retistephanocolpites* sp. and *Ginkgopites dubia.*

Miocene

Palynological work on the Surma Group has been carried out by Baksi (1962), Banerjee (1964a), Nandi and Sharma (1984) and Saxena and Rao (1996). Baksi (1962) recognized Simsang Palynological Zone IV representing the Surma sediments (Miocene). This zone is characterized by the abundance of conifer pollen (*Coniferipites garoensis, C. abiesimilis, C. wilsonii* and *C. chattacharai*), frequent occurrence of schizaeaceous (*Aneimia* type) and parkeriaceous (*Caratopteris* type) spores and *Densexinosporites minuta*, first occurrence of *Polygonaceaepites zonoides* and occurrence of

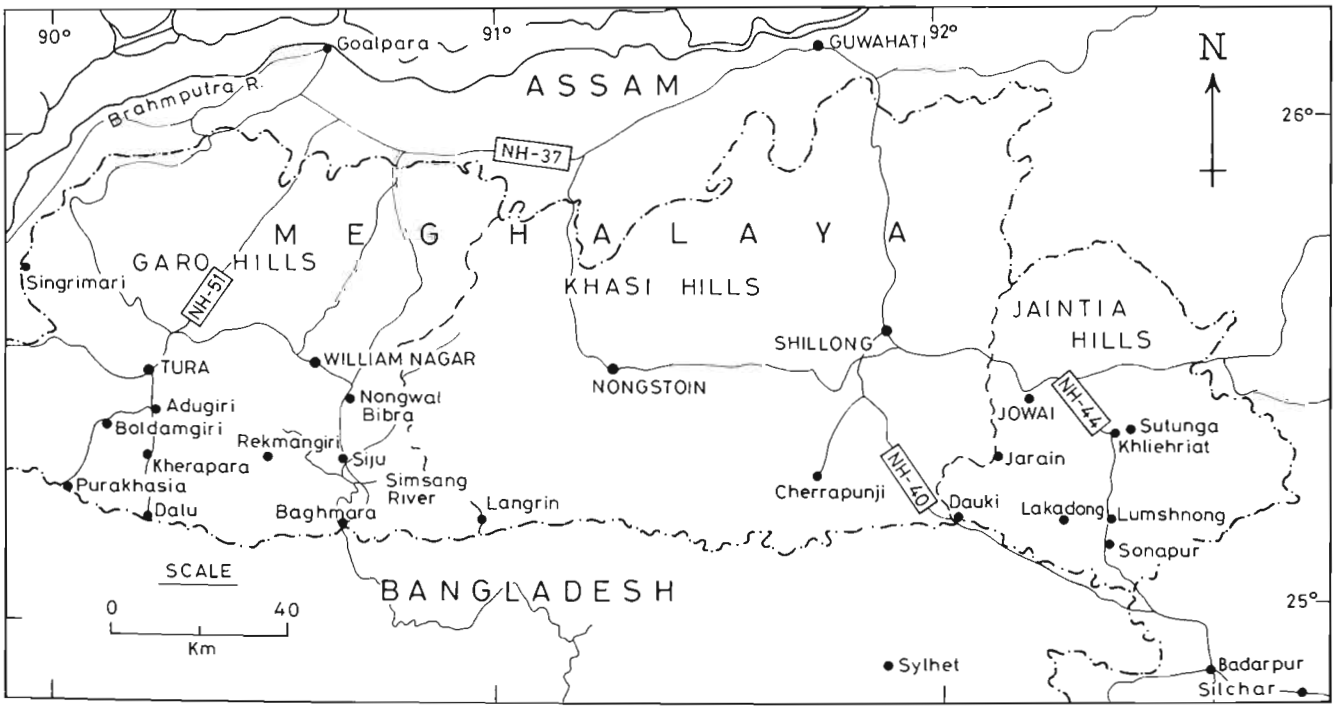

Fig. 2—Tertiary palynofossil localities in Meghalaya.

Tricolpopites radiistriaei, T. granulosa, Triporipites crescentipora and some dinoflagellate cysts.

Banerjee (1964a) also studied the Surma palynoflora from the above section and described spore-pollen types. He noticed a broad division of the sediments into two parts based on the presence and absence of certain types with restricted range and occurrence of coniferous pollen only in the upper part.

Nandi and Sharma (1984) studied palynoflora from the Boldamgiri Formation (=Bhuban Formation, Early Miocene) exposed along Tura-Damalgiri Road Section in West Garo Hills and divided the sequence into two subzones. According to them, these subzones constitute the lower part of the *Coniferipites-Cicatricosisporites* Assemblage Zone of Baksi (1974). The lower subzone, viz., *Cicatricosisporites-Palmaepollenites* Assemblage Subzone is marked by frequent occurrence of *Cicatricosisporites macrocostatus, C. dorogensis, Magnastriatites howardii, Palmaepollenites eocenicus, P. communis, Dicolpopollis kockeli, Striatopollis bellus, Striacolporites grandioratus, Striatocolporites grandis, Tricolpites reticulatus, T. minutus,* etc. with more or less high frequency of bisaccate pollen and presence of *Rhoipites nitidus, R. communis, R. psilatus, Araliaceoipollenites euphorii, A. psilatus, Margocolporites tsukadae, Meyeripollis naharkotensis, Neocouperipollis brevispinosus* and *N. rarispinosus*. The upper subzone, viz., *Polygonaceaepites zonoides* Assemblage Subzone is characterized by the significant occurrence of *Polygonaceaepites zonoides* and *P. ghoshii,* high frequencies of *Polypodiisporites* spp., *Polypodiaceoisporites simplex, Nyssapollenites barooahii, N. pseudocruciatus, Bombacacidites assamicus* and *Myricipites dubius,* comparatively higher percentage of *Corrugatisporites turpitus, Lygodiumsporites adriennis, Foveotriletes pachyexinous,* low frequencies of *Cicatricosisporites macrocostatus, Magnastriatites howardii, Pinuspollenites labdacus, Podocarpidites ellipticus, Striatocolporites grandis, Palmaepollenites eocenicus, P. communis,* etc. and restricted occurrence of *Alnipollenites verus* and *Chenopodipollis multiplex*. The palynoflora indicates tropical-subtropical climate, swampy environment of deposition having brackish water influence and elevated topography surrounding the basin of deposition.

Saxena and Rao (1996) studied palynoflora from the Boldamgiri Formation exposed along Adugiri-Purakhasia Road near Boldamgiri in West Garo Hills. This assemblage is dominated by *Striatriletes susannae* (20%), *Pinuspollenites foveolatus* (12%), *Lygodiumsporites lakiensis* (10%), *Biretisporites convexus* (8%), etc. The Boldamgiri Formation is divided into two informal zones. The lower zone is characterized by the restricted occurrence of *Lygodiumsporites pachyexinus, Biretisporites convexus, Striatriletes pseudocostatus, S. punctatus, Pinjoriapollis lanceolatus, Paleosantalaceaepites minutes, Meyeripollis naharkotensis, Varispinitriporites ratariaensis, Echistephanocolpites* spp. and *Chenopodipollis* sp. On the other hand, the upper palynozone has restricted occurrence of *Foveotriletes garoensis, Osmundacidites* sp., *Pilamonoletes excellensus, Triporopollenites robustus, Favitricolporites magnus* and *Pteridacidites* sp. The Boldamgiri assemblage of Garo Hills is largely comparable to that recorded from the Bhuban Formation of Jaintia Hills (Saxena *et al.*, 1987).

Mishra *et al.* (1996) recognized Biostratigraphic Zone 2 in the Baghmara Formation (=Boldamgiri Formation) exposed along Bugi River in West Garo Hills. This zone is characterized by *Pinuspollenites* spp., *Coniferipites abiesimilis, Abiespollenites* sp., *Lygodiumsporites* sp., *Polypodiisporites* sp., *Gleicheniidites* sp. and fungal remains. Biostratigraphic zones 3, 4 and 5 in the Chengapara Formation have been recognized on the basis of animal fossils.

No palynological information is so far available from the sediments younger than Boldamgiri (= Bhuban/Baghmara) Formation.

Khasi Hills

Palaeocene

The Langpar Formation (Danian) constitutes the basal stratigraphic unit of the Tertiary stratigraphic sequence in Khasi Hills. This formation has yielded spores, pollen, phytoplanktons and foraminifers. The palynofloral assemblages from this formation have been recorded by Sah *et al.* (1970), Sah and Dutta (1974), Jain *et al.* (1975), Singh R.Y. and Tewari (1978) and Salujha and Kindra (1981). Sah and Singh R.Y. (1977b) recognized *Assamialetes emendatus* Cenozone within this unit which includes the following characteristic palynotaxa: *Dandotiaspora dilata, D. telonata, Sestrosporites dettmanniae, Lycopodiumsporites palaeocenicus, L. speciosus, Assamialetes emendatus, Proxapertites assamicus, P. crassimurus, Palmaepollenites communis, P. eocenicus, Liliacidites major, L. microreticulatus, Neocouperipollis brevispinosus, Tricolpites levis, Tricolporopollis matanomadhensis, Meliapollis ramanujamii, Polycolpites speciosus, P. cooksoniae, Triorites communis* and *Droseridites parvus.* The occurrence of spores and pollen, in association with phytoplanktons, indicates a shallow marine depositional environment.

Jain *et al.* (1975) studied palynoflora from the Langpar Formation of Dawki and Cherrapunji areas. This assemblage is dominated by dinoflagellate cysts and acritarchs (95%) with meagre representation of spores-pollen (5%). Significant taxa of the Langpar assemblage of Dawki area are *Codoniella* (18%), *Ceratiopsis* (10%), *Deflandrea* (4%), *Palaeocystodinium* (10%), *Cordosphaeridium* (6%), *Cyclonephelium* (19%) and *Leiofusa* type (reworked, 20%) whereas the same of the Cherrapunji area is dominated by *Lanternosphaeridium* (60%) and *Cordosphaeridium* (30%). The dominant taxa of the underlying Gumaghat (= Jadukata)

and Mahadek formations, viz., *Dinogymnium* and *Ariadinaesporites*, are absent from the Langpar Formation.

The palynology of the Cherra Formation has been published by Biswas (1962), Sah and Dutta (1966, 1968, 1974) and Dutta and Sah (1970). Sah and Dutta (1974) divided the Cherra Formation into three palynozones, viz., *Proxapertites crassimurus* Cenozone, *Araliaceoipollenites reticulatus* Cenozone and *Tricolpites reticulatus* Cenozone. The characteristic palynotaxa of the *Proxapertites crassimurus* Cenozone are *Proxapertites crassimurus, Assamialetes emendatus, Polypodiisporites mawkmaensis, Polycolpites ornatus, Tricolporopollis matanomadhensis, Foveotriletes pachyexinous* and *Lycopodiumsporites palaeocenicus.* The *Araliaceoipollenites reticulatus* Cenozone is characterized by *Araliaceoipollenites reticulatus, A. psilatus, Droseridites parvus, Corrugatisporites formosus, Triorites communis, Assamialetes emendatus* and *Lycopodiumsporites palaeocenicus.* The *Tricolpites reticulatus* Cenozone is characterized by *Tricolpites reticulatus, Trifossapollenites constatus, Triporopollenites vimalii* and *Foveotriletes pachyexinous.* The palynoflora of the Cherra Formation suggests deltaic to near-shore environment of deposition and tropical climate.

Kar (1997) recognized *Acrostichumsporites meghalayaensis* Subzone in the Langpar Formation (Danian) exposed at Therriaghat on the UmSohryngkew River Section in Khasi Hills. It is characterized by *Acrostichumsporites meghalayaensis, Proxapertites operculatus, P. cursus, Matanomadhiasulcites maximus, Spinizonocolpites echinatus, Saturna enigmatus* and *Terscissus grandis.*

The Cherra Formation is overlain by the Sylhet Limestone Formation. The lower two members of this formation, viz., Lakadong Limestone and Lakadong Sandstone, pertain to Palaeocene. The Lakadong Limestone has yielded dinoflagellate cysts and foraminifers indicating Late Palaeocene age. The spores and pollen are not known from this member. From the Lakadong Sandstone Member, Dutta and Sah (1970) and Sah and Dutta (1974) recorded a spore-pollen assemblage and designated this sequence as the Lakadong Palynological Zone. This zone as characterized by the dominance of *Proxapertites dubius* and *Dandotiaspora* spp. Kar and Kumar (1986) studied palynoflora from the Lakadong Sandstone, exposed in six stratigraphic sections in Khasi Hills. They divided the sequence into two cenozones, viz., *Lycopodiumsporites speciosus* Cenozone and *Kielmeyerapollenites syncolporatus* Cenozone. The former is characterized by *Lycopodiumsporites speciosus, L. umstewensis, L. parvireticulatus, Dandotiaspora dilata, D. telonata, Pteridacidites meghalayaensis, P. robustus, Proxapertites crassimurus, P. emendatus, Matanomadhiasulcites maximus, Neocouperipollis kutchensis, N. wodehousei, Tricolpites reticulatus, Tricolporopollis matanomadhensis* and *Araucariacites australis* whereas the latter is characterized by *Dandotiaspora dilata, D. telonata, Polypodiisporites umstewensis, Lygodiumsporites lakiensis, Lycopodiumsporites concavus, Palmidites plicatus, P. excellensus, Psilastephanocolporites psilatus, P. subcircularis, Retistephanocolpites multirimatus* and *Polymargocolporites mawlensis.*

Mandal (1990) recorded a rich palynoflora from three coal seams in the Lakadong Sandstone exposed at Thanjinath, about 12 km southeast of Cherrapunji. The lower coal seam is rich in pteridophytic spores (*Lycopodiumsporites* spp. and *Lygodiumsporites* spp.); the middle coal seam is characterized by the dominance of angiospermous pollen (*Neocouperipollis* spp., *Kielmeyerapollenites eocenicus, Tricolpites* spp. and *Proxapertites* spp.), *Lygodiumsporites* spp. and fungal remains; and the upper coal seam has dominance of *Lygodiumsporites* spp., *Proxapertites* sp., *Neocouperipollis* spp., *Rhoipites kutchensis* and *Recemonocolpites* spp.

Singh R.S. (1990) recorded a rich palynoflora from 5 coal seams in Langrin Coalfield in West Khasi Hills. These coal seams are associated with the Tura Formation. Coal seam 1 and 2 are dominated by *Lycopodiumsporites palaeocenicus, L. speciosus, Proxapertites* spp., *Dandotiaspora* spp., *Matanomadhiasulcites maximus* and *Tricolporopollis ruber.* Coal seam 3 has slight dominance of angiospermous pollen (with predominance of *Kielmeyerapollenites eocenicus*). Coal seam 4 is dominated by angiospermous pollen with first appearance of *Lycopodiumsporites umstewensis, Schizaeoisporites crassimurus, Polypodiisporites mawkmaensis, Spinizonocolpites indicus, S. echinatus, Psilastephanocolpites psilatus, Polymargocolporites mawlensis* and *Triangulorites bellus.* The assemblage of coal seam 5 is more or less similar to that of coal seam 4 but for the overwhelming representation of *Spinizonocolpites.*

Palynofloras from the sediments younger than Lakadong Sandstone are not known.

Jaintia Hills

Palaeocene

Palynofloras from the Therria Formation (Palaeocene), exposed along Jowai-Sonapur Road, have been recorded by Tripathi and Singh H.P. (1984a, 1985) and Singh H.P. and Tripathi (1986, 1987). On the basis of this palynoflora, Tripathi and Singh H.P. (1984b) divided this formation into three zones, viz., *Lygodiumsporites psilatus* Cenozone, *Palmidites obtusus* Cenozone and *Apectodinium homomorphum* Cenozone. The *Lygodiumsporites psilatus* Cenozone has been equated with the lower two zones of Tura (Garo Hills), Cherra (Khasi Hills) and Mikir (North Cachar Hills) formations whereas *Palmidites obtusus* and *Apectodinium homomorphum* cenozones together have been equated with the third zone (from bottom upwards) of these formations. *Lygodiumsporites psilatus* Cenozone is characterized by the restricted occurrence of *Lygodiumsporites*

psilatus, L. marginiplicatus, Cyathidites australis, Intrapunctisporis densipunctis, Neocouperipollis wodehousei, Liliacidites microreticulatus, Ladakhipollenites elongatus and *Cordosphaeridium valiantum*. The *Palmidites obtusus* Cenozone is characterized by the restricted occurrence of *Tricolpites alveolatus* and *Palmidites maximus* and representation of *Lygodiumsporites meghalayaensis, L. eocenicus, Palmidites obtusus* (Predominant) and dinoflagellate cysts. The *Apectodinium homomorphum* Cenozone is rich in dinoflagellate cysts (78%), e.g., *Apectodinium* spp., *Polysphaeridium subtile, Adnatosphaeridium* spp., *Homotryblium* spp., *Codoniella langparensis, Cordosphaeridium multispinosum* and *Operculodinium* spp. alongwith spore-pollen taxa. The high representation of dinoflagellate cysts indicates a transgressive phase.

Dutta and Jain (1980) recorded dinoflagellate cysts and acritarchs from the Sylhet Limestone and Kopili formations in the area around Lumshnong. The Lakadong Limestone (Microplankton Assemblage A) has abundance of *Collumosphaera fruticosa* (71%) along with *Operculodinium major, O. centrocarpum, Cordosphaeridium multispinosum,* etc. whereas Lakadong Sandstone (Microplankton Assemblage B) has abundance of *Apectodinium parvum* (88%) with poor representation of *Apectodinium homomorphum* and *A. hyperacanthum.*

Mandal (1987) described a palynoflora from the coal beds probably belonging to the Lakadong Sandstone exposed at Sutunga, east of Khliehriat, in Jaintia Hills. The dominant palynotaxa of this assemblage are: *Lycopodiumsporites parvireticulatus, L. umstewensis, Lygodiumsporites lakiensis, Proxapertites* spp., *Tricolpites minutus, Neocouperipollis* spp., etc.

Kumar (1994) studied palynofloras from the Jarain and Laitrymbai coal seams belonging to the Lakadong Sandstone. Important palynotaxa of these assemblages are: *Dandotiaspora dilata, D. telonata, Lycopodiumsporites speciosus, Lygodiumsporites lakiensis, Dictyophyllidites* sp., *Neocouperipollis kutchensis, Palmidites plicatus, Matanomadhiasulcites maximus, Kielmeyerapollenites syncolporatus,* etc.

Eocene

The Therria Formation is overlain by the Sylhet Limestone Formation (Early-Middle Eocene). Tripathi and Singh H.P. (1984b) recorded a scanty palynoflora from this formation, which includes *Neocouperipollis brevispinosus, Liliacidites giganticus, Dandotiaspora telonata, Tricolporopollis ruber, Operculodinium major* and *Tricolpites alveolatus.*

Dutta and Jain (1980) recorded dinoflagellate cysts assemblage from the Prang Limestone Member of the Sylhet Limestone Formation (Microplankton Assemblage C) from near Lumshnong. This assemblage has dominance of *Hystrichokolpoma rigaudiae* (21%) followed by *Cordosphaeridium exilimurum* (14%), *Glaphyrocysta divaricata* (12%), *Operculodinium* spp. (14%), etc.

Kar (1992) recorded palynoflora from the Prang Formation (=Prang Limestone Member of the Sylhet Formation) exposed near 13·2 km post on Jowai-Badarpur Road. The palynoflora is represented by *Todisporites kutchensis, Lygodiumsporites lakiensis, Osmundacidites kutchensis, Cyathidites minor, Striatriletes susannae, Podocarpidites khasiensis, Polypodiaceaesporites chatterjii, Polypodiisporites repandus, Lakiapollis ovatus* and *Pellicieroipollis langenheimii.*

The Late Eocene sediments in Jaintia Hills are represented by the Kopili Formation. This formation overlies the Sylhet Limestone Formation. Palynofloras from the Kopili Formation have been recorded by Sein and Sah (1974), Tripathi and Singh H.P. (1984a, b, 1985), Singh H.P. and Tripathi (1986, 1987) and Trivedi (1985). Sein and Sah (1974) differentiated the Kopili sediments from the overlying Barail sequence in Jowai-Badarpur Road Section, on the basis of *Monolites mawkmaensis, Lycopodiumsporites* sp. and *Tricolpites* sp. characterising the former and their absence from the latter. The Barail sequence is also characterized by the abundance of *Cicatricosisporites macrocostatus* and *Meyeripollis naharkotensis.*

Dutta and Jain (1980) recorded dinoflagellate cysts from the Kopili Formation (Microplankton Assemblage D) from near Lumshnong. This assemblage has predominance of *Homotryblium plectilum* (97%). The other species present in the assemblage are *Homotryblium oceanica, Glaphyrocysta exuberans, G. divaricata, Distatodinium* sp., *Hystrichokolpoma rigaudiae, H. unispinum, Cordosphaeridium exilimurum* and *Hystrichostrogylon membraniphorum.*

Tripathi and Singh H.P. (1984b) divided the Kopili Formation into two cenozones, viz., *Turbiosphaera proximata* Cenozone and *Densiverrupollenites eocenicus* Cenozone. The *Turbiosphaera proximata* Cenozone is characterized by the dominance of *Turbiosphaera proximata, T. filosa, Polysphaeridium giganteum, Homotryblium plectilum, Operculodinium major, O. centrocarpum, Cordosphaeridium exilimurum, Striatriletes susannae, S. attenuatus, Lakiapollis assamicus, Todisporites major* and *Dandotiaspora telonata* and restricted occurrence of *Turbiosphaera proximata, T. filosa, Polysphaeridium giganteum* and *Striatriletes attenuatus.* The *Densiverrupollenites eocenicus* Cenozone is characterized by the dominance of *Striatriletes susannae, S. paucicostatus, Densiverrupollenites eocenicus, Lakiapollis assamicus, Tricolporopollis ruber, Dandotiaspora dilata, D. telonata, Lygodiumsporites eocenicus, Cordosphaeridium multispinosum, C. exilimurum, Homotrylium plectilum* and *Adnatosphaeridium vittatum* and restricted occurrence of

Striatriletes paucicostatus and Densiverrupollenites eocenicus.

Oligocene

Salujha *et al.* (1974) published palynoflora from the Palaeogene sediments of Khasi-Jaintia Hills. However, they did not mention occurrence of palynotaxa formation-wise. Palynological work on the Barail sediments of Jowai-Badarpur Road Section (Sein & Sah 1974) shows that the frequency of *Striatriletes* increased from 38% in the Laisong Formation to nearly 98% at the top of sequence. Detailed palynological study of the Barail (Oligocene) and Surma (Early Miocene) groups exposed in Jaintia Hills has been made by Rao (1983, 1986), Saxena and Rao (1984), Rao *et al.* (1985), Singh H.P. *et al.* (1986, 1987) and Rao and Singh H.P. (1987) which enabled Saxena *et al.* (1987) to divide the Barail Group into three cenozones, viz., *Polysphaeridium subtile* Cenozone, *Todisporites major* Cenozone and *Lygodiumsporites eocenicus* Cenozone. The lower two cenozones together correspond to the Laisong Formation whereas the upper cenozone corresponds to the Jenam and Renji formations. The *Polysphaeridium subtile* Cenozone is characterized by the dominance of *Adnatosphaeridium vittatum, Polysphaeridium subtile, Cordosphaeridium inodes, Impletosphaeridium insolitum, Homotryblium floripes, Striatriletes susannae, Lygodiumsporites lakiensis, L. eocenicus, Cyathidites minor* and *Pinuspollenites foveolatus* and restricted occurrence of *Adnatosphaeridium vittatum* and *Tricolpites* sp. The *Todisporites major* Cenozone is characterized by the dominance of *Cordosphaeridium multispinosum, C. fibrospinosum, Polysphaeridium subtile, Striatriletes susannae, Todisporites major, Biretisporites oligocenicus, Lygodiumsporites lakiensis, L. eocenicus, Polyadopollenites sahii* and *Echistephanocolpites meghalayaensis* and restricted occurrence of *Biretisporites oligocenicus* and *Cordosphaeridium multispinosum.* The *Lygodiumsporites eocenicus* Cenozone is characterized by the dominance of *Striatriletes susannae, S. pachyexinus, Todisporites major, Polypodiaceaesporites tertiarus, Podocarpidites meghalayaensis, Laricoidites punctatus* and *Polyadopollenites sahii* and restricted occurrence of *Striatriletes pachyexinus* and *Dictyophyllidites indicus.*

Singh R.Y. *et al.* (1986) recorded a rich palynoflora from the Barail Group exposed around Sonapur, on Jowai-Badarpur Road, and divided the Barail Group into three zones, viz., *Eximispora meghalayensis* Zone, Polypodiaceae Abundance Zone and *Striatriletes* Abundance Zone. The lower, *Eximispora meghalayensis* Zone (corresponding to the Laisong Formation) is characterized by *Eximispora meghalayensis, Todisporites plicatus, Polypodiaceaesporites tertiarus, Tricolporopollis matanomadhensis, Neocouperipollis brevispinosus, Striatriletes discontinuous, S. susannae,* etc.; the middle, Polypodiaceae Abundance Zone (corresponding to the Jenam Formation) is characterized by *Jaintiapollenites plicatus, Sahiapollis arcotense, Todisporites granulatus, T. crassilaesuratus, Polypodiaceaasporites indicus, P. meghalayaensis, P. punctatus, Striatriletes indicus, S. juxtacostatus, S. susannae,* etc.; and the upper, *Striatriletes* Abundance Zone (corresponding to the Renji Formation) is characterized by *Striatriletes indicus, S. juxtacostatus, S. discontinuous, S. susannae, Todisporites granulatus, T. crassilaesuratus, Polypodiaceaesporites meghalayaensis, P. punctatus, Scantigranulites triangulus, Cyathidites minor,* etc.

Miocene

The Surma Group is divisible into Bhuban and Bokabil formations. Saxena *et al.* (1987) recognized three palynostratigraphic zones in the Bhuban Formation. The lower zone, viz., *Striatriletes sinuosus* Cenozone is characterized by the restricted occurrence of *Striatriletes sinuosus* and significant representation of *Cordosphaeridium inodes, Homotryblium floripes, Striatriletes susannae, Lygodiumsporites lakiensis, L. eocenicus, Cyathidites australis, Polypodiaceaesporites chatterjii, Polypodiisporites favus, Abiespollenites surmaensis, Pinuspollenites foveolatus, Neocouperipollis robustus, Polyadopollenites sahnii, Echistephanocolpites meghalayaensis* and *Malvacearumpollis* sp. This zone is marked by the dominance of *Striatriletes* (62%) and gymnospermous pollen (up to 20%). The middle zone, viz., *Pinuspollenites foveolatus* Cenozone is characterized by *Cordosphaeridium inodes, Todisporites minor, Lygodiumsporites eocenicus, L. lakiensis, Striatriletes susannae, Polypodiaceaesporites tertiarus, P. chatterjii, Pinuspollenites foveolatus, Abiespollenites surmaensis* and *Malvacearumpollis* sp. Gymnospermous pollen constitute about 33% of the assemblage of this cenozone. The upper zone, viz., *Malayaeaspora costata* Cenozone is characterized by the restricted occurrence of *Malayaeaspora costata, Surmaspora sinuosa, Lygodiumsporites donaensis, Lycopodiumsporites abundans* and *Foveotriletes* sp. along with the significant representation of *Striatriletes susannae, Monolites major, Pinuspollenites foveolatus, Abiespollenites surmaensis, Assamiapollenites* sp. and *Malvacearumpollis* sp. The Bhuban palynoflora is dominated by pteridophytic spores and gymnospermous pollen followed by dinoflagellate cysts, fungal remains and angiospermous pollen. The phytoplanktons indicate a near-shore depositional environment whereas gymnospermous pollen suggest the presence of high land nearby.

Comparatively less palynological information is available from the Bokabil Formation (Salujha *et al.*, 1973; Saxena *et al.*, 1987). This formation is characterized by the predominance of *Magnastriatites mirabilis, Polypodiisporites speciosus, Striatriletes susannae* and *Triporopollenites triquetrus* and presence of *Lygodiumsporites lakiensis, Polypodiaceaesporites tertiarus, Simozonotriletes amplus,*

Foveosporites laetus, Abiespollenites surmaensis, Piceaepollenites sp., *Schizosporis amabilis, Assamiapollenites* sp., *Neocouperipollis* sp., *Stephanoporopollenites gratus, Triporopollenites commendabilis* and *Malvacearumpollis* sp. The Bokabil palynoflora is marked by the absence of phytoplanktons, presence of fresh water elements, pteridophytic spores and gymnospermous pollen suggesting regression of the sea and high land adjacent to the site of deposition supporting coniferous vegetation.

Salujha *et al.* (1973) attempted palynological demarcation of the Bhuban and Bokabil formations exposed along eleven traverses in the South Shillong Plateau. According to them, the Bhuban Formation is distinguished by the occurrence of *Eximispora tuberculata, Dicolpopllis eminens, Tricolpites ovatus, T. idoneus, Marginipollis grandis, Favitricolporites usitatus, Oudhkusumites immodicus, Couperipollis duraus, Hexapollenites artificiosus, Fusiformisporites adrogans* and *Stephanoporopollenites nitidus* whereas the Bokabil Formation can be distinguished by the occurrence of *Simozonotriletes amplus, Schizosporis amabilis, Stephanoporopollenites gratus, Fovesporites laetus, Triporopollis commendabilis* and a few reworked Permian palynotaxa.

Palynological information from the post-Bokabil sediments is not known.

GAPS IN OUR KNOWLEDGE

A perusal of the foregoing account shows that a large amount of palynodata has so far been generated from the Tertiary sediments of Meghalaya. However, there are considerable gaps in our knowledge which require urgent attention of palynologists. It is suggested that the objectives of the future studies need be directed towards bridging these gaps. Some of the gaps have been identified and are being mentioned below.

1. Although a detailed palynostratigraphic investigation of the Palaeocene-Early Eocene sediments of shelf facies of Meghalaya has been carried out, the same on their geosynclinal equivalents (Disang Group) still awaits attention of palynologists.
2. Palynological information from the Siju/Sylhet Limestone Formation is meagre and a detailed palynological study of these formations (particularly the limestone members) is yet to be carried out. These sediments contain a good assemblage of dinoflagellate cysts along with spores-pollen, which may be extremely useful in biostratigraphic zonation and dating of these sediments and in deducing environment of deposition.
3. The Kopili Formation in Jaintia Hills has been worked out in detail. The zones established there need be traced westwards to recognize potential of palynofossils in basinal and interbasinal correlations.
4. The Barail Group exposed along Jowai-Badarpur Section in Jaintia Hills has been divided into three palynozones. It is yet to be established whether or not these zones extend into the Kherapara Formation of Garo Hills.
5. The Bhuban Formation in Jaintia Hills and its equivalent Boldamgiri Formation in West Garo Hills have been worked out in detail. Efforts should be made to study its equivalent in South Garo Hills (Baghmara Formation) and in Khasi Hills.
6. The Bokabil/Angartoli palynoflora is poorly known. These sediments yield rich palynoassemblages and have good prospects for future studies.
7. The palynological information from the post-Bokabil/ Angartoli/Chengapara sediments, viz., Tipam Sandstone, Girujan Clay, Dupitila/Bilkona and Dihing/Rangapani and Dalu, of Meghalaya is not yet available. Systematic efforts are needed to generate palynodata from these sediments. Such studies will be helpful in establishing palynozonation and correlation of these sediments and also in recognizing Neogene/Quaternary Boundary in Meghalaya.

CONCLUDING REMARKS

Palynological studies carried out on the Tertiary sediments of Meghalaya resulted into records of rich palynofloras and their application in biostratigraphic zonation, correlation and dating of the sediments and in inferring palaeoclimate and depositional environment. Various palynozones established in these sediments can be recognized by their peculiar palynofossil assemblages which are useful in the correlation of homotaxial stratigraphic units in Garo, Khasi and Jaintia Hills and also in the interbasinal correlation. A synthesis of the palynodata from these sediments presents state-of-the-art of the Tertiary palynostratigraphy of Meghalaya and identifies gaps therein to be filled in future studies. It has been noticed that better palynological information is available from the Palaeogene sediments than the same from the Neogene.

It is strongly felt that the palynodata gathered so far require more precision. To achieve this, a synergistic approach should be adopted. Palynodata need be tagged, as far as possible, with data obtained from other disciplines in order to get better and more dependable results and conclusions. It has been observed that in a number of cases palynofloras have been recorded from the grab samples. This makes them of limited value in biostratigraphic studies. It is therefore necessary that palynological samples should be collected on measured stratigraphic sections with the precise location of their positions in the stratigraphic column. Use of obsolete and invalid names of palynotaxa create problems and should be avoided. It is advised that only those palynotaxa, that are prevalent, should be used. Character evaluation of palynotaxa

and standardisation of morphotaxonomy are therefore very important in palynostratigraphic studies. It has been observed that in some cases palynological assemblage zones (cenozones) are loosely proposed. These are formal biostratigraphic units and therefore their proposal need be in accordance with the requirements laid down in the International Stratigraphic Guide (Hedberg, 1976). Lastly, it is recommended to study subsurface sections, in addition to outcrop sections, as they provide uninterrupted stratigraphic sequences and fresh samples almost completely unaffected by weathering agencies.

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