Late Cretaceous and Tertiary palynological succession in India

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The Late Cretaceous and Tertiary palynological assemblages of India are divided into several phytogeoprovinces and cenozones. The Senonian palynoflora of India is clubbed with Brazil and West African palynoflora as *Constantinisporis* phytogeoprovince characterized by the presence of *Constantinisporis, Victorisporis* and *Andreisporis*. The Danian to Middle Eocene palynoflora of India are placed under pantropical *Proxapertites operculatus* zone and this is further subdivided into *Acrostichumsporites meghalayensis* subzone, *Dandotiaspora dilata* subzone, *Kielmeyerapollenites syncolporatus* subzone, *Lakiapollis ovatus* subzone, *Tricolporopilites robustus* subzone and *Pellicieroipollis langenheimii* subzone. The Oligocene and Miocene palynofossils are placed under *Trisyncolpites ramanujamii* subzone and *Hibisceaepollenites robustispinosus* subzone respectively and come under *Striatriletes susannae* pantropical zone. A comparison of the Indian palynological succession with Borneo, Caribbean and Atlantic Tertiary palynological assemblages reveals that the trans-Atlantic palynological assemblages have closer similarity than others.

Key-words—Palynology, Late Cretaceous, Tertiary palynozones (India).

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सारांश

भारत में अनंतिम क्रीटेशी एवं तृतीयक परागाणविक अनुक्रम

रंजीत कुमार कर

भारत में अनंतिम क्रीटेशी एवं तृतीयक परागाणविक अनुक्रम कई पादपभूप्रदेशों एवं नवमंडलों में विभक्त किये गये हैं। भारत के सीनोनियन परागाणुवनस्पतिजात की ब्राजील एवं पश्चिम अफ्रीकी परागाणुवनस्पतिजात से तुलना की गई है क्योंकि *कोन्सटेन्टीनिस्पोरिस* पादपभूप्रदेश क *ोन्सटेन्टीनिस्पोरिस, विक्टोरिस्पोरिस* एवं *एँड्रेस्पोरिस* की उपस्थिति से अभिलक्षणित है। भारत का डेनियन से मध्य आदिनूतन परागाणुवनस्पतिजात उष्णकटिबन्धीय *प्रोक्सापर्टाइटिस ओपर्कुलेटस* मंडल में रखा गया है तथा इसे पुनः *ऍक्रोस्टिकमस्पोराइटिस मेघालयेन्सिस, डेन्डोटियास्पोरा डाइलेटा, कीयॅलमेरापोलिनाइटिस सिन्कॉल्पोरेटस, लकियापॉलिस ओवेटस, ट्राइकोल्पोरोपाइलाइटिस रोबस्टस* एवं *पेल्लिसियॅरोइपॉलिस लैंगनहीमाई* नामक उपमंडलों में विभक्त किया गया है। ओलिगोसीन और मायोसीन (मध्यनूतन) परागाणुवनस्पतिजात क्रमशः *ट्राइसिन्कॉल्पाइटिस रामानुजमाई* उपमंडल एवं *हिबिस्सीपोलिनाइटिस रोबस्टीस्पाइनोसस* उपमंडल में रखे गये हैं तथा ये स्टूआर्ट्राईलिटीस सुसान्न उष्णकटिबन्धीय मंडल के अन्तर्गत आते हैं। भारतीय परागाणविक अनुक्रम की बोर्नियो, कैरिबियन एवं अटलाँटिक तृतीयक परागाणविक समुच्चयों से तुलना करने पर व्यक्त होता है कि ट्रांस–अटलांटिक परागाणविक समुच्चय अन्यों की अपेक्षाकृत अधिक घनिष्ठता प्रदर्शित करती है।

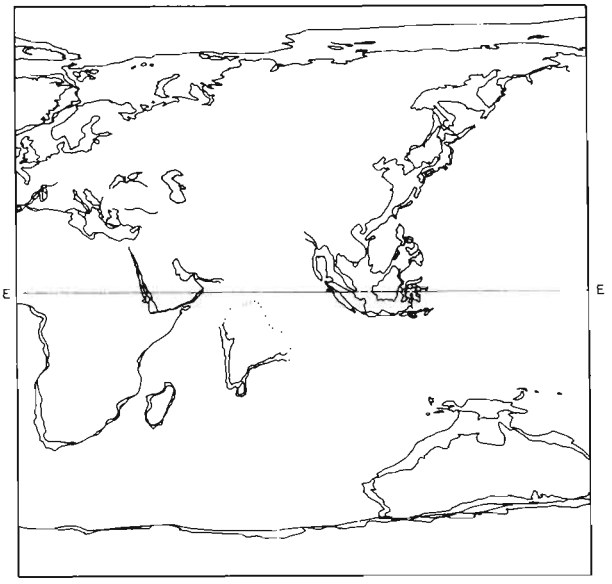
INDIA indeed is a land of floral diversity. With its 8°-36°N latitudinal spread sporting a varied temperature condition ranging from desert to ice cold region, receiving hardly to highest rainfall of the world, flat, monotonous plain to mightiest mountains, India harbours a rich and varied flora which differs according to its habitat.

The moist tropical forests of India nurse different species of *Dipterocarpus, Hopea, Artocarpus* and *Mangifera*. The Western Ghat flora exhibits the as-

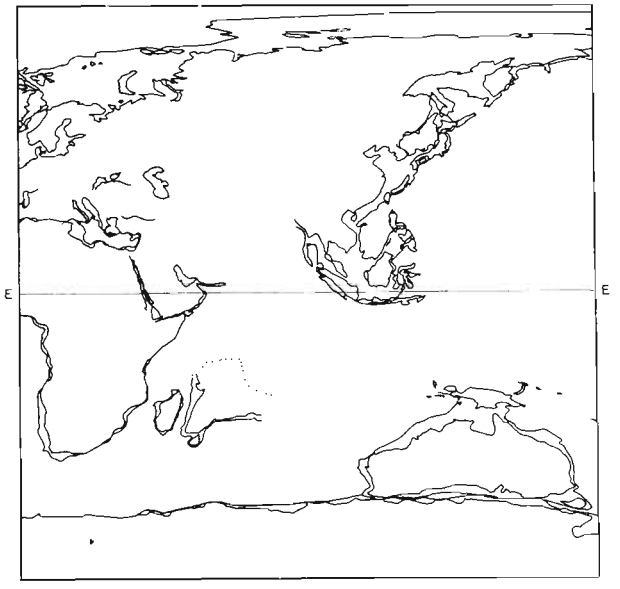
sociations of *Cullenia-Palaquium, Palaquium-Mesua, Mesua-Calophyllum* and *Vateria-Cullenia*. In Cachar tropical evergreen forest, *Dipterocarpus turbinatus, Artocarpus chaplasha* and *Michelia montana* offer a majestic view. *Pterocarpus dalbergioides, Terminalia bilata, Canarium euphyllum, Sterculia campanulata* rise from the sea level to lofty height in the Andaman Islands.

In contrast to this luxuriant vegetation, Rajasthan desert thorn forest adorns *Prosopis spicigera*. In Himalayan wet temperate forest, *Machilus edulis, Michelia cathcartii, Beilshmiedia* spp. etc. are found. *Quercus* and different species of *Rhododendron* thrive amongst *Abies, Cedrus, Picea, Tsuga* and *Pinus* in the moist temperate forest of Himalaya. Lastly, in the Alpine forest of the same region *Abies, Juniperus, Pinus, Betula utilis* and *Rhododendron* sp. flourish (Champion, 1936). The angiosperms outnumber the gymnosperms and pteridophytes and show maximum diversity. In the northeast India alone there are presumably more than 4,000 species of flowering plants.

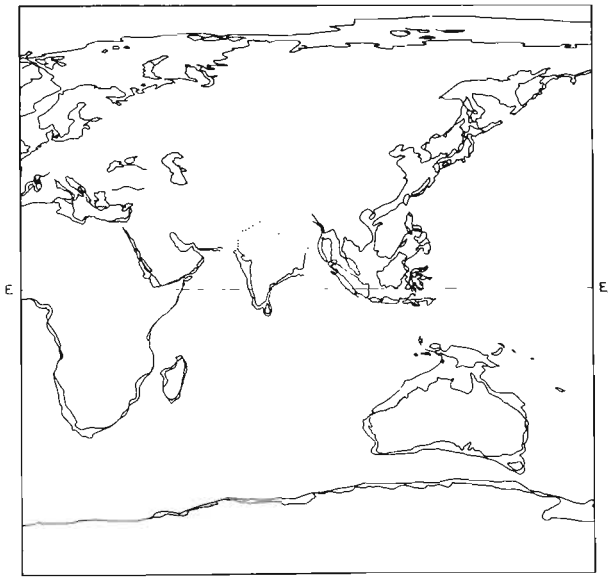
The plethora of the angiospermic flora in India commands respect and rapt attention. How and when this diversified flora reached India is an enigma to the palaeobotanists, plant geographers and systematic botanists. Was India only at the receiving end or also cradled and nursed some groups of plants to contribute to the world is a question to ponder. The paucity of palaeobotanical fossils hinders enormously to solve this quest. However, from the present state of knowledge, an attempt has been made to trace the evolution and development of Indian Late Cretaceous and Tertiary flora on the basis of palynology.



Text-figure 2—Showing the position of India during Palaeocene in the cylindrical equidistant map (after Smith, Hurley & Briden, 1981).



Text-figure 1—Showing the position of India during Santonian (Late Cretaceous) in the cylindrical equidistant map (after Smith, Hurley & Briden, 1981).



Text-figure 3—Showing the position of India during Late Eocene in the cylindrical equidistant map (after Smith, Hurley & Briden, 1981).

POSITION OF INDIA DURING LATE CRETACEOUS-MIOCENE

Palaeogeographic maps showing the position of wandering India were depicted by Smith and Briden (1977), Smith, Harley and Briden (1981), Owen (1983), etc. Smith, Hurley and Briden (1981) placed India around 15° S during Santonian in the cylindrical equidistant map. During Palaeocene, India was in between equator and 15° S. In Late Eocene, according to them major part of India crossed the equator and was below 15° N. In Early Miocene, even the southern tip of India was at the verge of crossing the line of equator and India was stationed in between the equator and 15° N (Text-figures 1-3).

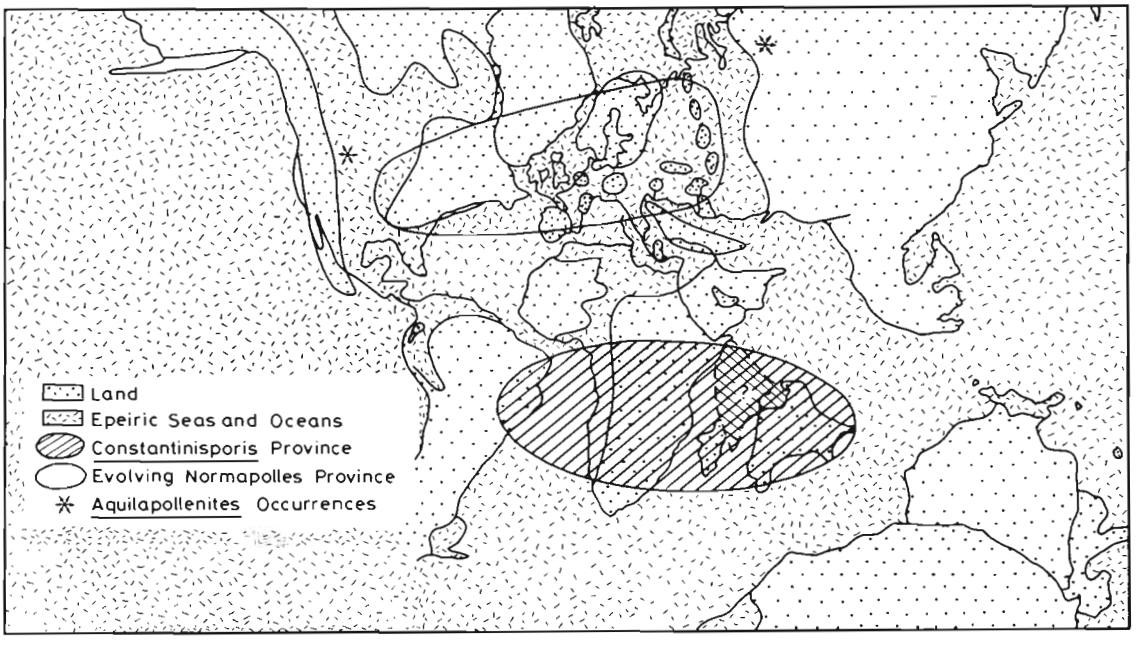
Constantinisporis Phytogeoprovince

According to Srivastava (1981) this is characterized by the presence of porotrichotomosulcate, small pollen with 3 pores placed at the apical ends on one surface. *Constantinisporis, Victorisporis* and *Andreisporis* are the typical examples of this group of pollen. This phytogeoprovince is found during the Senonian in Brazil, West Africa and India and is distinguished from the *Nothofagidites* phytogeoprovince comprising southern tip of South America, southern part of South Africa, Australia, New Zealand and Antarctica. During this time the Normapolles phytogeoprovince includes 'North America, Central Europe and China and the *Aquilapollenites* phytogeoprovince consisting of northern and western part of North America and Russia.

Zaklinskaya (1977), on the other hand, divided the Late Cretaceous-Early Palaeogene Central Atlantic palynoflora into *Proxapertites*-Proteaceae province and the Australian-Antarctic palynoflora into *Nothofagidites*-Proteaceae province. Her Normapolles province includes California-Kazakhastan. The *Aquilapollenites* province has Khatanga-Lena, Yenisey-Amur and Primorsky-Sakhalin basins (Text-figure 4).

Smith and Briden (1977) depicted land and sea distribution during the Senonian placing Brazil, Central Africa and India in the same latitudinal belt. This perhaps gave rise to common Constantinisporis flora in this region. Belsky *et al.* (1965), and Jardinè and Magloire (1965) recorded this flora from West Africa, Regali *et al.* (1974a, 1974b) and Herngreen (1975) from Brazil and Venkatachala and Sharma (1974) from India.

Venkatachala and Sharma (1974) worked on the palynology of a number of wells from the subsurface



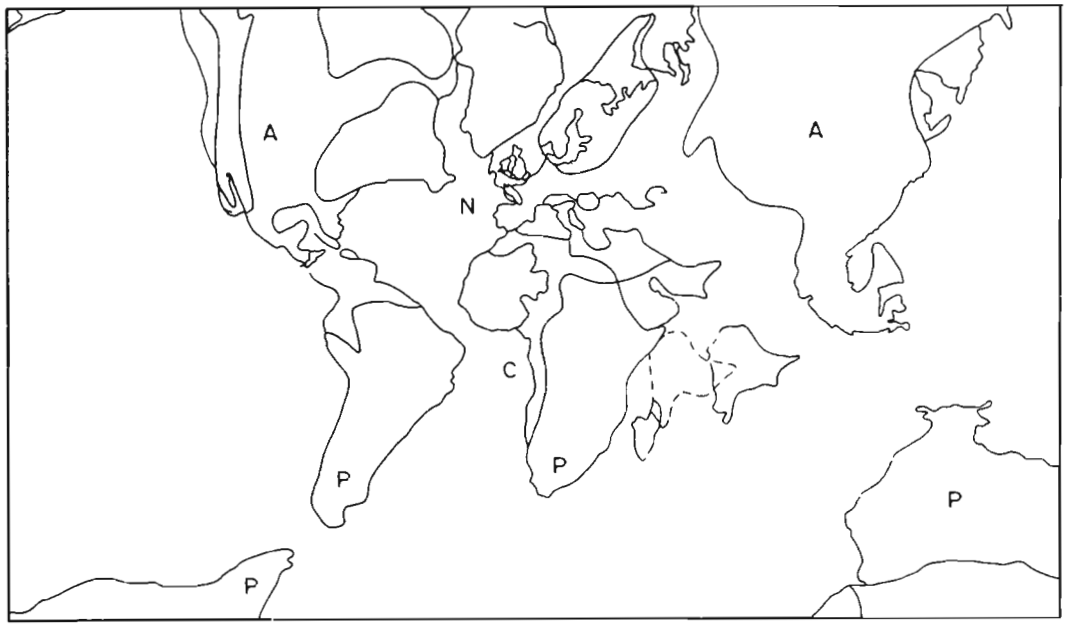
Text-figure 4—Land and sea distribution during the Senonian and the different phytogeoprovinces (after Smith & Briden, 1977).

of Vridhachalam area, Cauvery Basin. They found Early Senonian palynological assemblage in the Puvanur well and designated the assemblage into *Constantinisporis jacquei* Cenozone. This zone is characterized by the presence of *Constantinisporis, Andreisporis, Victorisporis* in association with *Tricolpites, Cupanieidites, Turonipollis, Liliacidites, Tricolpopollenites, Intratricolpopollenites, Proteacidites, Vacuopollis* and *Ulmoidipites.*

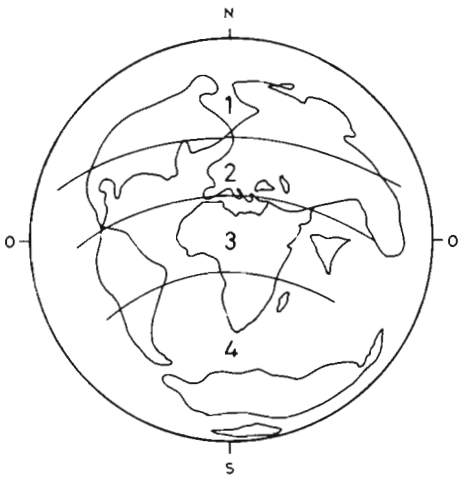
Mixing of Constantinisporis and Aquilapollenites flora— During the Cenomanian-Maastrichtian, the identity of *Constantinisporis* phytogeoprovince is blurred as many species of hitherto known Normapolles and *Aquilapollenites* phytogeoprovince enter into its realm as the dominant elements. Nandi (1983, 1990) recorded predominance of Normapolles pollen in some of these cenozones which are dated as Cenomanian from the Gumaghat Formation of Meghalaya. She noted *Plicapollis serta* Pflug 1953, *Pseudoplicapollis* spp., *Nudopollis endangulatus* Pflug 1953, *Minorpollis minimus* Krutzsch 1959, *Basopollis orthobasalis* Pflug 1953, *Extratriporopollenites spumoides* Pflug 1953, *Vacuopollis pyramis* Pflug 1953, *Vacuopollis semiconcavus* Pflug 1953, *Pseudotrudopollis pseudoalnoides* Krutzsch 1967, *Pecakipollis sernoensis* Krutzsch 1959, *Oculopollis lapillus* Pflug 1953, etc.

Banerjee and Misra (1968) first reported *Aquilapollenites* from the subsurface of Cauvery Basin. Venkatachala and Sharma (1981) also recorded 2 species of this genus from the subsurface in the Palk Bay, Cauvery Basin. The assemblage is dated as Senonian and besides *Aquilapollenites* has *Myrtacidites* sp., *Turonipollis* sp., *Sapotaceoidaepollenites* sp., *Polyvestibulopollenites* sp., *Triporoletes reticulatus* and *Dinogymnium* sp. Maheshwari and Jain (1982) also recorded *Aquilapollenites* from the Dalmiapuram Formation (Late Cretaceous), Tamil Nadu. Baksi and Deb (1976) recognised *Aquilapollenites bengalensis* Cenozone in the Late Cretaceous subsurface sediments of Bengal Basin. Nandi (1979) observed that Normapolles and *Aquilapollenites* occur together with *Dinogymnium* in the Gumaghat Formation of Meghalaya. Prakash, Singh and Sahni (1990) and Mathur and Sharma (1990) recorded *Aquilapollenites bengalensis* in the Deccan Intertrappeans (Maastrichtian) of Madhya Pradesh.

Occurrence of Normapolles and *Aquilapollenites* is not restricted to India in the Late Cretaceous. Regali *et al.* (1974a, 1974b) observed its presence in Brazil and Jardine and Magloire (1965) in West Africa. Ked-



Text-figure 5—Late Cretaceous land and sea distribution and the different phytogeoprovinces. **A** = *Aquilapollenites* Province, **N**=*Normapolles* Province, **C**=*Constantinisporis* Province, **P**=*Nothofagidites* Province (after Smith & Briden, 1977).



Text-figure 6—Senonian phytogeoprovinces shown on equal area projection and the different phytogeoprovinces: **1** = *Aquilapollenites* Province, **2** = Normapolles Province, **3** = *Constantinisporis* Province, **4** = *Nothofagidites* Province (after Srivastava, 1981).

ves (1971) and Ela (1978) recorded Senonian Normapolles from Egypt.

Srivastava (1981) opines that a severe marine regression during the Late Maastrichtian opened several land routes between the different phytogeoprovinces obliterating the characteristic of the said provinces.

The Late Cretaceous epeiric sea situated in North America was withdrawn in the Late Maastrichtian opening new land areas in the western interior. This enabled land connection between the Normapolles and *Aquilapollenites* provinces providing mixing of floras (Text-figure 5). *Nothofagidites* phytogeoprovince, however, could maintain its identity throughout the Tertiary as Australia, New Zealand and Antarctica remained separated from other continents due to the deep sea (Text-figure 6).

Batten (1981), however, opined that the occurrence of Normapolles outside its normal province is mostly found in the Tertiary and need not be thought bewildering. He thinks that it is possible that the morphophytes were produced by more than one plant genus and eventually might have found ecological niches in the *Aquilapollenites/Triprojectacites* province. Kar (1993) recorded Normapolles type of pollen from the Miocene sediments of India.

Tertiary rocks—The Tertiary sediments are well exposed in north-eastern, northern and western parts of India. In north-east, the Tertiary succession is almost complete from Palaeocene to Pliocene except the post Barail (Oligocene) unconformity. In Kutch, western India, Early-Middle Palaeocene and Late Eocene rocks are missing whereas the Siwaliks in north India mostly represent the Mio-Pliocene sediments. In south India, the Tertiary exposures are generally found along the west and east coasts. Palynological investigations have been carried out from all the major formations by different workers in last four decades (Kar, 1992). A wealth of information has been thus accumulated which enabled us to evaluate the floristic trends, the appearance and disappearance of some species and their subsequent spread in other regions.

Pantropical palynological zones—Germeraad, Hopping and Muller (1968) proposed few pantropical palynozones for the Tertiary rocks of the tropical areas covering South America, West Africa and Borneo after working roughly for twenty years. The zones in the ascending order are *Proxapertites operculatus* zone, *Monoporites annulatus* zone, *Verrucatosporites usmensis* zone, *Magnastriatites howardi* zone, *Crassoretitriletes vanraadshooveni* zone and *Echitricolporites spinosus* zone.

The Proxapertites operculatus zone—It ranges from Senonian to Early Eocene and is characterized by the presence of *Proxapertites operculatus, Proxapertites cursus, Spinizonocolpites echinatus* and *Echitriporites trianguliformis*. The *Monoporites annulatus* zone is identified by the first apearance of *Monoporites annulatus* and is confined to Middle Eocene. The *Verrucatosporites usmensis* zone is restricted to Late Eocene and is marked by the regular appearance of *Cicatricosisporites dorogensis* and *Verrucatosporites usmensis*. The *Magnastriatites howardi* zone covers entire Oligocene and Early Miocene and is indicated by the first appearance of *Magnastriatites howardi*. The *Echitricolporites spinosus* zone is found in the Middle and Late Miocene as well as Pliocene. The regular occurrence of *Echitricolporites spinosus* is the indication of this zone. These pantropical zones are again subdivided by Germeraad, Hopping and Muller (1968) into several Atlantic, Caribbean and Borneo zones.

Comparison between pantropical and Indian palynological zones—In India, only two pantropical

zones are recognizable, i.e., *Proxapertites operculatus* and *Striatriletes susannae* (= *Magnastriatites howardi*) zones. The genus *Magnastriatites* Germeraad, Hopping and Muller 1968 is regarded as a synonym of *Striatriletes* van der Hammen 1956 emend. Kar 1979. The *Proxapertites operculatus* zone ranges from Langpar Formation (Danian) of north east to Harudi Formation (Early-Middle Eocene) of Kutch. The *Proxapertites operculatus* zone is subdivided into *Acrostichumsporites meghalayensis* subzone, *Dandotiaspora dilata* subzone, *Kielmeyerapollenites syncolporatus* subzone, *Lakiapollis ovatus* subzone, *Tricolporopilites robustus* subzone and *Pellicieroipollis langenheimii* subzone. *Striatriletes susannae* zone has only two subzones—the lower *Trisyncolpites ramanujamii* subzone stands for the Oligocene and the upper *Hibisceaepollenites robustispinosus* subzone generally represents the Miocene.

Acrostichumsporites meghalayensis subzone—*Acrostichumsporites meghalayensis* subzone is confined to the Langpar Formation (Danian) exposed at Therriaghat on the Umshoryngkew River, Meghalaya. The assemblage is characterized by the presence of *Proxapertites operculatus, Proxapertites cursus, Matanomadhiasulcites maximus, Spinizonocolpites echinatus, Saturna enigmaticus* and *Terscissus grandis*.

The unique feature of this subzone is that all the important species are pantropical in distribution. *Acrostichumsporites* sp. is reported by Caratini *et al.* (1991) from Walalane bore-hole, Senegal. *Matanomadhiasulcites maximus* is recorded from Senegal (Caratini *et al.*, (1991), Niger (Boudouresque, 1980), Nigeria (Sonuga, 1987), Cameroun (Salard-Cheboldaeff, 1977), Colombia (Guzmàn,1967). *Matanomadhiasulcites* evolves in Maastrichtian, occurs commonly in Palaeocene and continues up to Early Eocene.

Saturna enigmaticus is recovered from Cameroun (Salard- Cheboldaeff, 1977) and Senegal (Caratini *et al.*, 1991). *Tercissus grandis* is observed in Late Cretaceous-Palaeocene of U.S.A. (Kieiser & Jan du Chène, 1979; Caratini *et al.*, 1991) and Niger (Boudouresque, 1980). *Matanomadhiasulcites maximus* according to Caratini *et al.* (1991) is comparable to the pollen of *Annona* though Muller (1981) rejected its affinity with this genus. Others contemplate it to be a monocot (see Caratini *et al.*, 1991). The pantropical distribution of *Proxapertites* and *Spinizonocolpites* is well known.

Dandotiaspora dilata subzone—*Dandotiaspora dilata* subzone starts from the Therria Formation (Late Palaeocene) of Meghalaya and ends in Matanomadh Formation (Late Palaeocene) of Kutch. *Dandotiaspora, Lycopodiumsporites, Palmaepollenites, Neocouperipollis, Diporoconia, Tripilaorites, Triangulorites* and some other genera appear for the first time in this subzone.

In north east India, different species of *Lycopodiumsporites* are found in abundance. This genus is, however, rather rare in west and so the subzone is named after *Dandotiaspora dilata*. Kar and Mandal (1984) studied the spore morphology of 23 species of *Lycopodium* growing in India. They noted that the spores of extant *Lycopodium* growing in India are mostly foveolate-fossulate whereas the Palaeocene species generally have reticulate type of ornamentation. They also observed that *Lycopodiumsporites assamicus* Mehrotra & Sah 1980 described from the Palaeocene of Mikir Hills closely resembles the spores of *Lycopodium veitchii*.

Dandotiaspora dilata subzone is recognized by the presence of *Dandotiaspora dilata, Dandotiaspora densicorpa, Dandotiaspora auriculata, Dandotiaspora telonata, Lycopodiumsporites speciosus* and *Lycopodiumsporites parvireticulatus*. These species do not range beyond Palaeocene. The other species which are also commonly found are *Neocouperipollis kutchensis, Neocouperipollis wodehousei, Palmaepollenites ovatus, Proxapertites cursus* and *Retitribrevicolporites matanomadhensis*.

Dandotiaspora dilata is found in Dandot, Pakistan (Vimal, 1952) and Colombia (Guzmàn, 1967). The author could also recover a few specimens from the Palaeocene of Senegal. Regarding its affinity, Kar (1985) remarked that the spores of *Gymnosphaera glabra* illustrated by Kremp and Kawasaki (1972, p. 66, fig. 129) comes close to *Dandotiaspora dilata* in general appearance but has smaller size.

Kielmeyerapollenites syncolporatus subzone—It has the association of *Kielmeyerapollenites eocenicus, Psilastephanocolporites psilatus, Psilastephanocolporites subcircularis, Retis-*

tephanocolporites multirimatus, Polycolporites indicus, Polycolpites flavatus and *Lakiapollis ovatus*. Besides, various species of *Dandotiaspora, Palmaepollenites, Neocouperipollis* and *Lycopodiumsporites* are also present in the assemblage.

The presence of tetrad pollen genus *Kielmeyerapollenites* and polycolpate-polycolporate pollen in good numbers distinguish this subzone from others. The genus *Kielmeyera* grows in the tropical forest of Brazil today. The pollen of this genus is found only up to Early Eocene (Sah & Kar, 1974) in India and afterwards it became extinct. Polycolpate and polycolporate pollen are produced by number of families like Acanthaceae, Euphorbiaceae, Lamiaceae and Scrophulariaceae; so it is difficult to tag the fossil species with the living ones. Kar (Ms.), however recovered fossil pollen very close to extant *Ocimum* pollen from the Early Eocene of Rajasthan polycolpate and polycolporate pollen are also occasionally found in Early Eocene and gradually they become rare. So at the end of Palaeocene, most of the species of *Dandotiaspora, Lycopodiumsporites, Polycolporites, Psilastephanocolporites* and *Retistephanocolporites* become extinct or only rarely met with. *Matanomadhiasulcites, Triangulorites, Tripilaorites, Lakiapollis, Retitribrevicolporites, Palmaepollenites* and *Neocouperipollis* continue in the Early Eocene.

Lakiapollis ovatus subzone—This subzone has *Retitribrevicolporites matanomadhensis, Meliapollis ramanujamii, Umbelliferoipollenites ovatus, Pellicieroipollis langenheimii* and *Lygodiumsporites lakiensis* as the distinguishing elements. This zone is confined to the Early Eocene.

Tricolporopilites robustus subzone—The Middle Eocene is characterized by the development of brevitricolporate type of pollen already ushered by *Lakiapollis ovatus* and *Retitribrevicolporites matanomadhensis*. *Tricolporopilites robustus* and *Tricolporocolumellites pilatus* are the marker species for the Middle Eocene. *Retipollenites confusus* also generally found in association with these species.

Amongst the pteridophytes, *Striatriletes* starts coming in good numbers. Kar (1984) advocated its origin in India during the Middle Eocene, but recently he could recover a few specimens of *Striatriletes* in the Early Eocene assemblage of Palana, Rajasthan, described by Sah and Kar (1974). *Osmundacidites wellmanii* and *Osmundacidites kutchensis* are at their zenith during this time. Polypodiaceous spores represented by *Polypodiaceaesporites, Seniasporites* and *Polypodiisporites* are also common.

Pellicieroipollis langenheimii subzone—The Late Eocene palynology has not been extensively worked out except Trivedi (1985) and Tripathi (1988), on Jowai-Badarpur road, Meghalaya. *Striatriletes* establishes itself firmly in Kopili Formation, but the general depletion of the angiospermic pollen is noticed. *Lakiapollis ovatus, Retitribrevicolporites matanomadhensis, Dermatobrevicolporites dermatus, Triangulorites bellus, Spinizonocolpites echinatus, Acanthotricolpites bulbospinosus* and *Pellicieroipollis langenheimii* are occasionally met with. *Operculosculptites globatus, Operculosculptites rokhiaensis* and *Pilamonoletes excellensus* appear for the first time.

New Innovations in spore pollen morphology—In the Middle Eocene, some new innovations in spore-pollen morphology are observed. Amongst angiosperms, tribrevicolporate forms with subequatorially placed apertures are common. *Lakiapollis, Retitribrevicolporites, Tricolporopilites*, and *Tricolporocolumellites* are the examples of this trend. Besides, heavily ornamented forms become more prevalent. *Tricolporopilites robustus* and *Retipollenites confusus* may be cited as examples. Of the pteridophytes, *Osmundacidites wellmanii, Osmundacidites kutchensis, Seniasporites verrucosus, Polypodiisporites repandus, Operculosculptites globatus, Operculosculptites rokhiaensis* and *Pilamonoletes excellensus* are all heavily ornamented.

The testimony of this trend is perhaps best exemplified in *Verrudandotiaspora verrucata*. Like *Dantodiaspora dilata*, it has warts on the distal side at each ray end but unlike *Dandotiaspora*, it has verrucae all over the distal surface. Perhaps sensing the drastic consequences, the lineage of *Dandotiaspora* also developed verrucae in the Middle Eocene due to some environmental pressure. The strongly costate *Striatriletes* may be another type of expression in this direction. This kind of developmental tendency is in striking contrast with the

Palaeocene-Early Eocene forms which are broadly aperturate and less ornamented. The various species of *Dandotiaspora* are almost laevigate except the presence of wart at each ray end as in *Dandotiaspora dilata*. The species of *Lycopodiumsporites* are either mildly reticulate with thin muri or foveolate-fossulate. *Lygodiumsporites lakiensis*, another common form in the Early Eocene, is also laevigate.

Palaeocene and Early Eocene angiospermic genera are mostly longiaperturate in contrast to the breviaperturate Middle Eocene forms. *Proxapertites, Spinizonocolpites* and *Saturna* are zonisulcate, *Matanomadhiasulcites, Palmaepollenites* and *Neocouperipollis* are broadly monocolpate. Polycolpate and polycolporate forms, e.g., *Psilastephanocolporites, Retistephanocolporites, Meliapollis, Polycolpites* and *Polycolporites* also possess long apertures, laevigate or less ornamented exine.

Irrespective of other different modes of innovation most of the marker taxa of Eocene disappeared at the terminal Eocene including *Lakiapollis ovatus, Retitribrevicolporites matanomadhensis, Tricolporopilites robustus, Tricolporocolumellites pilatus* and *Verrudandotiaspora verrucata*. Only *Pellicieroipollis langenheimii, Marginipollis kutchensis* and *Acanthotricolpites bulbospinosus* survived the onslaught and occasionally found in the Oligocene.

However, in the pteridophytic front the story is not that dismal. *Striatriletes, Osmundacidites, Polypodiaceaesporites, Polypodiisporites, Pilamonoletes* and *Seniaspora* not only continue their existence but also turn to be the dominant elements. *Operculosculptites* is also common.

Striatriletes susannae zone—This pantropical zone is found above the *Cicatricosisporites dorogensis* zone. According to Germeraad *et al.*, (1968) an Oligocene age is assigned to this zone on the presence of smaller foraminifera, viz., *Globigerina ampliapertura, G. ciperoensis, Globorotalia opina opina* and *G. kugleri*. Trivedi *et al.*, (1981) pointed out that the specimen assigned to *Cicatricosisporites dorogensis* by Germeraad *et al.*, (1968, pl. 2, fig. 2) in all probability belong to *Malayaeaspora* Trivedi *et al.*, (1981).

The first appearance of *Striatriletes susannae* is the lower limit of this zone in Paz Del Rio section, Colombia and Benin West-1, Nigeria. Germeraad, Hopping and Muller (1968) opine that this zone starts from the Early Oligocene in Caribbean, Nigeria and Borneo and continues up to Pliocene. Kar (1984) pointed out that in India the occurrence of *Striatriletes* is noted from the Middle-Late Eocene of Kutch, Gujarat. Kar (1992) also recorded it from the Middle Eocene sediments of Meghalaya and Early Eocene of Rajasthan which led him to postulate that *Ceratopteris*—the fern producing *Striatriletes* spores was evolved in India. In the Indian sediments, *Striatriletes* appear as a common element in Middle Eocene, shows its maximum development in Oligocene and Miocene and dwindles down in Pliocene.

Trisyncolpites ramanujamii subzone—The extinction of hitherto prevalent Eocene genera gave rise to new forms in Oligocene. These are *Trisyncolpites ramanujamii, Crassoretitriletes vanraadshooveni, Bombacacidites triangulatus, Compositoipollenites tricolporatus, Meyeripollis naharkotensis, Graminidites granulatus, Verrupolyporites globosus, Polyporina multiporosa* and *Polyadopollenites* sp.

A perusal of these forms reveals that most of them are heavily sculptured and the same morphological expression is noted in pteridophytes as well as in angiosperms. *Trisyncolpites ramanujamii, Crassoretitriletes vanraadshoveni, Compositoipollenites tricolporatus, Meyeripollis naharkotensis* and *Verrupolyporites globosus* are examples. Another characteristic feature of the Oligocene assemblage is the occurrence of polyporate forms represented by *Verrupolyporites globosus* and *Polyporina multiporosa*.

It may, however, be cited here that *Cryptopolyporites cryptus*—another polyporate form, was recorded in the Early Eocene but it was never a common element and disappeared soon.

The introduction of trisyncolporate pollen in Oligocene in the form of *Trisyncolites ramanujamii* reminds long forgotten porotrichomosulcate pollen of the *Constantinisporis* phytogeoprovince. *Trisyncolpites* resembles *Constantinisporis, Victorisporis* and *Andreisporis* in trichotomosulcate condition and the position of the pores at the apices. *Trisyncolpites* is, however, much bigger in size and heavily ornamented with bacula and pila. The reappearance of this apertural form was restricted to this genus only and it did not extend beyond Oligocene.

The appearance of bisaccate pollen in Oligocene also ushered a new vista of the palynological assemblage. *Pinuspollenites crestus, Abiespollenites cognatus* and *Piceapollenites excellensus* are the species which are generally met with. The upliftment of the Himalayas introduced these plants in the northern highlands and the air borne pollen also put their signature at the depositional sites of the plain. The frequent presence of *Polyadopollenites* is also characteristic of Oligocene. After the tetrad genus *Kielmeyerapollenites* of Palaeocene-Early Eocene, the polyad pollen get into considerable prominence for the first time.

Hibisceaepollenites robustispinosus subzone—The Miocene palynoflora is not much different from that of Oligocene. The gymnospermous pollen generally represented by *Pinuspollenites crestus, Abiespollenites cognatus, Piceapollenites excellensus, Podocarpidites densicorpus* and *Tsugaepollenites velatus* are more frequent. Some new polyporate forms like *Hibisceaepollenites robustispinosus* and *Hibisceaepollenites splendus* are widely distributed. Monoporate forms are of common occurrence in the north (Siwaliks) and *Dipterocarpus* type of pollen in the south (Kar, 1992). Besides, some new monocolpate and tricolporate forms are also witnessed. Thus the Miocene sediments are recognized by the presence of *Hibisceaepollenites robustispinosus, Hibisceaepollenites splendus, Conitricolporites triangulus, Quilonipollenites sahnii* and *Dipterocarpuspollenites retipilatus*.

COMPARISON WITH OTHER TROPICAL ASSEMBLAGES

Borneo palynological zones—Except for broad similarities, Borneo palynoassemblages are quite distinct and exhibit the dominance of some local plants. Oligocene and Miocene epochs witness the emergence of *Florscheutzia* and subdivided by Germeraad *et al.* (1968) into *Florscheutzia trilobata, Florscheutzia semilobata, Florscheutzia levipoli* and *Florschuetzia meridionalis* zones. The pollen grains assignable to *Florscheutzia* are almost absent in the Tertiary sediments of India.

Caribbean palynological zones—The pantropical *Proxapertites operculatus* zone is subdivided in Caribbean region by Germeraad *et al.* (1968) into *Foveotriletes margaritae, Ctenolophonidites lismae* and *Foveotricolpites perforatus* subzones. All these zones are confined to Palaeocene. The Middle Eocene pantropical *Monoporites annulatus* zone is subdivided into *Psilatricolporites crassus, Psilatricolporites operculatus* and *Retitricolporites guianensis*. The transatlantic Early Miocene *Verrutricolporites rotundiporis* zone is further divided into *Jandufouria seamrogiformis* and *Psiladiporites minimus* subzones. Similarly, the *Crassoretitriletes vanraadshooveni* zone is subdivided in South America into *Multimarginites vanderhammeni* and *Grimsdalea margiclavata* subzones. Except rare occurrence of *Jandufouria*, most of the other genera are not found in the Tertiary rocks of India.

Atlantic palynological zones—The *Proxapertites operculatus* zone is subdivided in Nigeria and other places by Germeraad *et al.* (1968) into *Proteacidites dehaani, Retidiporites magdalensis*, and *Retibrevitricolpites triangulatus* subzones. The Oligocene *Striatriletes susannae* (=*Magnastriatites howardi*) zone is again divided into *Cicatricosisporites dorogensis* and *Verrutricolporites rotundiporis*-subzones. *Proteacidites, Retidiporites* and ?*Malayaeaspora* (=*Cicatricosisporites dorogensis*) are occasionally found in the Tertiaries of India in low percentage.

Thus in comparison to Borneo and Caribbean regions, the transatlantic palynological assemblage comes somewhat closer to the Indian Tertiary assemblage.

REFERENCES

Baksi SK & Deb U 1976. On new occurrence of *Aquilapollenites* from eastern India. *Pollen Spores* **18**(3): 399-406.

Banerjee D & Misra CM 1968. Cretaceous microflora from south India in Cretaceous-Tertiary formations of south India. *Mem. geol. Soc. India* **2**:

Batten DJ 1981. Stratigraphic, palaeogeographic and evolutionary significance of Late Cretaceous and Early Tertiary Normapolles pollen. *Rev. Palaeobot. Palynol.* **35**: 125-137.

Belsky CY, Boltenhagen E & Potonié R 1965. *Sporae dispersae* der Oberen Kreide von Gabun, Aquatoriales Afrika. *Paläontol. Z.* **39**(1-2): 72-83.

Boudouresque L 1980. Contribution de la palèo-palynologie a' la reconstitution floristique, stratigraphique et palèogèographique de la bordure occidentale du bassin des lulleemmeden au Crètacè supèrieur et au palèogène (Niger et Mali Afrique de l' Ouest) *Thèse* Univ. Niamey et d' Ortèans.

Caratini C, Kar RK, Sarr R, Tissot C & Venkatachala BS 1991. Palaeocene palynoflora from Walalane borehole, Senegal. *Palaeoecol. Africa* **22**: 123-133.

Champion HG 1936. A preliminary survey of the forest type of India and Burma. *Indian Forest Rec. Silviculture* **1**(1). Manager of Publications, Delhi.

Ela NMA 1978. The palynological characteristics of the Upper Cretaceous sediments in Abu Tartur Plateau, Kharga Oasis, Egypt. *Rev. Esp. Micropaleont.* **10**(3): 421-442.

Germeraad JH, Hopping CA & Muller J 1968. Palynology of Tertiary sediments from tropical areas. *Rev. Palaeobot. Palynol.* **6**: 189-348.

Guzmàn GAE 1967. A palynological study on the Upper Los Cuervos and Mirador formations (Lower and Middle Eocene; Tribu area, Colombia). *Thesis. E.J. Brill. Leiden*: 1-68.

Herngreen GFW 1975. Palynology of Middle and Upper Cretaceous strata in Brazil. *Meded. Rijks Geol. Dienst.* New Ser. **26**(3): 39-91.

Jardiné S & Magloire L 1965. Palynologie et stratigraphie du Crètacè des bassins du Sènègal et de Côte d' Ivoire. *Mem. B. R. G. M.* **32**: 187-245.

Kar RK 1979. Palynostratigraphy of the Naredi (Lower Eocene) and the Harudi (Middle Eocene) formations in the district of Kutch, India. *Palaeobotanist* **24**(1-3): 161-177.

Kar RK 1984. India the original homeland of *Ceratopteris* Brong. (Parkeriaceae). *Palaeobotanist* **31**(3): 255-262.

Kar RK 1985. The fossil floras of Kachchh-IV. Tertiary palynostratigraphy. *Palaeobotanist* **34**(1): 1-280.

Kar RK 1992. Stratigraphical implications of Tertiary palynological succession in north-eastern and western India. *In* Venkatachala BS & Singh HP (Editors)—*Four decades of Indian Palaeobotany* (A Birbal Sahni Birth Centenary Tribute). *Palaeobotanist* **40**: 336-344.

Kar RK 1993. Occurrence of *Dipterocarpus* type of pollen from the Miocene sediments of Kerala, India. *J. Palynol.* **29**: 29-39.

Kar RK 1995. Diporocolpis-introducing a new type of aperture from the Early Eocene sediments of Rajasthan, India. *Palaeobotanist* **43.**

Kar RK 1996. On the Indian origin of *Ocimum* (Lamiaceae) - a palynological approach. *Palaeobotanist* **43**(3).

Kar RK & Mandal J 1984. Studies on the spores of *Lycopodium* and their fossil history with special reference to India. *Geophytology* **14**(1): 4-19.

Kedves M 1771. Prèsence de types sporomorphes importants dans les sèdiments prèquater nairs Égypiens. *Acta Bot. Acad. Sci. Hung.* **17**(3-4): 371-378.

Kieser G & Jan du Chene RE 1979. *Periretisyncolpites* n. gen. and *Tercissus* Tschudy 1970. Grands pollen syncolpès du Maastrichtien du Sènègal et du Nigèria. *Rev. Esp. Micropaleont.* **11**: 321-334.

Kremp GOW & Kawasaki T 1972. *The spores of Pteridophytes*. Tokyo.

Krutzsch W 1959. Mikropaläontologische (spoenpaläontologische) Untersuchungen in der Braunkohle des Geiseltales. *Geologie* **21-22**: 1-425.

Krutzsch W 1967. Der Florenwechsel im Alttertiär Mitteleuropas auf Grund vonsporenpaläontologischen Untersuchungen. *Abh. Zentr. geol. Inst.* **10**: 17-37.

Maheshwari HK & Jain KP 1982. Occurrence of the genus *Aquilapollenites* in the Upper Cretaceous Kallamedu Formation of Vridhachalam area, Cauvery Basin, southern India. *Palaeobotanist* **30**: 297-302.

Mathur YK & Sharma KD 1990. Palynofossils and age of the Ranipur Intertrappean bed, Gaur River, Jabalpur, M.P. *In*: Sahni A & Jolly A (Editors)—*Cretaceous event stratigraphy and the correlation of the Indian nonmarine strata* : 58-59.

Muller J 1981. Fossil pollen records of extant angiosperms. *Bot. Rev.* **47**(1): 1-142.

Nandi B 1979. Palynostratigraphy of the Gumaghat Formation with special reference to the significance of the Normapolles group. *In* Sharma AK, Chanda S & Banerji M (Editors)—*Symposium on Evolutionary botany and biostratigraphy* : 18-19. Univ. Calcutta (Abst.).

Nandi B 1983. Occurrence of Normapolles pollen from the Upper Cretaceous of north eastern India and its significance to Cretaceous floral provinces. *Indian J. Earth Sci.* **10**(1): 11- 18.

Nandi B 1990. Palynostratigraphy of Upper Cretaceous sediments, Meghalaya, north eastern India. *Rev. Palaeobot. Palynol.* **65**: 119-129.

Owen HG 1983. *Atlas of continental displacement, 200 million years to the present*. Cambridge Earth Science Series, Cambridge.

Pflug H 1953. Zur Morphologie der Sporomorphae (in Pollen und Sporen des mitteleuroäischen Tertiärs by Thomson PW & Pflug H). *Palaeontographica* **94** B: 16-48.

Prakash T, Singh RY & Sahni A 1990. Palynofloral assemblage from the Padwar Deccan Intertrappeans (Jabalpur), M.P. *In*: Sahni A & Jolly A (Editors)—*Cretaceous event stratigraphy and the correlation of the Indian nonmarine strata* : 68-69.

Regali MSP, Uesugui N & Santos AS 1974a. Palinologia dos sedimentos Meso-Cenozoicos do Brasil (I). *Bol. Tèc. Petrobras* **17**(3): 177-191.

Regali MSP, Uesugui N & Santos AS 1974b. Palinologia dos sedimentos Meso-Cenozoicos do Brasil (II) *Bot. Tèc. Petrobras.* **17**(4): 263-301.

Sah SCD & Kar RK 1974. Palynology of the Tertiary sediments of Palana, Rajasthan. *Palaeobotanist* **21**(2): 163-188.

Salard-Cheboldaeff M 1977. Palèopalynologie du bassin sèdimentaire littoral du Cameroun dans ses rapports avec la stratigraphie et la palèocologie. *Thèse Univ. Pierre & Marie Curie, Paris.*

Smith AG & Briden JC 1977. *Mesozoic and Cenozoic palaeocontinental maps*. Cambridge Univ. Press, Cambridge.

Smith AG, Hurley AM & Briden JC 1981. *Phanerozoic palaeocontinental world maps*. Cambridge Earth Science Series, Cambridge.

Sonuga MS 1987. Etude sèdimentologique et palynologique de la formation de Mamu (Maestrichtian) dans la règion d' Enugu (Nigèria). Palce du charbon. *Thèse 3° Cycle Univ. de Bourgogne.*

Srivastava SK 1981. Evolution of Upper Cretaceous phytogeoprovinces and their pollen flora. *Rev. Palaeobot. Palynol.* **35**: 155-173.

Tripathi SKM 1988. Age of the Therria Formation, Meghalaya, India, a review. *Geophytology* **18**(1): 121-123.

Trivedi GK 1985. Palynology of the Kopili Formation (Upper Eocene) exposed along Jowai-Badarpur Road, Meghalaya. *J. Indian bot. Soc.* **64**: 66-72.

Trivedi BS, Ambwani K & Kar RK 1982. Palynological studies on the Tertiary coal from Malaya with comments on its age. *J. Indian bot. Soc.* **61**(4): 432-443.

Tschudy RH 1970. Two new pollen genera (Late Cretaceous and Paleocene) with possible affinity to the Illiciaceae. *Geol. Surv. Prof. Paper* **643**F: 1-13.

van der Hammen T 1956. A palynological systematic nomenclature. *Boln. Geol. Bogota* **4**(2-3): 63-101.

Venkatachala BS & Sharma KD 1974. Palynology of the Cretaceous sediments from the subsurface of Pondicherry area, Cauvery Basin. *New Bot.* **1**(3-4): 170-200.

Venkatachala BS & Sharma KD 1981. Palynological zonation in subsurface sediments in Narsapur well no. 1, Godavari - Krishna Basin, India. *Proc. X Indian Colloq. Micropalaeont. Stratigr.* : 445-446.

Vimal KP 1952. Spores and pollen from Tertiary lignites from Dandot, West Punjab (Pakistan). *Proc. Indian Acad. Sci.* **36**(4): 135-147.

Zaklinskaya ED 1977. Angiospermae on the basis of palynological data. *In*: Development of floras on the boundary of Mesozoic and Cenozoic. *Nauka Moscow* : 147-153 (in Russian).