

Impact of plant fossil research on Indian geology *

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INTRODUCTION

PALAEOBOTANY, the systematic study of past vegetation, is an interdisciplinary study and has application value in stratigraphy, palaeoenvironment, palaeoclimatology, plant geography and floristics. It helps in tracing evolutionary and phyletic lineages and in deciphering past biological and geological events. Its role in the search for fossil fuels and other economic minerals associated with sedimentary rocks is well known.

Accrued data on the floristics and morphology, has now largely been synthesized and interpreted for a meaningful appreciation of extinct floras. Impact of plant fossil researches on the biostratigraphic zonation of non-marine and marginal marine sediments is well known. In the marine realm too phytoplankton, like nannoplankton and dinocysts, are important stratigraphic markers.

The synergistic approach adopted at the Sahni Institute, the nodal centre for palaeobotanical researches in the country, has appreciably increased interinstitutional and multidisciplinary collaborations. Sharing of expertise and resources with other organizations, and emphasis on national programmes, e.g., those on palaeoclimate, and origin and early evolution of life, have contributed extensively to the understanding of major geological events. In this address I will discuss only few broad areas which, I feel, are important and represent emerging areas of research.

ARCHAEOAN AND PRECAMBRIAN PALAEOBIOLOGY

Structural evidences of Archaeoan biogenic processes which form the initial steps in the evolution of the living system are rarely found preserved in ancient cratonic segments. This paucity of records is largely due to their

obliteration by subsequent events. The early evolutionary processes are biochemical in nature and it is difficult to decipher the altered structural evidences without understanding biochemical and isotopic signatures, in terms of evolutionary steps. Therefore, to decipher the evolution of living system and ecosystem during Archaeoan, a multidisciplinary approach has been adopted.

Fossil bacteria have been recorded and studied under SEM from Dharwar Craton in the graphites of Nagavand area in the Shimoga Schist Belt and Ganacharpur area of Kolar Schist Belt. These graphites show high degree of fractionation of carbon and provide δC^{13} values of -23‰ and -35‰ vs PDB respectively. Such low values of isotopic ratios of carbon indicate possibility of the presence of Methanogens and Methanotrophs (Venkatachala *et al.*, 1989). Coccoid and rod-shaped bacteria morphologically comparable to members of Siderocapsaceae have been found from sediments of Kudremukh Iron Formation, dated as 2.6-3.2 Ga by Drury *et al.* (1983). They provide structural evidence for sulphate reducing bacteria (Venkatachala *et al.*, 1987). This record predates the earlier known evidence of sulphur bacteria from 2 Ga old Gunflint Cherts (Schopf *et al.*, 1965). The recent work of Hoering (1989) on sulphur isotopes of barites and co-existing pyrites lends further support to the existence of biologically mediated geochemical cycle of sulphur at the time of deposition of 2.6 Ga old Dharwar sediments.

Occurrence of both stratified and columnar stromatolites has been reported in the Dharwar Craton by Srinivasan *et al.* (1989) and Vasudev *et al.* (1989). The presence of columnar stromatolites is indicative of the possible existence of filamentous photoautotrophs. Structural evidences of probable filamentous aerobic photoautotrophs have also been found in the Donimalai Formation (Venkatachala *et al.*, 1990b; Naqvi *et al.*,

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1987; Raha, 1990). The fossiliferous black cherts are interbedded in the BIF having moderate negative Cerium and distinct positive Europium anomalies which indicate oxygenated sea water (Venkatachala *et al.*, 1990b). The presence of columnar stromatolites, structurally mineralised filaments and evidence of oxygenated sea water from Rare Earth elements patterns strongly support Schopf's contention that "there are presumptive evidences of cyanobacteria dominated biocenoses around 2.8 Ga". However, evidences of anaerobic photoautotrophs in 3.5 Ga old Warrawoona Group and aerobic photoautotrophs in 2.8 Ga old Fortesque Group are already known and therefore there is need to search for photoautotrophic biological and chemical signatures in even older sediments.

Recently, bowl-shaped stromatolites have been found in the Joldhal and Vanivilas formations of Chitradurga Group, which developed due to repeated sun cracking of algal mats in tidal ponds. This evidence can be profitably used to delineate the shore line—an important step in assessing the morphology of Dharwar Basin.

PROTEROZOIC

Proterozoic sequences of 1,500-570 Ma, extensively developed in the Indian subcontinent, contain a varied biota which include acritarchs, coccoid and filamentous algae, metaphytes and metazoans besides profuse development of stromatolites.

Stromatolites—Stromatolite morphology is a product of environmental and biotic factors and consequently the stromatolites have been used both to assess depositional environment and as biostratigraphic markers. Use of stromatolites as biostratigraphic markers has been attempted since long in India. But recent finds of columnar branching forms characteristic of Middle Riphean and Late Riphean from the Archaean sediments of Dharwar Supergroup have raised questions about the usefulness of stromatolites as biostratigraphic markers. Probably it indicates that the stromatolite morphology characteristic of Riphean had manifested as early as Archaean though it seems to have stabilized during Riphean. Therefore intercontinental correlations based solely on the basis of stromatolites can be misleading; however, these may be used in building up depositional history.

Attempts have been made for correlation and biozonation of different Proterozoic successions, viz., Jammu Limestone (Raha, 1980); the inner sedimentary belts of Himalaya (Tewari, 1984) and Bijawar Group (Gupta *et al.*, 1988). Raha and Das (1989) have proposed five, while Tewari (1989) has proposed seven, assemblage zones of Lesser Himalayan sequences and

correlated with biozones in different Precambrian sequences of Peninsular India.

Microfossils—Precambrian microfossils have been studied from the primary cherts and argillaceous sediments of India. The chert biota, characterised mostly by benthic blue-green algae, have considerable significance in understanding the depositional environment and are mostly responsible for the formation of stromatolites. A few planktonic forms, viz., Vase-Shaped-Microfossils (VSM) and Acritarchs that are also present, reflect on the age. Microfossils reported from the Vindhyan Supergroup, Deoban Formation and In-frakrol sediments of Nainital (McMenamin *et al.*, 1983; Shukla *et al.*, 1987; Acharyya *et al.*, 1989; Venkatachala *et al.*, 1990a) are important in understanding the distribution of biotic communities in shallow water environments. The VSMs in Infra-Krol and smooth-walled acritarchs with VSMs in the Deoban Formation have helped in assigning a younger than 800 Ma age to the beds.

Acid resistant microfossils from shales have also been recovered. Venkatachala and Rawat (1973b) and Viswanathiah *et al.* (1975) found acritarchs, leiosphaerids and algal filamentous remains from Kaladgi Basin, and assigned Precambrian-Cambrian age. Viswanathiah *et al.* (1976) described an assemblage of scolecodonts and acritarchs from Badami Group of rocks indicating two distinct bio-facies in Kaladgi and Badami sediments; possibly marked by a para-unconformity between the two, as the scolecodont support much younger age of Early Palaeozoic. Venkatachala and Rawat (1972) and Salujha *et al.* (1972) reported microfossils from Bhima sediments and considered them to be of early to Late Cambrian age. Sahni and Shrivastava (1962) while recording spores of lycopsids and sphenopsids from Cuddapah sediments, postulated origin of vascular plants in the Precambrian. Salujha *et al.* (1972a) described acritarchs and algal filaments from the same sediments and ascribed a Late Cambrian age. Similarly, Ghosh and Bose (1950) on the basis of biota recovered from the Salt Range inferred the antiquity of vascular plants also to Precambrian-Cambrian. The interpretation of extending antiquity of vascular plants to Precambrian, is not tenable as the morpho-forms reported are contaminations of extant biotas.

Misra and Dube (1952) and Sitholey *et al.* (1953) suggested an Early Palaeozoic (Cambrian) age on the basis of microfossils recovered from surface exposures of Suket and Sirbu Shales, Vindhyan Supergroup. Maithy (1968) also found acritarch and other algal remains in Suket Shales of Ramapura, Madhya Pradesh and assigned an Ordovician age. Maithy and Shukla (1977), however, reassigned the same to Late Precambrian.

Venkatachala and Rawat (1972) made an obser-

vation that the absence of spinose acritarchs and Chitinozoa in Vindhyan sediments does not fully support Cambrian affinity and may well be referred to Precambrian-Cambrian interval. Maithy *et al.* (1983) studied the microbiota from the preunconformity sequence in the subsurface of Ganga Basin (equivalent of Vindhyan) and assigned it a Late Precambrian age.

Most of the papers, so far published on the Precambrian microbiota, have highlighted only the biotic assemblages in particular horizons, leaving a big gap of sequential development of biotas for use in biostratigraphy — a basic requirement for understanding the biotic events in space and time. Validity of the Precambrian time standards being followed in the country requires to be tested with reference to the absolute ages, before adopting them as standard norms. This is suggested in view of a recent study where the biota encountered from the Suket Shale includes low diversity of smooth-walled acritarchs, jelly fish, small algae. *Tawuia*, *Chuarua* assemblage indicative of Upper Vendian age (590-666 Ma), while the absolute age based on radiometric study is 950 Ma (Shukla & Sharma, 1990).

Metaphytes, Metazoa and Problematic fossils—The attainment of multicellularity is an important step in evolution. Definite records of multicellular plants and animals are known around 600 Ma ago. Animal fossils show much diversity, and are too complex to be records of the initial step in attainment of multicellularity. Percentage differences of globins (oxygen bounding proteins) among several invertebrate and some vertebrate also indicate that initial radiation of animal phyla occurred much early around 900-1,000 Ma ago (Runnegar, 1982). To support this view, there is hypothetical evidence in decline of stromatolites after 1,000 Ma, which has been explained as a result of metazoan grazing (Walter & Hayes, 1985). Such a decline is also known in India (Tewari, 1988). Therefore, records of early metazoan in India require reassessment as they may be the first step or early experimentation in the evolution of metazoans. Shukla *et al.* (1989) who reported pelmatozoan hold fast, jelly fish-like remains and Vendotaenoid algae, conjectured that attainment of multicellularity may not be an isochronous event. The early experimentation could have occurred in areas where stabilization of crust and development of shallow platforms occurred earlier. Shukla *et al.* (1991) further added that the precursor may have had planuloid morphology and may have possibly looked similar to large acritarchs or some hollow tubular forms having single celled margin which they found in sediments of both outer and inner sedimentary belt of Himalaya in Nainital and Deoban area respectively ranging between 900-1,000 Ma.

The early metaphytic remains are known from sedi-

ments of around 600 Ma in age. They are mostly represented by carbonaceous films or ribbons. These films sometime bear annulation similar to those known in worms. Thus opinions have been expressed to consider an animal affinity. On the other hand views to consider the same as belonging to brown algae, or of prokaryotic origin, can not be ruled out (Conway Morris, 1989). Such type of carbonaceous remains are also known from the sediments older than 600 Ma, viz., from 850 Ma in China, 1,300 Ma in Canada and 1,000 Ma in Suket Shales, India (Shukla & Sharma, 1990). They are also known from Krol-Tal sequence (Vendian; Tewari, 1989) though their biogenecity needs to be established.

The enigmatic carbonaceous discs from the Suket Shales are now considered *Chuarua* Walcott, and they have also been found in Bhima sediments (Suresh & Raju, 1983). They are large free swimming cysts, possibly of eukaryotic origin and are recorded between 600 and 1,000 Ma. This period is referred to as Churian in age.

Uppermost Vendian calcareous algae, viz., *Sajania*, *Epiphyton* and *Renalcis* are recorded from the inner-sedimentary belt of Pithoragarh (Shukla, 1984) and in Krols B and E (Singh & Rai, 1983). Neo-Proterozoic in the history of the earth has been an active period showing synergistic effect of physical and chemical forces on the resident biota helping diversification and explosion. It has, therefore, become necessary to examine the sediments between 1,000-600 Ma to understand the ecological stresses which resulted in attainment of multicellularity both by plants and animals. New biotic types could normally emerge at few places as experimentations before being finally accepted by nature as viable alternative modes of living. Therefore, attainment of multicellularity also need not be an isochronous event.

PRE-GONDWANA

Pre-Gondwana flora is known only from two basins, namely, Kashmir and Spiti in the Perigondwana (Gothari & Sahni, 1931; Dhar *et al.*, 1980; Pal, 1978; Pal & Chaloner, 1979; Singh *et al.*, 1982). Very little is known about the Devonian flora except from the Aishmuqam Formation (Devonian) in Kashmir Basin. Fossils attributed to *?Taenocrada* and *?Protolepidodendron* are reported. The Lower Carboniferous flora is known from the intercalations between Syringothyris Limestone and Fenestella Shale in Kashmir and Po Formation in Spiti. It is a Rhacopteris flora comparable with the Lower Carboniferous flora of Peru, Africa, Australia, as well as that from China. The flora occurs in shallow deposits in Spiti and Kashmir adjoining Kumaon, where there is a major hiatus after the Devonian (Muth Quartzite), the Kumaon region possibly served as platform for the Carboniferous vegetation which spread all along Spiti to Kashmir

(Kapoor & Maheshwari, 1991).

An Upper Carboniferous flora is yet not known from India. It is possible that the sediments, lying below the Nishatbagh beds in Kashmir Basin from where a Permian flora of Gondwana affinity has already been found may, contain an Upper Carboniferous flora and provide important clues in resolving many questions on the origin and lineage of the Gondwana flora, migration route in time and space and the boundary between Carboniferous and Permian systems.

GONDWANA

The term Gondwana, initially used by H.B. Medlicott in an unpublished report dated 1872, was published only in 1876 by Ottokar Feistmantel with the rank of a "System". Fox (1931) assigned a time span from Middle Carboniferous to Upper Jurassic to the Gondwana "System". The time span was subsequently changed to Upper Carboniferous to Lower Cretaceous in the *Lexique internationale* and to earliest Permian to Early Cretaceous in *Stratigraphical Lexicon of Gondwana formations of India* (Sastri *et al.*, 1977).

The Gondwana as envisaged by early workers comprised purely terrigenous facies. Later a marine bed was discovered near Umaria and then marine beds came also to be included in the Gondwana so much so that predominantly marine beds of Permian age in the extrapeninsula also came to be included under the gamut of Gondwana. All this resulted in a great deal of confusion regarding the exact definition, status, geographical extent, age and floristic composition of the Gondwana in the Indian context.

Recently, Venkatachala and Maheshwari (1991) used the term *Gondwana Supergroup* to include the "continuous sequence of sediments laid down in peninsular intracratonic basins of India, that comprises a glaciogene unit at the base and a red-bed facies at the top, being respectively preceded and succeeded by a large hiatus. The sediments are essentially terrigenous; occasional thin marine horizons may be intercalated. The main lithologies are tillites/tilloid, sandstone, argillaceous and carbonaceous shales and coal". This definition leaves out from the ambit of the Gondwana all post-Triassic beds of the peninsula, as well as the Tethyan sediments even though the latter have some characteristic Gondwana fossils.

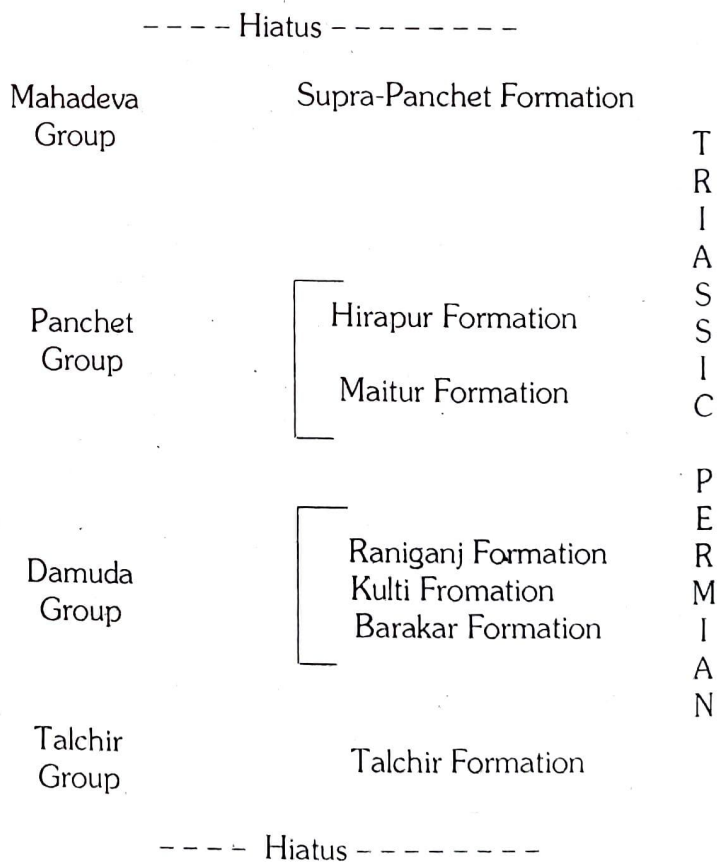
A standard succession of the *Gondwana Supergroup* as recognised in the Damodar Graben is as follows.

These formations are not necessarily developed in other grabens, but are represented by equivalent formations whose relation to the formations of Damodar Graben is essentially established on the basis of contained plant macro-and micro-fossils.

LOWER AND UPPER LIMITS

The Gondwana sedimentation was initiated by a glaciogene event. The Talchir Formation, the lowermost unit of the Indian Gondwana, is characterised by fluvio-glacial deposits comprising tillites, varves, needle shales, etc. The age of the basal unit of this formation has been variously computed as Upper Carboniferous, Carboniferous-Permian, Early Permian. However, the fauna present in the glaciomarine diamictite deposits, overlying the Archaean basement indicates a Late Asselian age at Manendragarh, while the younger Umaria marine bed as Sakmarian (Dickins & Shah, 1979; Nakazawa & Kapoor, 1977).

If the upper limit of the Indian Gondwana is to be considered in the floral context, due emphasis has to be placed on floral provincialism. The main floral provincialism, was mostly confined to the Permian, probably extending into the basal Triassic. The Triassic floras of the world, too, show a provincialism, but at a reduced scale. For example, the Late Triassic palynological assemblages recorded from Western Australia (Dolby & Balme, 1976) and from the Tiki Formation of the Son Graben (Maheshwari & Kumaran, 1979; Kumaran & Maheshwari, 1980) have a number of typical central European taxa at generic level. However, the megafloora does contain a number of taxa, e.g., *Dicroidium*, indigenous to the Gondwana. By Upper Mesozoic the Indian flora seems to have acquired a northern aspect. Thus, floristically the upper limit of Gondwana should be



placed above the Late Triassic. Lithostratigraphically too there is a big hiatus between the red-bed facies of Triassic age and the next succeeding sequence of sediments (Datta *et al.*, 1987) which are of Early Cretaceous age.

The Permian succession of the extra-peninsula comprises basically marine sequences belonging to a different tectonostratigraphic set up (Kapoor & Singh, 1987) and is not classified under the Gondwana. The Early Permian flora of the Kashmir Basin though has Gondwana affinity, yet contains in its upper part some elements showing a Cathaysian affinity. Depositional history being quite different, the region is considered to be a part of a separate province — the Perigondwana. On the same premise, the Permian deposits in eastern Himalaya may not be classified with the Gondwana. Though these have a flora resembling that of the Damodar Graben basins, the sequence is primarily a marine deposit, and have volcanic deposits, too, which are also known from the Perigondwana. The younger marine sedimentaries of the pericratonic basins of the peninsula are also excluded from the Gondwana Supergroup.

FLORISTICS, DIVERSITY AND CLIMATIC CHANGES

The period during which the Gondwana sedimentation took place saw the development of a very luxuriant vegetation. It was this vegetation that on entombment gave rise to major coal deposits of the country. The vegetation, however, was not equally luxuriant all through, it rather fluctuated, both in composition, diversity and in density, though retaining an overall uniformity.

The Gondwana vegetation primarily is a mesophytic vegetation. The cold conditions under which sediments of Talchir Formation (Asselian-Sakmarian) were laid, allowed limited diversification of plant species. Dominant floral elements of this period are *Gangamopteris* and *Noeggerathiopsis*. Slightly later appeared the genus *Glossopteris* with a few species and the only conifer reported is *Paranocladus*. The spores and pollen found dispersed in these sediments also reflect low diversification. Out of about ten genera of palynofossils, eight refer to saccate pollen and two to a trilete-bearing spore type (Lele, 1976).

With the amelioration of climatic conditions, the flora diversified and some new elements, viz., *Botrychiopsis*, *Euryphyllum*, *Rubidgea* and *Buriadia* appeared in the late Early Permian (Karharbari Formation, Artinskian). Species of the genera *Noeggerathiopsis*, *Gangamopteris* and *Glossopteris* also increased in number. There is also a rapid increase of palynotaxa in the younger sediments of the Karharbari where pteridophytic spores represent about one third of the population.

By the late Early Permian (Barakar Formation, Kun-

gurian), the *Noeggerathiopsis-Gangamopteris* association gave way to the *Glossopteris* dominated association. The genera *Botrychiopsis*, *Rubidgea* and *Buriadia* became extinct. Two new elements, viz., *Rhabdotaenia* and *Walkomiella* appeared. A well-marked change in palynofloral composition has also been recorded, the diversity in species of the pteridophytic (including lycopsid) spores increased many-fold and the gymnospermous disaccate striate and nonstriate pollen dominated (Tiwari & Tripathi, 1988). Floral elements suggest a mesic environment that was probably warm-temperate with ample water supply and sufficient light intensity. The flora of late Middle Permian (Kulti Formation) is poorly known.

The Late Permian (Raniganj Formation) had the peak development of *Glossopteris* and allied genera, viz., *Rhabdotaenia*, *Palaeovittaria*, etc. The climate was warm-temperate with heavy rainfall. Palynofossils also support this contention. By late Late Permian (upper part of Raniganj Formation) the vegetation became rather impoverished.

At the beginning of the Early Triassic (Panchet Group) the megafloora shows a continuum in characteristic elements, such as *Schizoneura gondwanensis*, *Glossopteris* spp. and *Rhabdotaenia* sp. Even the sphenophyll *Trizygia speciosa* has been reported, as well as some new elements, such as, ? *Lepidopteris* and *Pecopteris concinna*. A change, however, is noticed in the composition of the palynoflora. The spore-pollen genera consistent in their occurrence in the Early Triassic are *Klausipollenites*, *Lunatisporites*, *Lundbladispora*, *Densiporites*, *Playfordiaspora*, *Alisporites*, *Satsangisacites*, etc. (Tiwari & Singh, 1986).

The diversified palynoassemblage of Raniganj Formation is dominated by disaccate pollen, viz., *Striatopodocarpites*, *Faunipollenites*, *Crescentipollenites*, *Striatites* and *Densipollenites* and has 44 species of spores having pteridophytic affinity, 97 species (70% striate disaccate + 30% pteridophytic spores) of Raniganj do not continue into the Lower Triassic.

MARINE INCURSIONS

The ice-cover of the earliest Permian peneplained much of Peninsular India and in some of the areas, mostly close to Son-Narmada lineament marine transgression occurred. The first marine signatures in an otherwise non-marine sequence were discovered by Sinor (1923) in the thin calcareous bed containing brachiopods near Umaria in the Son Graben which includes *Stepanoviella* (Dickins & Shah, 1979). Another, such occurrence was also discovered from Manendragarh in the same graben but with older fauna and containing *Eurydesma* and *Deltopecten* (Ghosh, 1954; Dickins & Shah, 1979). Subsequently, many more marine beds have come to

light, to mention a few, Badhaura in Rajasthan, Daltonganj and Hutar in Koel Valley, and Raniganj (Mishra *et al.*, 1961; Dutt, 1965; Chaudhuri, 1988). Most of the occurrences are very close to the Son-Narmada lineament and suggest some downwarping along the zone, making a way for the marine transgression. In Arunachal Pradesh, further north-east, however, the marine succession is relatively well-developed and thick and closely comparable with those found in Salt Range and Kashmir.

Earlier the *Eurydesma-Stepanoviella* assemblage of Asselian-Sakmarian interval was the only unequivocal evidence for a marine environment of deposition. Now, on the basis of consistent association with this fauna, the leiosphaerid group of palynofossils has emerged as an indicator of a marine environment (Venkatachala & Rawat, 1973a, 1984). The leiosphaerids which range in age from Precambrian to present, have been recorded from many of the localities referred to above and also sediments not bearing marine animals such as from Dodhara in Satpura Basin, Athgarh in Mahanadi Graben, Chingleput in Palar Basin and in Upper Assam and Arunachal Pradesh (Venkatachala & Tiwari, 1988). Evidently the Early Permian Period in India witnessed a marine incursion in the form of an epicontinental, shallow, transgressive sea in all the grabens. Whether it was one single event or a succession of incursions, will only be known only after the precise correlations of different occurrences. It is generally accepted that the marine incursion was connected with the Tethys. The direction(s) through which the transgression took place are still being debated. A regional north-westerly drainage pattern has been postulated on the basis of palaeo-ice transport and of associated outwash conglomerate and sandstone (Cashyap & Tewari, 1988). The palaeodrainage probably emptied sediments into the sea both on the west and the north-east. Thus the Early Permian marine sea was connected from west (the Salt Range) to east and north through Badhaura and along Son Narmada downwarped zone. This, of course, is evident that some visible major changes took place during Early Permian in the southern continent.

UPPER MESOZOIC FLORA

The Upper Mesozoic witnessed major diversification in the plant groups. Cycadeoids and Cycads are represented by a large number of taxa, majority of which became extinct during the Early Cretaceous itself. Several other groups including the Bennettitales, and Pentoxylales which dominated the Early Cretaceous scene in India became extinct, no sooner than they diversified.

The Jurassic was a period of virtual non-deposition of fresh water sediments on the Indian Craton; however, few records of vegetation in the marginal marine sequen-

ces of Kutch are known. Palynologically the Upper Jurassic-Lower Cretaceous boundary is placed within the upper member of the Jhuran Formation (Maheshwari & Jana, 1988).

The Lower Cretaceous is marked by the appearance of a new set of cryptogamic spores. These incoming spores are *Cicatricosisporites*, *Impardecispora*, *Aequitriradites*, *Crybelosporites*, *Cooksonites*, *Foraminisporis*, *Contignisporites*, *Coptospora*, *Appendicisporites*, *Boseisporites* and *Coronatispora*.

As stated earlier, the Late Mesozoic sequence attributed as the East Coast Gondwana, has been delinked from Gondwana Supergroup. It is now considered to be marginal marine deposits related to transgressive/regressive cycles. Plant megafossils from the Sivaganga Formation support an Early Cretaceous age. The palynoassemblages recorded from the Mesozoic sequence in the so-called "East Coast Gondwana" in the Cauvery, Palar, Krishna-Godavari and Mahanadi basins indicate Neocomian-Aptian - Early Albian age. Cosmopolitan palynotaxa, such as, *Cicatricosisporites*, *Aequitriradites*, *Foraminisporis*, *Crybelosporites*, *Coptospora*, *Trilobosporites*, *Densoisporites* and *Coronatispora* indicative of Early Cretaceous age are known from all these basins. All stratigraphic, tectonic, palynologic, palaeontologic and environmental evidences indicate an Early Cretaceous age to the formations. (Venkatachala & Rajanikanth, 1988). Distinct Early Cretaceous palynofossil suites in sediments of the Cauvery Basin represented by *Microcachryidites antarcticus* zone, *Coptospora cauveriana* zone and *Triporoletes reticulatus* zone (in parts) are Neocomian and Aptian - Early Albian in age (Venkatachala *et al.*, 1972). Palynological investigations and the study of foraminifera have established that the marine incursions in the Cauvery Basin took place during Neocomian-Aptian, and not in the Upper Cretaceous. The palynoassemblage of Krishna-Godavari Basin resembles those of *Crybelosporites stylosus* and *Dictyosporites speciosus* zones of Australia (Venkatachala & Sinha, 1986). The marginal marine Mesozoic sediments of East Coast sedimentary basins bear an analogy to West Coast of Australia (Sastri *et al.*, 1974). Palynoassemblages of Berriasian to Aptian age are also known from the South Rewa and Satpura basins (Dev, 1961; Singh, 1966).

The flora of Rajmahal Intertrappean beds, earlier considered as Middle/Upper Jurassic in age, is composed of Cycads, Bennettitales, Pentoxylales and Conifers. The flora has traditionally been compared with the Yorkshire flora of England and as such has been dated as Upper Jurassic in age. Radiometric dates of 105 Ma for some of the Rajmahal flows (McDougall & McElhinny, 1970; Klootwiczjck, 1971; Agarwal & Rama, 1976), and new palynological data are now available that unequivocally

position during Oligocene-Miocene and this placement perhaps favoured the migration and subsequent settlement of genera such as *Durio* and *Gonystylus*. The relative location of Malaysia and India may also have permitted the invasion of India by taxa of Malaysian affinities as stated by Axelrod (1974). *Dulhuntyispora Potonié* is recorded as a reworked fossil from the Oligocene-Miocene of Assam and Tripura-Cachar basins of India. The genus is so far known from Australia and Africa and is a Late Permian marker fossil. Sea or oceanic currents were possibly responsible for the reworking of this fossil along with Permian sediments from Australia to north-east India when the Indian and Australian plates were juxtaposed (Venkatachala & Kar, 1988).

The Palaeocene-Eocene Indian palynoflora comes mainly from coal and lignite deposits of Meghalaya, Assam, Kutch, Cambay, Rajasthan and other basins. This palynoflora is characterised by swamp dwellers, such as, *Barringtonia* (*Marginipollis*), *Durio* (*Lakiapollis*), *Gonystylus* (*Cryptopolyporites*), *Nypa* (*Spinizonocolpites*) in association with evergreen forest representatives related to Ctenolophonaceae (*Ctenolophonidites* and *Retistephanocolpites*), Olacaceae (*Anacolosidites*), Caesalpiaceae (*Margocolporites* and *Striacolporites*).

The swampy condition did not continue in India after Oligocene. The Neogene sediments of India are predominantly riverine deposits and the change in edaphic condition could have also led to temporary disappearance of the swampy vegetation. That is likely the explanation for the absence of *Spinizonocolpites-Nypa* during the Upper Palaeogene and the Lower Neogene. It occurs again in the Quaternary sediments of India (Venkatachala *et al.*, 1988) and *Nypa* is still growing now a days in some parts of the Indian coastal areas such as the Sunderban Delta.

Here, it is necessary to point that some of publications on significant finds do not furnish the requisite details of location and position of samples. This restricts their use in subsequent analysis and synthesis. More difficulty is felt in others, where authors have attempted to discuss some of the geological events, without properly assessing other scientific parameters. Therefore, in the present age of analysis and synthesis our data should be precise and we must take into account all parameters before finalising our results on a specific problem.

Cuddalore Sandstone

The Cuddalore Sandstone exposed in the western part of the Cauvery Basin was considered as Mio-Pliocene in age and continental in origin. A large number of fossil woods of families Podocarpaceae, Arecaceae, Anacardiaceae, Dipterocarpaceae, Fabaceae and others are known from it, and also includes a flora represented by

tropical evergreen elements such as *Sindora*, *Gonystylus*, and *Dryobalanops*, etc. Some of them are presently known only in tropical evergreen forests of Malaysia and Indonesia. The Neyveli Lignite deposits occur within these sandstones. The analysis of recovered palynofossils from the subsurface of Cauvery Basin and Neyveli Lignite suggests that the formation is of Eocene age and may be time transgressive (Venkatachala, 1973). The records of mangroves and associated coastal pollen in the Neyveli Lignite negate their attribution to continental type of deposition.

FLORISTIC DIVERSITY AND MIGRATION PATTERN DURING CENOZOIC

The Miocene flora in Kerala-Lakshdweep, Cauvery, Jaisalmer, Cambay, Assam-Arakan and Bengal basins and the Lower and Middle Siwalik was constituted overwhelmingly of tropical evergreen elements, presently known from Indo-Malayan region indicating warm and humid conditions (Awasthi, 1974b, 1982a, b, 1984; Awasthi & Panjwani, 1984; Lakhanpal *et al.*, 1981, 1984). However, cooling and dry trends occurred in the post-Miocene time. Coinciding with the collision of the Indian Plate with the Asian Plate, appearance of several physical barriers and further rise of the Himalaya, increased continentality and reduced precipitation.

Turnover of palynotaxa through Eocene-Oligocene in Cauvery, Godavari and Kutch basins in India is illustrated in Table 1 (after Ragubanshi *et al.*, 1991). The lowering of temperature during the Late Cretaceous, Palaeogene and Neogene, reduced precipitation levels all over the globe. The decline in precipitation prompted the expansion of low biomass, openland and aridland vegetation and the evolution of open land plant taxa. Arid and semi-arid land vegetation which hitherto occupied limited dry locations thus expanded into areas at the lower spectral end of the precipitation gradient in the low and middle latitudes. During warmer and wetter interglacials tree vegetation was able to encroach into areas formerly occupied by open land vegetation at both high and low latitudes resulting in the advance in tree lines polewards and into former deserts during interglacials. The reverse happened during glacial phases when openland, treeless herbaceous vegetation returned (Singh, 1988).

During the mid-Miocene there existed an incipient latitudinal zonation of vegetation in the Himalaya, then only 2,200-2,400 m high. There occurred wet tropical forests on the lower slopes, wet temperate forests on the higher slopes, with wet subtropical in between. The palearctic genera occurred in the top two zones as they do today in the eastern Himalaya. There was not much difference in the generic composition between the Neogene floral assemblages of eastern and western

Table 1. Distribution of fossil spore and pollen taxa through Eocene-Oligocene Epoch in India (after Raghunathi et al., 1990)

PALYNOTAXA/AGE	EOCENE	OLIGOCENE
<i>Araliaceopollenites rugulatus</i>	-----	-----
<i>Arecipites indicus</i>	-----	-----
<i>Asperitricolporites pilosus</i>	-----	-----
<i>Caprifoliipites descretus</i>	-----	-----
<i>Cupanieidites flabelliformis</i>	-----	-----
<i>Dicopolpites kalevensis</i>	-----	-----
<i>Favitracolporites ornatus</i>	-----	-----
<i>Neocouperipollis symbatus</i>	-----	-----
<i>Palmaepollenites baculatus</i>	-----	-----
<i>Proteacidites debaani</i>	-----	-----
<i>Retibrevicolpites foveolatus</i>	-----	-----
<i>Retitricolpites florentinus</i>	-----	-----
<i>Rhoipites baculiferus</i>	-----	-----
<i>Rhoipites communis</i>	-----	-----
<i>Schizosporis rugulatus</i>	-----	-----
<i>Spinatraportites densispinus</i>	-----	-----
<i>Sicphanocolpites globatus</i>	-----	-----
<i>Striatricolporites obscurus</i>	-----	-----
<i>Symplocopollenites gracilis</i>	-----	-----
<i>Tricolpites brevicolpus</i>	-----	-----
<i>Tricolpites fissilis</i>	-----	-----
<i>Triorites pseudoreticulatus</i>	-----	-----
<i>Triorites tubiferus</i>	-----	-----
<i>Araliaceopollenites matanomadbensis</i>	-----	-----
<i>Arecipites bellus</i>	-----	-----
<i>Bakspollis primitiva</i>	-----	-----
<i>Cupuliferopollenites ovatus</i>	-----	-----
<i>Dandotiaspora plicata</i>	-----	-----
<i>Dermatobrevicolporites dermatus</i>	-----	-----
<i>Dracaenopollis circularis</i>	-----	-----
<i>Intrapunctisporis apunctis</i>	-----	-----
<i>Lakiapollis ovatus</i>	-----	-----
<i>Neocouperipollis brevispinosus</i>	-----	-----
<i>Neocouperipollis kutchensis</i>	-----	-----
<i>Osmundacidites kutchensis</i>	-----	-----
<i>Palmaepollenites nadhamunii</i>	-----	-----
<i>Palmaepollenites ovatus</i>	-----	-----
<i>Palmaepollenites plicatus</i>	-----	-----
<i>Pellucopollis langensheimii</i>	-----	-----
<i>Polybrevicolporites nadhamunii</i>	-----	-----
<i>Pseudonitobfagidites kutchensis</i>	-----	-----
<i>Retistephanocolpites flavatus</i>	-----	-----
<i>Retistephanocolpites globatus</i>	-----	-----
<i>Retitricolporites matanomadbensis</i>	-----	-----
<i>Sentiasporites verrucosus</i>	-----	-----
<i>Siriactiporites cephalus</i>	-----	-----
<i>Siriactiporites ovatus</i>	-----	-----
<i>Symplocopollenites kutchensis</i>	-----	-----
<i>Tricolpites reticulatus</i>	-----	-----
<i>Umbelliferopollenites ovatus</i>	-----	-----
<i>Verrucopollis verrucosus</i>	-----	-----
<i>Cricotriporites cauveriensis</i>	-----	-----
<i>Paleocaesalpiniaecopites miocenicus</i>	-----	-----
<i>Proteacidites bellus</i>	-----	-----
<i>Retitricolpites bispidus</i>	-----	-----
<i>Stephanocolpites tetraocolpites</i>	-----	-----
<i>Tricolpites pilosus</i>	-----	-----
<i>Marginipollis kutchensis</i>	-----	-----
<i>Favitracolporites magnus</i>	-----	-----
<i>Symplocopollenites punctatus</i>	-----	-----
<i>Psilatricolporites operculatus</i>	-----	-----
<i>Proxapertites operculatus</i>	-----	-----
<i>Anacolosidites trilobatus</i>	-----	-----
<i>Cupanteidites flaccidiformis</i>	-----	-----
<i>Engelhardtoidites minutiformis</i>	-----	-----
<i>Myricaceopollenites dubius</i>	-----	-----
<i>Polycolpites pedallaceoides</i>	-----	-----
<i>Proteacidites terrazus</i>	-----	-----
<i>Proxapertites hammenii</i>	-----	-----
<i>Psilodiporites hammenii</i>	-----	-----
<i>Rhoipites conatus</i>	-----	-----
<i>Favitracolporites magnus</i>	-----	-----
<i>Jugopollis tetraporoides</i>	-----	-----
<i>Spinizonocolpites echinatus</i>	-----	-----
<i>Palmaepollenites kutchensis</i>	-----	-----
<i>Araliaceopollenites mannargudi</i>	-----	-----
<i>Tricolpites longicolpatus</i>	-----	-----
<i>Margocolporites siboleyi</i>	-----	-----
<i>Mauritidites densispinus</i>	-----	-----
<i>Siriapollis bellus</i>	-----	-----
<i>Tricolpites margocolpites</i>	-----	-----
<i>Caryapollenites cauveriensis</i>	-----	-----
<i>Marginipollis conctinus</i>	-----	-----
<i>Myricipites barrisi</i>	-----	-----
<i>Palaecoproamadis arcotense</i>	-----	-----
<i>Biretisporites convexus</i>	-----	-----
<i>Cbellaniboidispora momoleta</i>	-----	-----
<i>Cyatidites australis</i>	-----	-----
<i>Cyatidites minor</i>	-----	-----
<i>Laevigatospores laktensis</i>	-----	-----
<i>Lygodiumspores laktensis</i>	-----	-----
<i>Palaomalvaceaeapollis mammillatus</i>	-----	-----
<i>Palaesantalaceaeapites minutus</i>	-----	-----
<i>Proxapertites microreticulatus</i>	-----	-----
<i>Siriactites microreticulosus</i>	-----	-----
<i>Siriactites susannae</i>	-----	-----
<i>Todisporites kutchensis</i>	-----	-----
<i>Zonocostites ramonae</i>	-----	-----
<i>Margocolporites sabnii</i>	-----	-----
<i>Proteacidites granulatus</i>	-----	-----
<i>Sapotaceoidaeapollenites obscurus</i>	-----	-----
<i>Subirporopollis scabratus</i>	-----	-----
<i>Araliaceopollenites descretus</i>	-----	-----
<i>Bombacacidites triangulatus</i>	-----	-----
<i>Compositopollenites tricolporatus</i>	-----	-----
<i>Graminidites granulatus</i>	-----	-----
<i>Leptolpidites chandrae</i>	-----	-----
<i>Palaomalvaceaeapollis ridis</i>	-----	-----
<i>Podocarpidites cognatus</i>	-----	-----
<i>Polypodiaceaeapollis chatterji</i>	-----	-----
<i>Polypodiisporites constrictus</i>	-----	-----
<i>Polyporina multiporus</i>	-----	-----
<i>Proxapertites scabratus</i>	-----	-----
<i>Punctatisporites sarangwarensis</i>	-----	-----
<i>Retitricolpites delicatus</i>	-----	-----
<i>Torolisporis dikis</i>	-----	-----
<i>Triporapollenites exactus</i>	-----	-----
<i>Trisyncolpites ramanujamii</i>	-----	-----
<i>Verrupolyporites globosus</i>	-----	-----

Legends :

Cauvery Basin	-----
Kutch Basin	-----
Godavari Basin	-----
Ranges Extended	-----
on the basis of	
their occurrence in	
Miocene	

Data after : Venkatachala (1973), Venkatachala & Rawat (1972, 1973), Kar (1985), Venkatachala & Sharma (1984)

Himalaya. However, the specific affinities of the taxa differentiating these floral assemblages are only tentative; indications are that they had a number of common species (Vishnu-Mittre, 1984). At that time the tropical wet evergreen forests of the western Himalaya consisted overwhelmingly of Malayan and southeastern elements (e.g., *Dipterocarpus*, *Cynometra*, *Anisoptera*, *Gluta*, *Diospyros*, *Elaeocarpus*, *Sterculia*, *Bursera*) while the temperate forests consisted of a number of palearctic genera (e.g., *Pinus*, *Abies*, *Picea*, *Alnus*, *Betula*, and *Magnolia*). The tropical wet evergreen vegetation of the eastern Himalaya had somewhat different species (Awasthi, 1974a; Mohan, 1933) composition. Some of the present day common tree taxa with which older taxa had affinities were *Calophyllum*, *Dipterocarpus*, *Shorea*, *Kaya*, *Gluta*, etc. It may be pointed out that only the eastern Himalayan region still contains a wet evergreen tropical forest. Several of the modern species, however, were also present during the Miocene.

The Miocene orogeny and perhaps planetary dynamics led to mark climatic changes involving the pluvial cycles, i.e., the repetition of cold (and dry) and warm (and mesic) phase during the Pliocene. These cycles brought about drastic changes in physiogamy and in vegetation, which include the disappearance of some forest types (e.g., tropical wet evergreen *Dipterocarpus-Anisoptera* forests from the western Himalaya), arrival of species from extra-Himalayan regions, relative increase and decrease in the area occupied by different biomes such as forest and steppe, etc. It is, however, difficult either to interpret the sequences of such changes precisely, or to suggest at what rate and at which time the vegetational changes occurred (Vishnu-Mittre, 1984).

By the end of the Miocene (Lower Siwalik), tropical African elements, such as, *Ziziphus mauritiana* had reached the lower slopes of the western Himalaya (Lakhanpal, 1965; Lakhanpal & Awasthi, 1984). In subtropical and temperate belts of Kashmir, a continuous flux between the forests of *Quercus-Carya*, *Larix*, *Engelhardtia*, *Quercus-Alnus* and *Pinus roxburghii* on the one hand, and steppe (*Poaceae* with or without *Chenopodium* and *Artemisia*) on the other, occurred between 3.5-2.47 Ma B.P. The steppe attained preponderance during the cooling-phase and the forests during the warming phase. *Cedrus deodara*, a Mediterranean species, immigrated during the Pliocene. In the Kashmir Valley, during Pliocene, subsequent to the decline of *Cedrus-Quercus* forests, *Pinus wallichiana* arrived and expanded. *Pinus wallichiana* declined subsequently to be replaced by *Picea-Cedrus-Quercus* forests.

The sub-alpine and alpine conditions developed in the Himalaya after the final uplift. At the time, *Quercus semecarpifolia* and *Betula utilis* were the chief subalpine and alpine forest forming species. During the last glacia-

tion (about 0.7 Ma ago), the steppes encompassed most of the areas in higher elevations (above 3,000 m), but the subsequent warm-phase led to the expansion of junipers in dry areas and of *Quercus semecarpifolia* and *Betula utilis* in relatively mesic areas. Similar alternations were found between steppe and *Ephedra* communities in arid parts.

More recently, between about 8,000 and 4,500 years ago, a warm phase which resulted in massive snow-melting and concomitant increase in the sea level coincided with the invasion of chir pine (*Pinus roxburghii*) forests by oaks (*Quercus* spp.) in the central Himalaya (Vishnu-Mittre, 1984). At this time, in fact, oaks predominated in the entire subtropical and temperate belts of the western Himalaya. In some regions, such as the Kashmir Valley (within about the last 500 years ago) and Himachal Pradesh (during 1,400-500 years ago) oaks disappeared or were pushed to sheltered areas within the conifer regimes. The present flora of Kashmir Valley is devoid of either oaks or *Pinus roxburghii* (Puri *et al.*, 1983). In Kashmir, at higher elevations (2,000-3,000 m), *Pinus wallichiana* (blue pine) was the main pine species, while in Himachal Pradesh and Kumaon in the lower elevations, the pine was mainly *Pinus roxburghii*.

It is interesting that the oaks predominated and invaded the pine forests during the warm-phase of the climate, because at present the oak forests are located at higher elevations (hence cooler environment) than the chir pine (*Pinus roxburghii*) forest (Singh & Singh, 1987).

While reviewing the geologic history of biotic diversity, Signor (1990) has concluded: (i) evolutionary change leading to increased alpha diversity in marine and benthic communities contributed directly to increased diversity on regional and global scales; (ii) coevolutionary interactions between terrestrial plants and animals led to increased species richness in terrestrial communities; (iii) continental drift has been a major force controlling global diversity, both in the marine and terrestrial realms; and (iv) climate and sea level undoubtedly played a role in the short term but are unlikely to control diversity in the long term (Raghubanshi *et al.*, 1991).

PALYNOLOGY AND ORGANIC MATTER STUDIES

Recent researches have established that the main source for hydrocarbons is vegetal debris including phytoplankton, marine and terrestrial algae as well as lipid rich land plant remains (Venkatachala, 1984). Terrestrially sourced debris are carried into the off shore marine realm in enormous quantities and become incorporated into marine sediments. This material contributes sig-

nificantly to the generation of hydrocarbons. In fact, the transition zone between land and sea, particularly in tropical and sub-tropical regions, where the accumulation of mixtures of terrestrially and marine derived palynodebris is at its greatest, provides optimum conditions for hydrocarbon formation and pooling. Evaluation of hydrocarbon source rock potential necessitates recognition of type and amount of organic matter contained in the sediment and the level of thermal transformation.

Different environments are characterised by different plant communities which, upon death and decay, yield recognisably different populations of palynodebris. Thus the type of palynodebris in a sediment is, in large part, a measure of the depositional environment. This is, of course, more true of non-marine than of marine environments. By studying the palynodebris of present day environments it is possible to establish patterns of distribution that may be employed in the interpretation of past environments. This method of palaeoenvironmental interpretation has proved of practical value for sediments of the Mesozoic and Tertiary eras.

Biodiagenesis of structured organic materials results in a breakdown of large, complex molecules into smaller (simpler) entities. This is accompanied by chemical changes which frequently influence the hydrogen richness of the material and, therefore, its hydrocarbon source potential. In the case of higher plants this change is normally in the direction of hydrogen enhancement and improvement of hydrocarbon source potential. Thus, it may be stated as a broad generalisation that biodiagenesis of structured plant materials results in the enhancement of the organic matter as a possible source for the generation of fossil hydrocarbons. Also, in general, the higher the proportion of amorphous material in a sediment, the better hydrocarbon source potential that sediment will possess.

By means of the quantitative or analytical approach we can assign numerical values to the hydrogen richness of the various palynodebris types and also derive formulae for estimating changes in composition during processes of biodegradation. By this means we should be able to derive numerical values expressing the hydrogen potential of any sediment which can be employed in calculating the fossil hydrocarbon potential of any area.

The examples of organic matter typing in Neogene and Palaeogene sediments encountered in drill-cores of Narsahpur, Cauvery and Bombay high are well documented.

Integrated palynological research involving spore-pollen-phytoplankton studies, organic matter facies using both transmitted and reflected light microscopy are needed to decipher environmental and source rock regimes. This new dimension will certainly augment constructive palynological study.

CONCLUSIONS

1. The preliminary palaeobiological evidences available from the Archaean sediments of Dharwar Craton indicate presence of anaerobic chemoheterotrophic signature in 2.6 Ga old sediments. The association of probable sulphate reducing bacteria with pyrite is suggestive of presence of eubacteria and traces back anaerobic chemoautotrophic activity to 2.6 Ga. Presence of columnar stromatolites which are considered to have been formed by filamentous photoautotrophs; presence of structurally mineralized filamentous microfossils in the cherts interbedded with BIF and REE ratio indicating oxygenated sea water in 2.6 Ga old Dharwar sediments provide presumptive evidence of filamentous photoautotrophs at 2.6 Ga. Presence of extensive carbonate-orthoquartzite type shelf association in which stromatolites develop indicates possibility of stabilisation of the crust in the Indian Craton at the time of deposition of Dharwar sediments and extensive development of shelf conditions. Subject to the authenticity and reproducibility of the persisting reports of possible metazoan activity prior to 800 Ma from Vindhyan sediments, a possibility exists that metazoan activity had started much earlier than accepted so far.
2. The assessment of available floristic and lithostratigraphic evidences indicates that the Gondwana sedimentation commenced in the Early Permian and continued up to top of Triassic.
3. The Jurassic sediments were not deposited in the intracratonic basins. The Rajmahal flora is now considered to be of Early Cretaceous in age.
4. The paralic sediments of East Coast are now considered to be Neocomian-Aptian in age, contrary to the earlier Jurassic age assignment based on megafloreal evidences. Thus, the first marine influence now dates back to Neocomian-Aptian time in Cauvery Basin. The palynofossil assemblage indicates Maestrichtian age for 4 widely separated and distinct geological settings (Padwar, Naksal, Narsapur subsurface section and Tiruchirapalli). This documents near synchronicity of flows over extensive areas and cosmopolitan nature of terminal Cretaceous biotas of Indian peninsular region.
5. The extinction pattern at the terminal Eocene in India indicates northward migration of India after Cretaceous-Palaeocene. The change in the latitudinal position and resulting variations in climate may have been responsible for such extinctions in India.
6. The extra-peninsular Palaeozoic-Mesozoic plant bearing horizons need special attention. The re-assessment of stratigraphic positions and taxonomic status of this biota may provide key for correlation and palaeogeography.

7. The source for hydrocarbon is vegetal debris and consequent study of the organic matter contained in the sediments and level of the thermal transformation indicate hydrocarbon source rock potential of the sediments.
8. A detailed study is to be promoted for the levels of biological diversity and factors controlling it in view of their wide application in drawing time scale boundaries and modelling for future changes.

Comparatively much finer resolutions can be attained in biostratigraphy and taxonomy by developing quantitative biostratigraphy parameters and ultrastructural studies.

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