Diversification and evolution of Early Cretaceous East Coast flora of India

A. Rajanikanth

Rajanikanth A 1996. Diversification and evolution of Early Cretaceous East Coast flora of India. *Palaeobotanist* **45** : 369-377.

The Early Cretaceous continental sediments in the East Coast of India are characterized by the *Ptilophyllum* flora. Interplay of tectonism and sedimentation caused plant fossil preservation in different unconnected paralic deposits distributed in Cauvery, Palar, Krishna-Godavari and Mahanadi basins and in the associated Pranhita-Godavari Graben. Plant megafossils assigned to pteridophytes, pteridosperms, cycadophytes, Taxales, Ginkgoales and Coniferales are variously distributed in these basins. Differential preservation of plant parts denotes an incomplete evolutionary pattern. Variation within the basinal flora reflects a localised aspect. Plant fossils preserved in the Cauvery, Palar, Krishna-Godavari and Mahanadi basins reflect a near shore continental sedimentary fill subjected to more dynamic events like marine transgression, which probably did not allow better preservation of plant fossils. Paucity of carbonised/silicified material, abundance of impressions of plant leaf fossils, scarcity of wood and reproductive parts indicate an unfavourable environment for plant fossil preservation in these pericratonic basins. Whereas in the associated Pranhita-Godavari Graben the plant fossils are better preserved in the subaerially exposed basinal areas away from the main coast-line.

The Early Cretaceous flora of Cauvery, Palar and Krishna-Godavari basins dominated by cycadophytes suggests presence of seaward margins of fluviodeltaic palaeoenvironment. The pteridophyte dominant flora of Mahanadi Basin represents a decreasing marine influence contrary towards the south-eastwards. The evolution and diversification of the East Coast Early Cretaceous flora runs parallel to other intracratonic basinal flora. The uniformity in the floral component supports an equable climate. Conifers being the upland floral elements constitute chief components of intracratonic basinal flora. The fluviomarginal elements like cycadophytes predominate the pericratonic sedimentation with some upland near basinal taxa. Pteridosperms and Ginkgoales are scanty. Presence of leaves with entire margin indicates a favourable growth environment.

Key-words—Taphonomy, *Ptilophyllum*, East Coast, Early Cretaceous (India).

A. Rajanikanth, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

सारांश

भारत के प्रारम्भिक क्रीटेश्यस युगीन पूर्व तटीय वनस्पतिजात में विभिन्नता एवं विकास

अन्नमराजु रजनीकान्थ

भारत के पूर्व तट के प्रारम्भिक क्रीटेश्यस महाद्वीपीय अवसाद टाइलोफिल्लम् वनस्पतिजात से अभिलक्षणित हैं। विवर्तन और अवसादन के कारण अश्मित पौधों का परिरक्षण विभिन्न असम्बद्ध कावेरी, पलार, कृष्णा-गोदावरी एवं महानदी द्रोणीयों तथा सहयुक्त प्रणहिता-गोदावरी द्रोणिका के निक्षेपों में हुआ है। इन द्रोणीयों में टेरीडोफाइटी, टेरीडोस्पर्म, साइकेडोफाइटी, टैक्सेल्स, गिन्क्गोएल्स एवं कोनिफरेल्स पौधों के अवशेष मिलते हैं। पौधों के कुछ कम परिरक्षण के कारण पौधों का विकासीय स्वरूप कुछ अपूर्ण सा लगता है। एक ही द्रोणी से प्राप्त वनस्पतिजात में विभिन्नता स्थानीय कारणों से हो सकती है। कावेरी, पलार, कृष्णा-गोदावरी एवं महानदी द्रोणीयों से उपलब्ध पौधों के अवशेषों से तटीय परिस्थितियाँ व्यक्त होती हैं जिसके कारण सम्भवतया पौधों का अच्छा परिरक्षण नहीं हो सका । इसी प्रकार कार्बनमय/सिलिकायुक्त सामग्री, पत्तियों के पर्ण-छापों की अधिकता तथा काष्ठों एवं जननांगों के कम अवशेषों से अवसादन के समय प्रतिकूल वातावरण का होना इंगित होता है। जबकि प्रणाहिता–गोदावरी द्रोणिका में पौधे अपेक्षाकृत अच्छे परिरक्षित हैं।

महानदी द्रोणी में टेरीडोफाइटी पौधों की बाहुल्यता से समुद्री प्रभाव की समाप्ति व्यक्त होती है। कावेरी, पलार एवं कृष्णा-गोदावरी द्रोणीयों में साइकेडोफाइटी अवशेषों की प्रचुरता से नदीय एवं तटीय वातावरण का होना इंगित होता है। परन्तु महानदी द्रोणी में टेरीडोफाइटी पौधों की बाहुल्यता से समुद्री प्रभाव की समाप्ति प्रदर्शित होती है। इस क्षेत्र के वनस्पतिजात में विभिन्नता और विकास अन्य अन्तराक्रेटोनी द्रोणीयों की तरह ही हुआ है। जिससें एक ही प्रकार के तापक्रम तथा अन्य परिस्थितियों का होना इंगित होता है। इस वनस्पतिजात में टेरीडोस्पर्म और गिन्क्गोएल्स बहुत कम हैं तथा प्राप्त पत्तियों के किनारों से अनुकूल वातावरण का होना प्रस्तावित होता है।

THICK succession of dominantly marine Cretaceous deposits with intercalations of fluviatile sediments characterise the East Coast sedimentary basins of India. Development of these basins was correlated with intense tectonism related to breakup of the Gondwanic greater Indian Continent (Datta *et al.*, 1983; Acharyya & Lahiri, 1991; Biswas *et al.*, 1993). These tectonically active basins embody Early Cretaceous (Neocomian-Aptian) sediments represented by upland, near basinal and marginal type floral components. These sedimentary units occur as narrow disconnected patches in four pericratonic basins, namely Mahanadi, Krishna-Godavari, Palar and Cauvery and in associated intracratonic Pranhita-Godavari Graben. Wherein the former four basins bear coeval, paralic, lagoonal deposits, the latter graben primarily embody terrestrial to deltaic fill (Sastry *et al.*, 1981). All these sediments share a common floral bondage — the Ptilophyllum flora. Plant fossil data of different lithounits was synthesised (Lakhanpal *et al.*, 1976; Chandra & Tewari, 1991; Srivastava, 1991; Rajanikanth & Prakash, 1994) and their distribution and stratigraphic implications were discussed (Venkatachala, 1977; Venkatachala & Rajanikanth, 1987; Singh & Venkatachala, 1987; Sukh-Dev, 1987; Bose *et al.*, 1990).

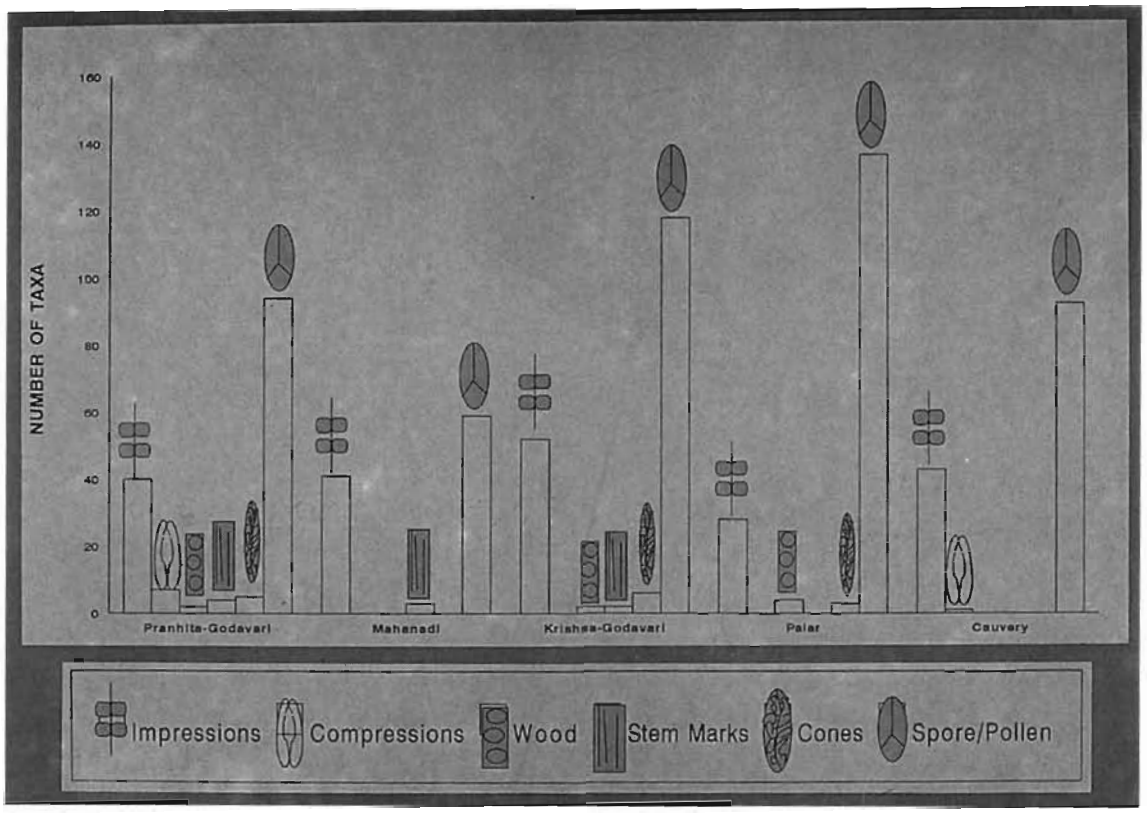
The Early Cretaceous flora of India is mainly represented by the Gondwana stock that flourished in western, central and eastern parts of the country. Indian Plate was tectonically active during the Early Cretaceous time, which resulted in admixture of European floral elements. Indian megafloral data indicate an Indo-European provincial affinity (Sukh-Dev, 1987). The palynological data support an austral province to which India was a part as evidenced by *Microcachryidites* assemblage (Srivastava, 1983).

The Early Cretaceous East Coast flora is characterized by the members belonging to bryophytes— Hepaticopsida, Anthocerotopsida; pteridophytes— Lycopodiaceae, Selaginellaceae, Osmundaceae, Gleicheniaceae, Schizaeaceae, Matoniaceae, Cyatheaceae, Dicksoniaceae, Polypodiaceae, Marattiaceae, Dipteridaceae; gymnosperms — Pteridospermales, Cycadophytales, Coniferales, Taxales and Ginkgoales (Ramanujam, 1983; Venkatachala & Rajanikanth, in press). The present research communication focuses the significance of palaeobotanical and palynological data to educe evolution and diversification of Early Cretaceous East Coast flora. Distribution patterns of various fossils in different basins, their taphonomic and palaeoecological considerations are explored to exemplify differential preservation. The breakup events of Gondwana related tectonic and oceanographic changes and their impact on variable sedimentological processes involved in recording plant fossils are discussed.

PRANHITA-GODAVARI GRABEN

This is an intra-cratonic rift basin extending up to the East Coast and plunges into Krishna-Godavari pericratonic rift. Sedimentation is predominantly terrestrial to deltaic with occasional marine transgressions (Biswas *et al.*, 1993). The Early Cretaceous sediments are represented by two lithounits namely Chikiala and Gangapur. The former is characterised by conglomerates, sandstones with minor bands of shales and clays. Plant fossils from this unit are little known except some sporadic records (Rao & Shah, 1960). The Gangapur unit is fairly well known for its floristic composition. The sediments are mostly yellow light brown and buff sandstones, conglomerates with clayey interbeds. Plant remains of these sediments are critically evaluated (Rajanikanth, 1994). The megaflora consists of 10 species and 6 genera of pteridophytes (Equisetaceae/ Gleicheniaceae/Dipteridaceae/Incertae sedis); 15 species and 8 genera of cycadophytes, one species of pteridosperm, 23 species and 11 genera of conifers (Text-figure 1). Probably, a conifer dominant forest near the depositional basin mainly characterized by Araucariaceae and Podocarpaceae made the upper canopy with undertier cycadophytes and lowland pteridophytic representatives (Text-figure 1).

The megaflora is chiefly represented by *Elatocladus, Brachyphyllum, Pagiophyllum, Allocladus, Araucarites, Strobilites, Satpuria, Ptilophyllum, Pterophyllum, Dictyozamites, Taeniopteris, Pachypteris, Cladophlebis, Gleichenia* and *Equisetites*. The palynoflora is characterized by *Cicatricosisporites, Aequitriradites, Cooksonites* and *Microcachrydites*. This preangiosperm flora did not maintain its identity in post Aptian-Cretaceous records as these are botanically and geologically impoverished. The preservation of fossils is varied. Leaf-impressions dominate the assemblage with fairly well represented compressions with cuticular details (Sukh-Dev & Rajanikanth, 1988). Two woods, two reproductive structures and stem impressions are also known (Manik & Srivas-



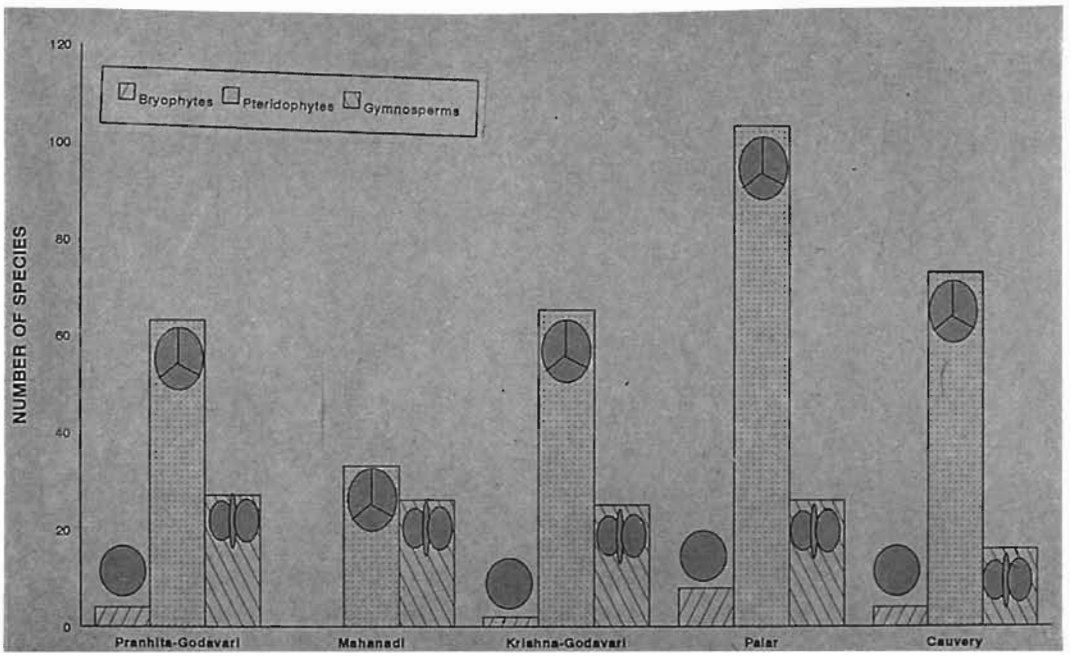
Text-figure 1—Distribution of plant parts in East-Coast basins.

tava, 1991; Rajanikanth, 1994) (Text-figure 3). Reactivation phase during the Early Cretaceous time resulting in major faults controlled the evolution of depositional sites and sedimentation (Sastry *et al.*, 1981). Sedimentation in this intracratonic rift basin was probably not frequently affected by marine transgression events. The terrestrial fill consisting of plant remains got buried and preserved in fluviatile deposits and varied plant organs got preserved. Preferential sorting is demarcated by differential distribution of cycadophyte and conifer leaves. Due to hydraulic properties of both types of leaves differential sorting occurred in a fluvio-lacustrine delta environment. It is further exemplified by poor preservation of pteridophytic leaves but abundance of fern spores (Ramanujam *et al.*, 1987).

Megaflora as a whole is fairly well comparable with flora in the East Coast pericratonic Early Cretaceous sediments. Numerically less representation of cycadophytes in the Gangapur unit may indicate the preference of these forms to coastal zones. Besides, there has been a remarkable similarity of conifer species of Gangapur and Sehora in South Rewa Gondwana Basin. The regional floristic composition of intracratonic sediments is slightly varied than the coastal paralic sediments. Palynological data of Gangapur too indicate a conifer dominant vegetation (Ramanujam, 1983). Members of Chierolepidaceae like *Classopollis* indicate prevalence of local brackish environments. Floral regionalism with in the basin was probably influenced by topographic and edaphic factors. Poor representation of animal fossils in the Early Cretaceous sediments of Pranhita Godavari Graben makes it more important to use plant fossil data for stratigraphic evaluation. Palynological data support a Neocomian-Aptian age which also derives support from megafossil data (Rajeshwar Rao, 1977; Sukh-Dev, 1987; Bose *et al.*, 1990).

MAHANADI BASIN

The Mahanadi Basin covered mostly by Holocene deposits and consists of only sedimentary unit the Athgarh Sandstone. This unitd exposed near the western margin of the basin bears a lithology mainly of white to grey, hard sandstones with intercalations of lenticular greyish white to pinkish clays and carbonaceous shales bearing plant fossils. Megafossil

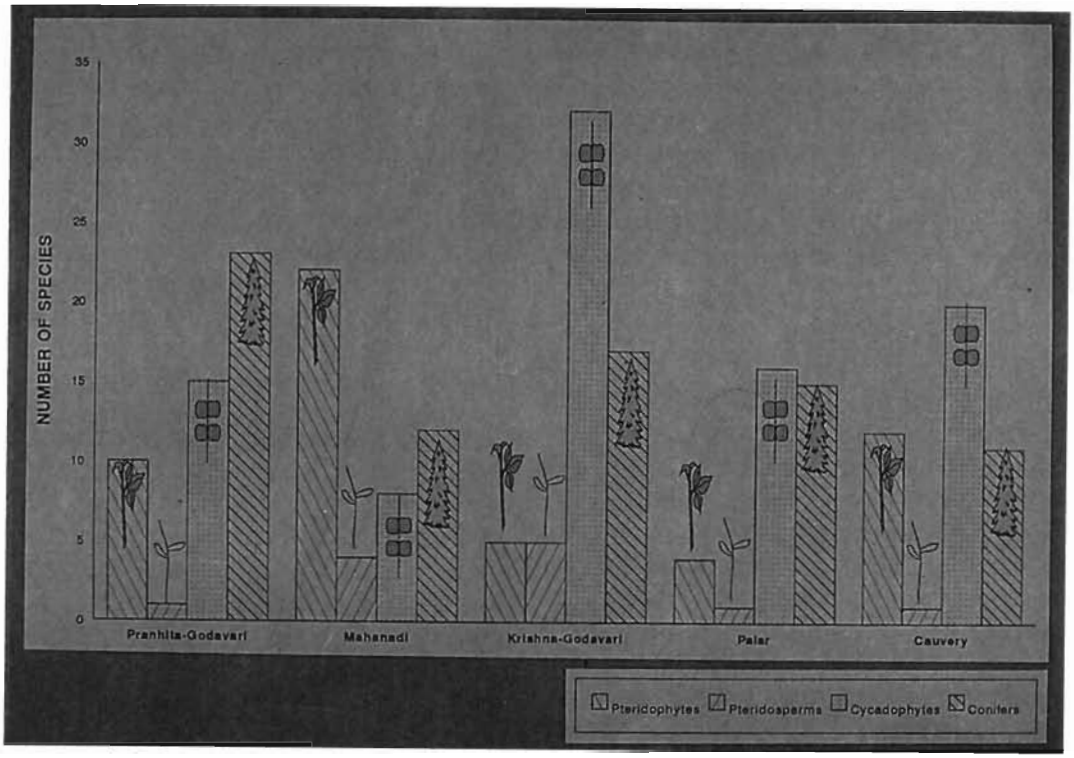


Text-figure 2—Distribution of plant groups in East-Coast basins (palynoflora).

data indicate a pteridophyte dominant flora, supported by palynological evidences. Megaflora consists of pteridophytes with 15 genera and 22 species, pteridosperms with 3 genera and 4 species, cycadophytes with five genera and 8 species and conifers with 6 genera and 12 species. The flora in general is characterised by *Phlebopteris, Marattiopsis, Gleichenia, Eboracia, Cycadopteris, Onychiopsis, Hausmania, Anomozamites, Ptilophyllum, Brachyphyllum* and *Araucarites* (Venkatachala & Rajanikanth, 1987). Megaplant fossils are primarily leaf impressions with some stem impressions. No compactions and petrifactions are recorded. The paucity of cycadophytes and conifers and abundance of pteridophytes indicate preservation of basinal flora particularly plants growing near water bodies. Meagre representation of upland flora probably indicates taphonomical factors like transport and diagenesis. Poor duripartic preservation and non-abundance of palynofossils may indicate decay in aerobic conditions. Palynoflora is represented by *Lametatriletes, Boseisporites, Monoletes, Impardecispora* and *Podosporites* (Singh & Venkatachala, 1987) indicating an Early Cretaceous age, which also derives support from megafossil evidences (Sukh-Dev, 1987; Patra & Sahu, 1994).

KRISHNA-GODAVARI BASIN

The Krishna-Godavari Basin characterised by several depressions bear Early Cretaceous *Ptilophyllum* bearing sediments exposed towards western and north-western fringes of the basin. The deposition was a result of ocean floor spreading and nearshore, paralic sediments intermingled with fluvial deposits (Datta *et al.*, 1983). Plant Mega fossils are known from different lithounits—Gollapalli, Raghavapuram, Tirupathi, Budavada, Vemavaram and Pavalur. It was suggested that these represent lithofacial variants of a major argillaceous sequence (Venkatachala & Sinha, 1986). The lithology of these sediments primarily consists of micaceous sandstones with conglomerate bands, grey china clays, brittle shales with thin bands of ferruginous sandstones, fossilliferous yellowish brown shales, siltstones and hard compact haematitic jasperoid sandstones. Plant fossils are preserved in the sandstones, clays, shales and siltstones. Variety of plant fossils are obtained from the micaceous sandstones with poor preservation. High energy currents probably brought all the plant parts which got preserved in sandstones but their organic content was easily decayed and only impressions could be seen. Though morphologically the leaf fossils got well preserved in clays/shales but were mostly oxidised. The mudstone/siltstone facies showed poor preservation of plant fossils.



Text-figure 3—Distribution of plant groups in East-Coast basins (megaflora).

Palaeobotany of Gollapalli, Raghavapuram and Vemavaram units is relatively well known (Venkatachala & Rajanikanth, 1987). The Early Cretaceous flora of the basin comprises pteridophytes — 3 genera and 5 species, pteridosperms — 2 genera and 5 species, cycadophytes — 11 genera and 32 species and conifers—7 genera and 17 species. Plant megafossils are preserved mainly in the form of impressions (leaves), stem impressions, petrified woods and reproductive structures (Text-figure 3). Of them, cycadophytes represented by *Pterophyllum, Ptilophyllum, Dictyozamites, Otozamites, Williamsonia, Elatocladus, Pagiophyllum, Araucarites* and *Conites* are dominant. Poor representation of pteridophytes and variable representation of cycadophytes and conifers in different lithounits is attributable to taphonomic reasons. Plant assemblages of Golapalli, Raghavapuram, Budavada and Vemavaram units are treated under *Allocladus-Brachyphyllum-Pagiophyllum* assemblage zone and that of Pavalur and Tirupati units under *Weichselia-Onychiopsis-Gleichenia* Assemblage zone (Sukh-Dev, 1987). The occurrence of *Ginkgoites, G. crassipes, G. feistmantelli, Cupressinoxylon alternans, Torreyites constricta, Williamsonia blandfordii, W. gigas, W. kakadbhitensis* indicates diverse representation of Ginkgoales, Cupressales, Taxales and Cycadeoidales and their occurrence can be reasoned as a chance preservation and existence of variable ecological niches (Baksi, 1967; Pandya & Sukh-Dev, 1989). Palynology of Krishna-Godavari Basin is mainly known from the subsurface sequences met in shallow wells. The important taxa include *Microcachryidites, Aequitriradites, Crybelosporites, Cooksonites, Impardecispora, Cicatricosisporites* and *Appendicisporites.* The palynological assemblage was comparable with other assemblages known from the Cauvery Basin and Australia. Palynofossils of Krishna-Godavari Basin consist of two species of bryophytes, 65 species of pteridophytes and 25 species of gymnosperms. These evidences helped to designate a marine swamp mainly consisting of members of Osmundaceae, Schizaeaceae, Cyatheaceae, Lycopodiaceae and Gleicheniaceae. Saccate gymnospermous pollen indicate an allochthonous component and members of Cheirolepidaceae (*Classopollis*) indicate brackish marine environment (Venkatachala & Sinha, 1986). Presence of phytoplankton, foraminifera—*Ammobacu-lites, Ammodiscoides, Haplophragmoides* (Venkata-chala, 1977; Sastry *et al.*, 1963, 1974, 1981; Bhalla, 1969, 1979; Baksi, 1966), marine invertebrates -

Holocoleras, Trigonia, Pseudomonotis, Limia. Belemnite (Sastry *et al.*, 1977) suggests marine influence. An analogy between fauna (Sastry *et al.*, 1981), and dinocyst assemblage (Kumar, 1986) from different shallow wells in Krishna-Godavari Basin with Australian assemblage was suggested (Kumar, 1986).

PALAR BASIN

The Early Cretaceous sediments of Palar Basin are recognised under two lithounits—Sriperumbudur and Satyavedu. The former with splintery grey greenish shales, dark grey gypsum clays, interbedded with sandstone is palaeobotanically well known. The latter with coarse boulder beds and conglomerates interbedded with sandstone is little known. In the entire basin outcrops of sedimentary sequence are poor and mostly seen in the northwestern fringes of basin (Sastry *et al.*, 1974). Plant megafossils are mainly represented by leaf-impressions and rarely petrified woods and reproductive parts. Leaf fossils are found mostly in the splintery grey and greenish shales. Megaflora consists of pteridophytes (4 species and 2 genera), pteridosperms (1 species), cycadophytes (16 species and 6 genera) and Coniferales (15 species and 7 genera). Rarity of pteridophytes and dominance of gymnosperms indicates an allochthonous deposition. Variable distribution of these fossils is due to incompleteness of knowledge and oxidisation of most leaf fossils. Megaflora is represented by *Ptilophyllum, Anomozamites, Pterophyllum, Dictyozamites, Otozamites, Elatocladus, Pagiophyllum, Brachyphyllum, Araucarites, Conites, Araucarioxylon, Podocarpoxylon* and *Cupressinoxylon* (Shah *et al.*, 1973; Bose *et al.*, 1990; Jeyasingh & Kumarasamy, 1994). Pteridosperms and Ginkgoales are very rare. The palynoflora consists of 103 species of pteridophytes, 26 species of gymnosperms and 8 species of bryophytes. The discrepancy in the relative abundance of plant groups represented by mega- and palynofossils is better explained by differential preservation,while abundance of pteridophytic spores indicates autochthonous swampy deposition. The palynoflora is mainly represented by *Coptospora, Microcachyridites, Crybelo-sporites, Foraminisporis, Aequitriradites, Cooksonites, Impardecispora, Cicatricosisporites, Neorais-trickia* and *Concavisporites* (Ramanujam & Verma, 1977; Singh & Venkatachala, 1987). The pterido-phytic spores are represented by 103 species, gymnosperms by 26 species and bryophytes by 8 species. Agglutinated foraminifera comprising *Bathysiphon, Pelosina, Ammobaculites, Ammodiscus, Lituotuba, Spiroplectammina, Haplophragmoides* indicate brackish water near shore deposition during the Neocomian-Aptian times in the Palar Basin (Murthy & Sastry, 1962).

CAUVERY BASIN

This basin lies in the south eastern part of peninsular India and mostly covered with Holocene deposits. The Early Cretaceous sediments are categorised under Sivaganga and Dalmiapuram lithounits. The latter is palaeobotanically less known. The Sivaganga unit is characterised by continental, coarse, pebbly and gritty sandstones. The subsurface comprises paralic shales and argillaceous shales (Sastry *et al.*, 1974). Megaplant remains are preserved as impressions (Sukh-Dev & Rajanikanth, 1988; Achyuthan *et al.*, 1994), except a report of cuticular material of *Thinnfeldia* (Maheshwari, 1986). Variations in pH level, mineral supply, reducing anaerobic microenvironmental conditions releasing iron and iron oxide influenced nature of preservation and different colouration of leaf-impressions (Achyuthan *et al.*, 1994). The megaflora is represented by 7 genera and 12 species of pteridophytes, one species of pteridosperm, 8 genera and 20 species of cycadophytes and 6 genera and 11 species of conifers. The important taxa include *Ptilophyllum, Taeniopteris, Anomozamites, Cladophlebis, Sphenopteris, Thinnfeldia, Pterophyllum, Dictyozamites, Otozamites, Elatocladus, Pagiophyllum, Araucarites* and *Ginkgoites* (Sukh-Dev & Rajanikanth, 1988; Maheshwari, 1986). The palynoflora on the otherhand known from mostly subsurface sediments show Early Cretaceous marker genera—*Microcachryidites, Klukisporites, Aequitrirdites, Staplinisporites, Crybelosporites, Impardecispora, Cooksonites, Neoraistrickia, Ischyosporites* and *Contignisporites* (Venkatachala & Rajanikanth, 1987; Singh & Venkatachala, 1987). Palynoflora is represented by 73 species of pteridophytes, 16 species of gymnosperms and four species of bryophytes (Text-figure 2).

Subsurface sequences met within the Karaikudi Well, Sivaganga area confirm marine influence during the Early Cretaceous (Venkatachala, 1977).

The palynological assemblage is comparable with *Microcachryidites* assemblage described by Balme (1964) from Australia (Sastry *et al.*, 1981). Besides the reports of ammonites and foraminifera from the Sivaganga lithounit indicate marine influence during Early Cretaceous (Neocomian-Aptian times) (Mamgain *et al.*, 1973; Venkatachala, 1977; Banerji, 1982).

DISCUSSION

The present conspectus aids to understand evolution and diversification of Early Cretaceous East Coast flora of India. The overall similarities of fossil floras of different basins of East Coast delimit floristic differentiation. Incompleteness of taxonomic records, long ranging nature of megafossils constraints their precise stratigraphic correlation. Though biostratigraphic zonations were attempted (Shah *et al.*, 1971; Borkar, 1986; Sukh-Dev, 1987), uniformly correlatable sequences are wanting. The mixed gymnosperm and fern dominant flora with quantitative and qualitative differences of mega- and micro-floral components was a result of variable influence of taphonomy, transportation and diagenesis. Conflicting age assignments on the basis of megapalynofloras and fauna, lessened the utility of this data for global interpretation. Recent researches have strongly supported an Early Cretaceous age to *Ptilophyllum* bearing East Coast sediments (Venkatachala & Rajanikanth, 1987; Sukh-Dev, 1987), thus solved the long standing stratigraphic dispute.

The East Coast flora is a typical leaf assemblage with regional variations. In all, about 45 megafossil genera with 135 species and 94 palynofossil genera with 240 species have been recorded.

The Early Cretaceous sediments of Pranhita-Godavari Graben are known for variously preserved fossil leaves, impressions and compactions, stem streaks, reproductive structures, fossil woods and pollen/spores (Text-figure 3). A conifer dominated vegetation was inferred by the megafloral and palynofloral evidences (Ramanujam *et al.*, 1987; Rajanikanth, 1994). Quantitative and qualitative evidences of mega- and palyno-floras markedly differ. Stupendous production of pollen by conifers and their durapatric preservation reflect quantitatively rich palynoassemblage (Rao *et al.*, 1983). The Early Cretaceous tectonism in the East Coast area reinitiated sedimentation. The sediments in which plant fossils are preserved are mostly mudstones and silty mudstones of a fluviatile regime (Kutty *et al.*, 1981). The clays in which plant fossils are preserved consist of trace element concentration of Cu, Cr, Ni, Ba, Zn, B, Rb, Li, Ga, V and Gallium, Boron which fall in fresh water zone (Yadagiri & Rao, 1987). The environment of deposition was congenial for plant fossil preservation as there were no extrinsic forces like marine incursions which did not drastically effect the pH, temperature and nutrient status of waters in which sediments accumulated. Generalization of floral assemblages on the basis of relative abundance of plant fossils, as rare occurrence of *Ptilophyllum* in the Pranhita Godavari Graben (Gangapur sediments) (Bose *et al.*, 1990) may not be correct as differential sorting channelised the *Elatocladus* dominant beds and *Ptilophyllum* dominant beds.

The sedimentation in the pericratonic basins was a result of rifting of plates from the Antarctica /Australia and gradual opening up of East Coast of India from the southern most to northern most (Cauvery to Bengal Basin) parts in a zip like fashion. The marine influence in these East Coast basins exemplified by dinoflagellates (Garg *et al.*, 1987), marine animal fossils (Sastry *et al.*, 1981) and co-existence of plant mega- and micro-fossils advocate interdigitating of continental and marine facies. In such depositional environments with dynamic tectonic forces at work, the water bodies with fluctuating chemical changes like pH, thermal gradients probably affected plant fossil preservation.

Paucity of compactions and petrifactions indicate variability in sediment load and geochemical and biological agents affecting the preservation of finer details of plant parts. Most of the plant fossils in these basins were transported to much distances as the easterly tilting of peninsula (Subrahmanya, 1994) contributed to commencement of sedimentation along the East Coast. If the beginning of opening of the East Coast started from the extreme south then the plant fossils of the Sivaganga Unit, Cauvery Basin represent older aspect (Lower Neocomian) and of Athgarh Unit, Mahanadi Basin represent an Aptian affinity. The Early Cretaceous sediments of Cauvery Basin encompass a cycadophyte/conifer dominant vegetation and in the Mahanadi a pteridophyte dominant assemblage. It may be argued that most of the cycadeoidales represented by *Ptilophyllum, Otozamites, Dictyozamites, Anomozamites* and associates started declining as evidenced by their poor

representation in Athgarh assemblage. This group gradually got extinct due to arrival of more adoptable angiosperms. Most of the ferns with rich diversity in Mahanadi Basin indicate a floristic transition. Araucarians constitute the important constituents followed by podocarps in the upland areas.

The poor representation of pteridosperms, Pentoxylales and Ginkgoales in all the East Coast floral assemblages probably reflects their confinement to selective niches. Preferential preservation of small leaves (conifers and Bennettitales) is attributable to hydrodynamic and taphonomic factors (Spicer, 1991). Fern spores were abundant and diverse in the coastal regions. These homogeneous floral associations with regional variations indicate a climatic uniformity on the continents. Depositional processes were affected by sea level changes and tectonic disturbances (Haq *et al.*, 1987; Acharyya & Lahiri, 1991).

Though iterative evolutionary changes cannot be highlighted in the East Coast assemblages, the predominance of entire margin leaves represented by cycadophytes, conifers and some ferns indicates a favourable environment for luxurious growth. The cuticular analyses indicate thick cuticle of *Thinnfeldia* (Maheshwari, 1986) with several species of fungi infected on it. This probably indicates decaying of most of the organic parts by biological means. As the sediments accumulated in a paralic setup the water fauna probably fed on these organic remains. The cuticles recovered from the intracratonic Gangapur unit, comprising *Pachypteris, Dictyozamites, Ptilophyllum, Pagiophyllum* and *Brachyphyllum* with little or no fungal infected cuticles explain slow decaying process and low biological activity. Most of these forms resemble plant fossils of Satpura Basin. This probably indicates favourable habitat niche differentiation (Whittakar, 1971). The mixed gymnosperms with mostly perennial trees occupied continental intracratonic zones. The report of conifer winged seeds from the Palar Basin (Jeyasingh & Kumarasamy, 1994) is significant.

Nature of forms like *Brachyphyllum* and *Bennettitales* probably does not allow proper grazing of these plants by terrestrial animals which allowed their representation in fossil records (Coe *et al.*, 1987) which was also a case in most of the Indian records. It is suggested that high ^{13}C values in some Cheirolepidiaceae indicate dry conditions and water stress (Bucherens *et al.*, 1994). Forms like *Brachyphyllum* and *Classopollis* are known from the coastal basins of India. Occurrence of *Pachypteris* alongwith dinoflagellates (Vankonijnenburg-van Cittert, 1971) in Yorkshire indicates marginal marine habit whereas in Europe, Russia and India it occurs mostly in littoral deposits (Bose & Roy, 1968; Sukh-Dev & Rajanikanth, 1987; Vakhrameeve, 1991).

Comparison of *Ptilophyllum* flora of India with Yorkshire flora and Hope Bay plants by earlier workers was attributed to close floral similarities. Revised Hope Bay Flora was suggested to be of Early Cretaceous age affinity (Gee, 1987). Regionalism in pre-angiosperm floras of southern Gondwana was also suggested to be influenced by climatic, topographic and edaphic factors (Dettmann, 1992). Most of the pre-angiosperm flora of Antarctica and Australia belong to Early Cretaceous age affinity (Drinnam & Crane, 1990; Hill, 1994). It may be thus concluded that the East Coast flora was a typical Early Cretaceous flora preserved in coastal basins under extrinsic and intrinsic forces in dynamic ecological regime.

REFERENCES

Acharyya SK & Lahiri TC 1991. Cretaceous palaeogeography of the Indian subcontinent : a review. *Cretaceous Res.* **12** : 3-26.

Achyuthan H, Nagendra R & Mohandas C 1994. Heteropigmentation of plant impressions, Karai, Ariyalur, Tamil Nadu. *Curr. Sci.* **67**(8) : 606-608.

Axelrod DI 1974. Revolutions in the plant world. *Geophytology* **4**(1) : 1-6.

Baksi SK 1966. On the Foraminifera from Raghavapuram mudstone, West Godavari District, Andhra Pradesh, India. *Bull. geol. Min metall. Soc. India* **37** : 1-19.

Baksi SK 1967. Fossil plants from Raghavapuram mudstone west Godavari District, Andhra Pradesh. *Palaeobotanist* **16** : 106-216.

Balme BE 1964. The palynological record of Australian Pre-Tertiary floras. *In*: Cranwell LM (Editor)—*Ancient Pacific Floras : The pollen story* : 49-80. Univ. Hawaii Press, Honolulu.

Banerji RK 1982. Sivaganga Formation its sedimentology, micropalaeontology and sedimentation history. *J. geol. Soc. India* **23** : 450-456.

Bhalla SN 1969. Foraminifera from type Raghavapuram shales (Early Cretaceous), East Coast Gondwana, India. *Bull. geol. Soc. India* **2** : 39-43.

Biswas SK, Bhasin AL & Ram J 1993. Classification of Indian sedimentary basins in the framework of plate tectonics. *In* : Biswas SK *et al.* (Editors)—*Proc. II Sem Petroliferous Basins of India,* **1** : 1-46. Dehradun.

Borkar VD 1986. An attempt to identify a possible succession within megaflora of Wealden Rock formations of Indian Peninsula. *Gondwana Geol. Mag.* **1**(1) : 51-56.

Bose MN & Roy SK 1968. On the occurrence of *Pachypteris* in the Jabalpur Series of India. *Palaeobotanist* **16**(1) : 1-9.

Bose MN, Taylor EL & Taylor TN 1990. Gondwana floras of India and Antarctica : A survey and appraisal. *In* : Taylor TN & Taylor EL (Editors)—*Antarctic Palaeobiology, its role in the reconstruction of Gondwana* : 118-148.

Chandra S & Tewari R 1991. *A catalogue of fossil plants from India, Part-2. Palaeozoic and Mesozoic megafossils.* Birbal Sahni Institute of Palaeobotany, Lucknow.

Coe MJ, Dilcher DL, Farlow Jo Jarzen DM & Russel DA 1987. Dinosaurs and land plants. *In* : Fries EM, Chaloner WG & Crane PR (Editors)—*The origin of angiosperms and their biological consequences* : 225-258. Cambridge Univ. Press.

Datta NR, Mitra ND & Bandyopadhyay SK 1983. Recent trends in the study of Gondwana basins of peninsula and extra-peninsular India. *Petroleum Asia* : 159-169.

Dettmann ME 1992. Structure and floristics of Cretaceous vegetation of southern Gondwana : implications for angiosperm biogeography. *Palaeobotanist* **41** : 224-233.

Drinnan AN & Crane PR 1990. Cretaceous palaeobotany and its bearing on the biogeography of Austral angiosperms. *In* : Taylor TN & Taylor EL (Editors)—*Antarctic palaeobiology, its role in the reconstruction of Gondwana* : 193-218. Springer-Verlag, New York.

Gee CT 1987. Revision of the Early Cretaceous flora from Hope Bay, Antarctica. *XIV Int. Bot. Congress, Berlin, West Germany* (Abst.) : 333.

Garg R, Ateequzzaman K & Jain KP 1987. Jurassic and Lower Cretaceous dinoflagellate cysts from India with some remarks on the concept of Upper Gondwana. *Palaeobotanist* **36** : 254-267.

Haq BU, Hardenbol J & Vail PR 1987. Chronology of fluctuating sea levels since Triassic. *Science* **235** : 1156-1167.

Hill RS (Editor) 1994. *History of the Australian vegetation : Cretaceous to Recent.* Cambridge Univ. Press.

Jeyasingh DEP & Kumarasamy D 1994. Occurrence of *Pityospermum* Nathorst in the Sriperumbudur Formation, Tamil Nadu. *Curr. Sci.* **67**(5) : 305-306.

Knoll AH 1986. Patterns of change in plant communities through geological time. *In* : Diamond J & Case TJ (Editors)—*Community ecology* : 126-145. Harper & Row, New York.

Knoll AH & Niklas KJ 1987. Adaptation, plant evolution and the fossil record. *Rev. Palaeobot. Palynol.* **50** : 127-149.

Kumar A 1986. A sequence of dinocysts from the subsurface sediments (Velangian-Hauterivian) of the Krishna-Godavari Basin, India. *J. palaeont. Soc. India* **31** : 26-38.

Kutty TS, Jain SL & Roychowdhuri TR 1987. Gondwana sequence of the northern Pranhita-Godavari Valley—its stratigraphy and vertebrate faunas. *Palaeobotanist* **36** : 214-229.

Lakhanpal RN, Maheshwari HK & Awasthi N 1976. *A catalogue of fossil plants 1821-1970.* Birbal Sahni Institute of Palaeobotany, Lucknow.

Maheshwari HK 1986. *Thinnfeldia indica* Feistmantel and associated plant fossils from the Tiruchirapalli District, Tamil Nadu. *Palaeobotanist* **35**(1) : 13-21.

Mamgain VD, Sastry MVA & Subbaraman JV 1973. Report of ammonites from Gondwana plant beds at Terani, Tiruchirapalli District, Tamil-Nadu. *J. geol. Soc. India* **14** : 198-200.

Manik SR & Srivastava SC 1991. Conifer woods from new sites of Gangapur Formation, India. *Acta Biol. Szeged* **37** : 45-55.

Murthy NGK & Sastry VV 1962. Foraminifera from Sriperumbudur bed near Madras, India. *Rec. geol. Surv. India* **89**(2) : 446-456.

Pandya N & Sukh-Dev 1989. Fossil flora of Gollapalle Formation. *Palaeobotanist* **38** : 147-154.

Patra BP & Sahoo NK 1994. Megafloral assemblage of the Athgarh Sandstone and its comparison with the other East Coast Upper Gondwana floras of India. *9th Int. Gondwana Symposium, Hyderabad* (Abst.) : 34-35.

Rajanikanth A & Prakash N 1994. *Indian Gondwana: Annotated synopses Vol. II, IV. Mesozoic Megaplants.* Birbal Sahni Institute of Palaeobotany, Lucknow. 1-68.

Rajanikanth A (in press). Palaeobotany and stratigraphic implication of Mesozoic 'Gondwana' sediments of Pranhita Godavari Graben. *Proc. 9th International Gondwana Symposium, Hyderabad.*

Ramanujam CGK, Muralidhar Rao G & Ramakrishna H 1987. Floristic and stratigraphic significance of the megafloral assemblage of Gangapur Formation in Andhra Pradesh. *Gondwana Geol. Mg.* **2** : 1-5.

Ramanujam CGK 1983. Floristics and palaeoecological significance of the Lower Cretaceous microfloras of southern India. *Proc. Symp. Cretaceous of India, palaeoecology, palaeogeography and time boundaries.* Indian Association of Palynostratigraphers, Lucknow.

Rao PVR, Ramanujam CGK & Varma YNR 1983. Palynology of the Gangapur beds, Pranhita-Godavari Basin, Andhra Pradesh. *Geophytology* **13**(1) : 22-45.

Sastry VV, Venkatachala BS & Narayanan V 1981. The evolution of the East Coast of India *Palaeogeography, Palaeoclimatology, Palaeoecology* **36** : 23-54.

Sastry VV, Chandra A & Pant SC 1963. Foraminifera from the Raghavapuram shales near Tirupati, Andhra Pradesh, India. *Rec. geol. Surv. India* **92** : 311-314.

Sastry VV, Raju ATR, Singh RN & Venkatachala BS 1974. Evolution of the Mesozoic sedimentary basins on the East Coast of India. *Jour. APEA* : 29-41.

Shah SC, Singh G & Gururaja MN 1973. Observations on the post- Triassic Gondwana Sequence of India. *Palaeobotanist* **20**(2) : 221-237.

Singh HP & Venkatachala BS 1987. Upper Jurassic-Lower Cretaceous spore pollen assemblages in peninsular India. *Palaeobotanist* **36** : 168-176.

Spicer R 1991. Plant taphonomic processes. *In* : Allison PA & Briggs (Editors)—*Taphonomy releasing the data locked in the fossil record, Vol. 9. of Topics in Palaeobotany* : 74-111. Plenum Press, New York.

Srivastava SK 1983. Cretaceous phytogeoprovinces and palaeogeography of the Indian plate based on palynological data. *Proc. Symp. Cretaceous of India, palaeoecology, palaeogeography and time boundaries* : 141-157. Indian Association of Palynostratigraphers, Lucknow.

Srivastava Suresh C 1991. *A catalogue of fossil plants from India Part 3A. Palaeozoic and Mesozoic spores and pollen.* Birbal Sahni Institute of Palaeobotany, Lucknow.

Subramanya KR 1994. Post Gondwana tectonics of the Indian Peninsula. *Curr. Sci.* **67**(7) : 527-530.

Sukh-Dev 1987. Floristic zones in the Mesozoic formations and their relative age. *Palaeobotanist* **36** : 161-167.

Sukh-Dev & Rajanikanth A 1988a. The Gangapur Formation—Fossil flora and stratigraphy. *Geophytology* **18**(1) : 1-27.

Sukh-Dev & Rajanikanth A 1988b. The Sivaganga Formation—Fossil flora and stratigraphy. *Geophytology* **18**(2) : 186-205.

Vakhramey VA 1991. *In:* Hughes NF (Editor)—*Jurassic and Cretaceous floras and climates of the earth.* Cambridge University Press, Cambridge.

Vankonijnenburg-van-Cittert JHA 1971. *In situ* gymnosperm pollen from the Middle Jurassic of Yorkshire. *Acta. Bot. Burl.* **20** : 1-96.

Venkatachala *BS* 1977. Fossil floral assemblages in the East Coast Gondwanasa critical review. *J. geol. Soc. India* **18** : 378-397.

Venkatachala BS & Rajanikanth A 1987. Stratigraphic implication of Late Gondwana floras in the East Coast. *Palaeobotanist* **36** : 183-196.

Venkatachala BS & Rajanikanth A (in Press). Geological significance of the Ptilophyllum flora in India—a critical reassessment. *ONGC Bulletin.*

Venkatachala BS & Sinha RN 1986. Stratigraphy, age and palaeoecology of Upper Gondwana equivalents of the Krishna Godavari Basin, India. *Palaeobotanist* **35** : 22-31.

Whittakar RH 1977. Evolution of species diversity in land communities. *Evol. Biol.* **10** : 1-67.

Yadagiri P & Rao BRJ 1987. Contribution to the stratigraphy and vertebrate fauna of Lower Jurassic Kota Formation, Pranhita Godavari Valley, India. *Palaeobotanist* **36** : 230-244.