Tertiary floristic complexes of southern India — A critical appraisal*

C.G.K. Ramanujam

Department of Botany , Post Graduate College of Science, Saifabad, Hyderabad 500 004

I wish to express my deep appreciation to the Executive Council of the Palaeobotanical Society for the honour they have done by inviting me to deliver this maiden **Golden Jubilee Lecture**.

I have been associated with the Palaeobotanical Society over the last four decades. Starting humbly during mid-Nineteen Fortys in the none too hospitable atmosphere of the then plant science fraternity, the Society made rapid strides and now constitutes one of the brilliant stars in the botanical firmament of this subcontinent. The various activities and programmes envisaged by the Society during this Golden Jubilee Year are a befitting testimony to its healthy and robust growth and development. In connection with man's life span, it is said that Fortys represent the old age of the youth and Fiftys, the youth of the old age. Applying this yard stick to our Society we may say that it has now entered its youth.

The last three decades have witnessed the blossoming of studies on Tertiary plant fossils of southern India resulting in an extensive and significant data that merit a critical analysis for a meaningful comprehension of the floristic complexes. These studies encompass both mega- and microfossils i.e., involve both palaeobotanical and palynological aspects. The Tertiary plant fossils are of varied nature represented as they are mostly by silicified and carbonized woods, mummified foliage and twigs and a host of spore and pollen types of bewildering diversity. These categories individually and collectively have their own story to tell and information to convey, which may be useful to Palaeobotanists of myriad backdrop.

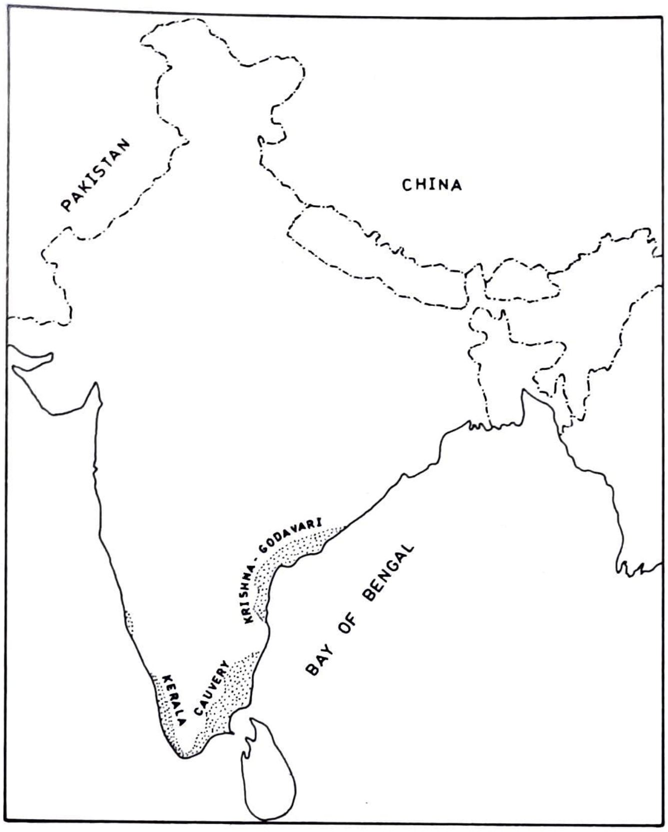
I personally consider that both mega- and microfossil studies are complementary and not antagonistic. There is however, a tendency among the researchers to deal exclusively either with mega- or microfossils, which more often than not results in a lop-sided, dwarfed and dubious caricature of the total floristic scenarios. The situation can be ameliorated if a healthy co-operation, understanding and comradiere exists among experts of varied training and background. A holistic approach is the need of the hour.

The botanical data obtained from studies of both mega- and microfossils furnish a wholesome picture of the floral composition and vegetational patterns. It is towards the consummation of this goal that prospective studies are to be zeroed upon, designed and executed. A reasonably good number of Tertiary palynomorphs (especially from Neogene) can be affiliated with the modern taxa. This information would then facilitate application of Tertiary Palynology in broad spectral floristic and environmental considerations in addition to its accredited potential in resolving stratigraphic problems.

Over the last so many years in the context of the Tertiary floristics of southern India, some people have said many things and many have said some thing, but perhaps none have said enough because the more we know the more conscious we become of the inadequacy and incompleteness of our knowledge.

In view of the obvious temporal constraints, only the nodal points and highlights of the floral composition and vegetational complexes are presented based upon both palaeobotanical and palynological data in the Krishna-Godavari (KG), Cauvery and Kerala basins (Text-fig. 1) and their relevance to our understanding of some palaeoclimatic and phytogeographic considerations.

* Golden Jubilee Lecture delivered during the Golden Jubilee Year inaugural function of The Palaeobotanical Society, Lucknow on 3rd June 1995.



Text-fig. 1. Map showing Krishna-Godavari, Cauvery and Kerala basins.

GENERAL COMMENTS ON THE THREE BASINS

Krishna-Godavari basin: The Krishna-Godavari basin occupies much of the coastal area of Andhra Pradesh and extends into the coastal waters of Bay of Bengal. It is spread over West and East Godavari, Krishna and Guntur districts. The basin consists of 3 sub-basins separated by two major ridges, such as : *Krishna sub-basin, Bapatla ridge, West Godavari sub-basin, Bhimavaram-Tanuku ridge and East Godavari sub-basin*.

A number of wells both offshore and onshore have been drilled in the basin and their Tertiary palynomorphs (ranging from Palaeocene to Mio-Pliocene) were studied for floristic considerations.

Cauvery basin: The sedimentary regime extending from Pondicherry in the north to south of Rameshwaram in Tamil Nadu is considered as the Cauvery basin. The basin shows a number of sub-basins such as South Arcot, Tanjore, Tanjore delta and Ramnad sub-basins. Palaeocene to Miocene-Pliocene strata have been recognized in these sub-basins either as outcrops or subcrops and these yielded rich palyno-and megafloral assemblages. The basin is made up mostly by Cretaceous sediments in the western part and Tertiary sediments in the eastern part.

Kerala basin: The Tertiary strata in this basin extend all along the Kerala coast in a north-south linear alignment. Because of extensive lateritic and alluvial cover, in conjunction with the presence of several estuarine and lagoonal water bodies, the Tertiary strata are very much obscured and hence encountered only as discontinuous discrete patches in the southern and northern parts of Kerala coastal belt. The Kerala Tertiaries include the essentially marine Quilon Formation (Quilon beds) overlain by the continental Warkalli Formation (Warkalli beds).

Raha *et al.* (1983) in a recent classification of the Cenozoic sediments of Kerala have included all the Tertiary strata under a single category viz., Warkalli Group, comprising Ambalapuzha, Quilon and Mayyanad Formations from top to bottom. The Ambalapuzha and Mayyanad Formations are basin margin fluviatile and deltaic facies and the Quilon Formation consists of calcareous platform facies. Both palynofloral and megafloral assemblages are known from the Kerala Tertiaries.

In general the information available on the Neogene (Mio-Pliocene) floras of southern India is more varied, diverse and extensive when compared to that of the Palaeogene. Knowledge of Neogene floras in the Cauvery and Kerala basins is based upon studies involving megafossils and microfossils; that of Krishna-Godavari basin barring a few records of palm and dicot leaf impressions (Ramanujam & Rao 1967; Mahabale & Rao 1968, 1973) is provided almost entirely by palynomorphs. Knowledge of Palaeogene floras, however, is based upon essentially palynological studies in all the three basins. Almost all the information on the Tertiary plant fossils of southern India has been generated at three centres of research activity i.e., ONGC, Birbal Sahni Institute of Palaeobotany and Osmania University. It is this information that furnished the source material for today's lecture.

I must make it explicit at the very outset that only such fossils, either mega- or micro- for which the botanical affinities could be reliably deciphered (either a genus or family) have been considered for the present theme.

FLORISTIC COMPLEXES

The Tertiary floras of southern India consist almost entirely of Pteridophytes and Angiosperms. The Angiosperms are the predominant elements of the floral composition.

The Pteridophytes constitute 15-20% in all the basins. Sporomorphs that are unequivocally referable to Lycopodiaceae, Gleicheniaceae, Osmundaceae, Ophioglossaceae, Hymenophyllaceae, Schizaeaceae, Pteridaceae, Cyatheaceae/Dicksoniaceae, Parkeriaceae and Polypodiaceae are known from the Tertiaries of southern India: At the generic level the fossil spore types can be clearly affiliated with *Lycopodium, Gleichenia, Osmunda, Ophioglossum, Hymenophyllum, Lygodium, Schizaea, Pteris, Ceratopteris* and *Polypodium*. Both qualitatively and quantitatively the Pteridophytes enjoyed better representation during Neogene (Miocene) than in Palaeogene. Table 1 shows the Pteridophytes recorded in various basins in Palaeogene and Neogene strata. Schizaeaceae and Polypodiaceae constitute the predominant Pteridophytes in the Tertiary floras of southern India.

The Gymnosperms were either extremely sporadic or totally lacking. From the intertraps of Rajahmundry area in KG basin, *Taxaceoxylon* and *Mesembrioxylon* woods were recorded by Mahabale and Rao (1973). The notable exception, however, is a small patch around Tiruvakkarai not far from Pondicherry in Cauvery basin with numerous silicified trunks of *Podocarpoxylon* (= *Mesembrioxylon*), virtually a pure strand of *Podocarpus* trees, preserved in the Cuddalore Sandstones. Whether these *Podocarpus* trunks were indigenous to the locality or drifted/transported by streams from nearby hill ranges, is a moot point. Meher-Homji's contention that *Podocarpus* perhaps represented a local gregarious edaphic facies (around Tiruvakkarai) similar to the present day *Taxodium distichum* (Bald Cypress) swamps in the eastern and southernUSA, merits serious consideration (Meher-Homji, 1978, 1980). From the Neyveli lignite deposit the only record of gymnospermous pollen grains consists of some bisaccate grains described as *Podocarpidites* sp. by Jeyasingh *et al.* (1989). Only a single record of very few bisaccate pollen is known from the Tertiary beds of Kerala basin(Kar & Jain, 1981).

29 families of Angiosperms could be recognized in the KG basin. Of these, 3 represent monocots and 26, dicots. Arecaceae is the best represented family among monocots. Some of the fossil pollen of Arecaceae show remarkable similarities with the pollen of such extant palms as *Eugeissona, Nypa, Cocos, Calamus* and

Table 1 : Pteridophytes from the Tertiaries of southern India

Family	Fossil spore & related modern genus	Palaeogene	Neogene	Basin
LYCOPODIACEAE	*Lycopodiumsporites (Lycopodium)*	+	+	C,K
	Verrucosisporites (Lycopodium)	+	–	K
	Camarozonosporites (Lycopodium)	–	+	C
GLEICHENIACEAE	*Gleicheniidites (Gleichenia)*	+	+	C,K
OSMUNDACEAE	*Osmundacidites (Osmunda)*	–	+	C,K
	Todisporites	–	+	C,K
OPHIOGLOSSACEAE	*Foveosporites (Ophioglossum)*	–	+	KG,K
SCHIZAEACEAE	*Lygodiumsporites (Lygodium)*	–	+	KG,C,K
	Crassoretitriletes (Lygodium)	+	+	KG,C,K
	Neyvelisporites (Schizaea)	+	+	KG,C,K
	Schizaeoisporites (Schizaea)	+	+	KG,C,K
	Intrabaculisporis	–	+	K
HYMENOPHYLLACEAE	*Hymenophyllumsporites (Hymenophyllum)*	–	+	C
PTERIDACEAE	*Pteridacidites (Pteris)*	–	+	KG,C,K
CYATHEACEAE/ DICKSONIACEAE	*Cyathidites*	–	+	KG,C,K
POLYPODIACEAE	*Polypodiaceoisporites*	–	+	K
	Laevigatosporites	+	+	KG,C,K
	Seniasporites	+	–	K
	Polypodiisporites (Polypodium)	+	+	KG,C,K
	Verrucatosporites (Polypodium)	+	+	C
PARKERIACEAE	*Striatriletes (Ceratopteris)*	+	+	KG,C,K

+ : Present; – : Absent; KG : Krishna-Godavari basin; C : Cauvery basin; K : Kerala basin.

Data collected from : Ramanujam 1972, 1987; Venkatachala & Rawat 1972, 1973; Venkatachala & Sharma 1984; Rao & Ramanujam 1978; Ramanujam, Ramakrishna & Mallesham 1985, 1989; Ramanujam & Reddy 1984.

Sclerosperma. Among the Dicots, the pollen of Fabaceae, Bombacaceae, Ctenolophonaceae, Combretaceae and Sapotaceae are the more frequently encountered ones. The Palaeogene strata are characterized essentially by Arecaceae, Araliaceae, Fabaceae, Rhizophoraceae, Anacardiaceae, Sapindaceae, Olacaceae, Proteaceae etc. (Venkatachala & Sharma, 1984). The Neogene strata show not only these families continuing but also members of Asteraceae, Barringtoniaceae, Bombacaceae, Malvaceae, Polygonaceae, Sapotaceae, Sonneratiaceae, Symplocaceae, Tiliaceae and Poaceae (Ramanujam *et al.*, 1985, 1989). All such pollen of KG basin with reliably deciphered botanical affinities are shown in Table 2. On the whole 40 genera of Angiosperms with known

Table 2. Angiosperms from the Tertiaries of Krishna-Godavari basin

Family	Fossil pollen & related modern genus
ACANTHACEAE	*Multiarcolites*
ANACARDIACEAE	*Rhoipites*
APIACEAE	*Umbelliferoipollenites*
ARALIACEAE	*Araliaceoipollenites*
ARECACEAE	*Mauritidites* *Proxapertites* *Longapertites* *Quilonipollenites (Eugeissona)* *Spinizonocolpites (Nypa)* *Palmaepollenites (Cocos)* *Dicolpopollis (Calamus)* *Trilatiporites (Sclerosperma)*
ASTERACEAE	*Compositoipollenites*
AVICENNIACEAE	*Retitricolporites sitholeyi (Avicennia)*
BARRINGTONIACEAE	*Marginipollis (Barringtonia)*
BOMBACACEAE	*Bombacacidites*
CHENOPODIACEAE	*Polyporina*
COMBRETACEAE	*Heterocolpites (Lumnitzera)*
CTENOLOPHONACEAE	*Ctenolophonidites (Ctenolophon)*
DROSERACEAE	*Ornatetradites (Drosera)*
EUPHORBIACEAE	*Psilatricolporites operculatus (Alchornia)*
FABACEAE	*Margocolporites (Caesalpinia, Peltophorum)* *Trisyncolpites (Poinciana, Caesalpinia)* *Palaeocaesalpiniaceaepites*
MALVACEAE	*Malvacipollis* *Malvacearumpollis*
OLACACEAE	*Anacolosidites*
PLUMBAGINACEAE	*Plumbaginacipites*
POACEAE	*Monoporopollenites*
POLYGALACEAE	*Polygalacidites (Polygala)*
POLYGONACEAE	*Polygonacidites (Polygonum)*
POTAMOGETONACEAE	*Retipilonapites (Potamogeton)*
RHIZOPHORACEAE	*Zonocostites (Rhizophora)*
RUBIACEAE	*Palaeocoprosmadites (Coprosma)*
SAPINDACEAE	*Cupanieidites (Cupania)*
SAPOTACEAE	*Sapotaceoidaepollenites*
SONNERATIACEAE	*Florschuetzia (Sonneratia)*
SYMPLOCACEAE	*Symplocoipollenites (Symplocos)*
TILIACEAE	*Tiliapollenites, Lacrimapollis (Brownlowia)*

Data collected from : Venkatachala & Sharma 1984; Ramanujam, Ramakrishna & Mallesham 1985, 1989.

botanical affinities (genus or family) have been recognized in this basin.

The Tertiary mega- and microfloras of the Cauvery basin have been studied extensively.Only palynofloras, however, are known from the Palaeogene strata, whereas both megafloras and palynofloras are known in sufficient detail from the Neogene strata. As of today, 57 families of Angiosperms could be recognized reliably of which 5 represent monocots and 52, dicots. Arecaceae is again the best represented family among the monocots both in Palaeogene and Neogene strata. *Cocos, Eugeissona, Nypa, Calamus, Sclerosperma* and *Livistona* are the palms that could be identified in the Arecaceae. The Palaeogene of the Cauvery basin shows the presence of Arecaceae (*Nypa*), Loranthaceae, Barringtoniaceae (*Barringtonia*), Fabaceae (*Caesalpinia - Peltophorum*), Sapotaceae, Caprifoliaceae, Araliaceae (*Aralia*), Sapindaceae (*Cupania*), Olacaceae (*Anacolosa*), Proteaceae, Solanaceae, Rhizophoraceae (*Rhizophora*), Euphorbiaceae (*Alchornia*), Onagraceae and Ericaceae. Almost all these are also found in the Neogene strata. The Neogene flora represented both by mega-and microfossils, however, is much more extensive and diversified. Of the 52 families of the dicots recognized, Anacardiaceae, Barringtoniaceae, Clusiaceae, Combretaceae, Dipterocarpaceae and Fabaceae (Caesalpinoidae and Mimosoidae) are numerically better represented ones. The occurrence of Dipterocarpaceae, Ebenaceae, the dominance and diversity of Fabaceae (Leguminosae), and the appearance of taxa such as *Afzelia, Intsia, Gluta, Swintonia, Eugeissona, Aegialitis, Brownlowia, Polygonum* etc. generally distinguish the Neogene floras from those of the Palaeogene. At the generic level, on the whole 111 genera of Angiosperms which could be reliably referred to a modern genus or family have been recognized in the overall Tertiary floras of the Cauvery basin and a sizeable number of these were arborescent in habit. The details of the floristic elements as evidenced by the record of fossil woods and pollen types are shown in Table 3. In addition to the above, cuticles of leaves of Arecaceae, Lythraceae, and Combretaceae have been described from the Neyveli lignite (Srivastava, 1984; Upadhyay & Verma, 1986; Verma *et al.*, 1989; Mallesham, 1987). More recently Agarwal (1990b) recorded the occurrence of the leaves of Euphorbiaceae (*Excoecaria*) and Rubiacea (*Randia*) from the Neyveli lignite.

Table 3. Angiosperms from the Tertiary strata of Cauvery basin

Family	Fossil wood & related modern genus	Fossil pollen & related modern genus
AGAVACEAE	Carbonized stem (*Dracaena*)	
ALANGIACEAE	*Alangioxylon* (*Alangium*)	*Lonagiopollis* (*Alangium*)
ANACARDIACEAE	*Mangiferoxylon* (*Mangifera*)	*Rhoipites*
	Glutoxylon (*Gluta*)	
	Bouea (*Bouea*)	
APIACEAE		*Umbelliferoipollenites*
ARALIACEAE		*Araliaceoipollenites* (*Aralia*)
ARECACEAE	*Palmoxylon* (*Livistona*)	*Palmaepollenites* (*Cocos*)
		Arecipites
		Quilonipollenites (*Eugeissona*)
		Longaperitites
		Proxapertites
		Dicolpopollis (*Calamus*)
		Trilatiporites (*Sclerosperma*)
AROIDEAE		*Spinainaperturites* (*Typhonia*)
AVICENNIACEAE		*Retitricolporites sitholeyi* (*Avicennia*)
BARRINGTONIACEAE	*Barringtonioxylon* (*Barringtonia*) *Careyoxylon* (*Careya*)	*Marginipollis* (*Barringtonia*)
BOMBACACEAE		*Bombacacidites*
		Lakiapollis (*Cullenia*)
BORAGINACEAE	*Cordioxylon* (*Cordia*)	
BRASSICACEAE		*Cruciferoipollenites*

Family	Fossil wood & related modern genus	Fossil pollen & related modern genus
CAPRIFOLIACEAE		*Cauveripollis*
CARYOPHYLLACEAE		*Polyporina*
CHENOPODIACEAE		*Polyporina globosa*
CLUSIACEAE	*Calophylloxylon (Calophyllum)*	*Pachydermites (Symphonia)*
	Mesuoxylon (Mesua)	*Pentadesmapites (Pentadesma)*
COMBRETACEAE	*Terminalioxylon (Terminalia)* *Anogeissusoxylon (Anogeissus)*	*Heterocolpites (Lumnitzera)*
CTENOLOPHONACEAE		*Ctenolophonidites (Ctenolophon)*
DIPTEOCARPACEAE	*Dipterocarpoxylon (Dipterocarpus)*	*Retitricolpites dipterocarpoides (Dipterocarpus)*
	Dryobalanoxylon (Dryobalanops)	
	Anisopteroxylon (Anisoptera)	
	Shoreoxylon (Shorea)	
	Hopenium (Hopea)	
DROSERACEAE		*Droseridites*
EBENACEAE	*Ebenoxylon (Diospyros-Maba)*	
EUPHORBIACEAE	*Putranjivoxylon (Putranjiva)*	*Crotonoidaepollenites (Jatropha)*
	Bridelioxylon (Bridelia)	*Crotonipollis*
FABACEAE	*Cynometroxylon (Cynometra)*	*Margocolporites (Caesalpinia)*
	Milletioxylon (Milletia)	*Trisyncolpites (Poinciana, Caesalpinia)*
	Pterocarpoxylon (Pterocarpus)	*Palaeocaesalpinaceaepites*
	Pterogynoxylon (Pterogyne)	*Polyadopollenites (Acacia, Albizia)*
	Peltophoroxylon (Peltophorum)	
	Pahudioxylon (Afzelia - Intsia)	
	Tamarindoxylon (Tamarindus)	
	Euacaioxylon (Acacia)	
	Hopeoxylon (Sindora)	
	Pericopsoxylon (Pericopsis)	
	Albazinium (Albizia)	
HALORAGACEAE		*Haloragacidites (Myriophyllum)*
HIPPOCRATEACEAE		*Hippocrateaceaedites*
		Dakshinipollenites
ICACINACEAE		*Icacinoipollenites*
LAMIACEAE		*Polycolpites*
LORANTHACEAE		*Gothanipollis*
		Cranwellia
LAURACEAE	*Litsea (Litsea)*	
LENTIBULARIACEAE		*Neyvelipollenites (Utricularia)*
LYTHRACEAE	*Lagerstroemioxylon (Lagerstroemia)*	*Verrutricolporites rotundiporis (Crenea)*
MALVACEAE		*Malvacearumpollis*
MENISPERMACEAE		*Assamialetes*
MORACEAE		*Triporopollenites (Artocarpus)*
NYMPHAEACEAE		*Monosulcites neyveliense (Nymphaea)*
ONAGRACEAE		*Triorites*

Family	Fossil wood & related modern genus	Fossil pollen & related modern genus
OLACACEAE		*Anacolosidites (Anacolosa)*
OLEACEAE		*Retitricolporites cuddalorense (Ligustrum)*
POACEAE		*Graminidites*
POTAMOGETONACEAE		*Retipilonapites (Potamogeton)*
PLUMBAGINACEAE		*Warkallipollenites (Aegialitis)*
		Plumbaginacipites
POLYGALACEAE	*Xanthophyllum (Xanthophyllum)*	*Polygalacidites (Polygala)*
POLYGONACEAE		*Polygonacidites (Polygonum)*
PROTEACEAE		*Proteacidites (Isopogon)*
ROSACEAE	*Parinarioxylon (Parinari)*	
RUBIACEAE		*Palaeocoprosmadites (Coprosma)*
RHIZOPHORACEAE	*Carallioxylon (Carallia)*	*Żonocostites (Rhizophora)*
SOLANACEAE		*Striatopollis*
SAPOTACEAE	*Chrysophylloxylon (Chrysophyllum)*	*Sapotaceoidaepollenites*
SAPINDACEAE	*Sapindoxylon*	*Talisipites, Cupanieidites (Cupania)*
SIMAROUBACEAE	*Ailanthoxylon (Ailanthus)*	
SONNERATIACEAE	*Sonneratioxylon (Sonneratia)*	*Florschuetzia (Sonneratia)*
	Duabangoxylon (Duabanga)	
STERCULIACEAE	*Sterculinium (Sterculia)*	*Tricollareporites (Pterospermum)*
SYMPLOCACEAE		*Symplocoipollenites (Symplocos)*
THYMELIACEAE		*Thymelaepollis* *Clavaperiporites (Wikstroemia)*
TILIACEAE	*Grewioxylon (Grewia)*	*Intratriporopollenites*
		Lacrimapollis (Brownlowia)
ULMACEAE	*Holoptelioxylon (Holoptelea)*	

Data collected from : Agarwal 1988, 1990a, 1990b, 1991a, 1991b; Ambawani 1982; Lakhanpal & Awasthi 1964; Awasthi 1965, 1967, 1969a, 1969b, 1969c, 1970a, 1970b, 1971, 1974a, 1974b, 1975, 1977a, 1977b, 1979, 1980, 1981, 1984, 1986; Awasthi & Agarwal 1986; Navale 1956, 1959, 1964, 1973; Navale & Misra 1979; Bande & Ambwani 1982; Ramanujam 1953a, 1953b, 1954, 1956a, 1956b, 1956c, 1958, 1960, 1961, 1966a, 1966b, 1966-67, 1968; Ramanujam & Rao 1966, 1969; Ramanujam *et al.* 1981; Ramanujam & Reddy 1984; Ramanujam *et al.* 1985; Reddy 1981, 1989; Reddy *et al.* 1984; Venkatachala & Rawat 1972, 1973; Alpana Singh *et al.* 1992.

The Tertiary mega- and microfloras of the Kerala basin have also been studied fairly extensively. So far 51 families of Angiosperms could be identified reliably, of which 6 represent monocots (Aroidae, Arecaceae, Iridaceae, Lemnaceae, Poaceae and Potamogetonaceae) and 45 dicots. Arecaceae is again the best represented taxon among the monocots both in the Palaeogene and Neogene sediments. *Cocos, Eugeissona, Salacca, Calamus, Metroxylon* and *Sclerosperma* are the palm taxa that could be identified in the Arecaceae. The Palaeogene sediments discovered recently in the sub-surface of the Kerala basin show the presence of Arecaceae, Bombacaceae, Ctenolophonaceae (*Ctenolophon*), Fabaceae (Caesalpinoidae - *Margocolporites*), Proteaceae, Solanaceae and Rhizophoraceae (*Rhizophora*) (Raha *et al.*, 1986, 1987). The Neogene flora represented both by mega- and microfossils, however, is much more extensive and varied. Of the 45 families of dicots recognized, Anacardiaceae, Bombacaceae, Combretaceae, Dipterocarpaceae and Fabaceae (Caesalpinoidae) are numerically and distributionally better represented ones. The occurrence of Dipterocarpaceae, Ebenaceae, Asteraceae, Malvaceae, the dominance of Fabaceae and the appearance of taxa such as *Gluta, Swintonia, Eugeissona, Aegialitis, Brownlowia* etc. distinguish the Neogene flora from that of the Palaeogene. At the generic level, on the whole, 94 genera of Angiosperms which could be reliably referred to a modern genus or family have been recognized in the overall Tertiary floral complex of the Kerala basin and a sizeable number of these were arborescent in habit. Recently, Awasthi and Srivastava (1992b) recorded the leaf impressions of Clusiaceae

(*Calophyllum*), Anacardiaceae (*Gluta*) and Lauraceae (*Cinnamomum*) besides a fruit affiliated to Euphorbiaceae from the sandy clays of Warkalli beds. The details of the floristic elements are provided in Table 4.

There are quite a few families in the Neogene sediments, which are represented by more than one fossil type i.e., silicified wood, carbonized wood, pollen, cuticle and mummified leaf. These are obviously of considerable significance in any discussion on floristics. These families include Arecaceae, Dipterocarpaceae, Anacardiaceae, Ebenaceae, Rhizophoraceae, Clusiaceae, Combretaceae, Sonneratiaceae, Barringtoniaceae, Fabaceae, Sapotaceae, Euphorbiaceae and Thymeliaceae.

Table 4. Angiosperms from the Tertiary strata of Kerala basin

Family	Fossil wood & related modern genus	Fossil pollen & related modern genus
AMPELIDACEAE	*Leeoxylon (Leea)*	*Retitricolporites variabilis (Leea)*
ANACARDIACEAE	*Swintonioxylon (Swintonia)* *Glutoxylon (Gluta)*	*Rhoipites anacardioides (Gluta)*
ARALIACEAE		*Araliaceoipollenites (Aralia)*
ARECACEAE		*Palmaepollenites (Cocos), Arecipites* *Longapertites* *Proxapertites* *Quilonipollenites (Eugeissona)* *Paravuripollis (Salacca)* *Clavapalmaedites* *Spinizonocolpites (Nypa)* *Dicolpopollis (Calamus)* *Disulcipollis (Metroxylon)* *Trilatiporites (Sclerosperma)* *Spinomonosulcites*
AROIDAE		*Spinainaperturites*
ASTERACEAE		*Compositoipollenites*
AVICENNIACEAE		*Retitricolporites sitholeyi (Avicennia)*
BARRINGTONIACEAE	*Caryeoxylon (Careya)*	*Marginipollis (Barringtonia)*
BOMBACACEAE		*Bombacacidites, Lakiapollis (Cullenia), Jandufouria (Catostemma)*
BURSERACEAE	*Canarium (Canarium)*	
CAPRIFOLIACEAE		*Cauveripollis, Caprifolipites*
CARYOPHYLLACEAE		*Caryophyllidites (Arenaria - Silene)*
CHENOPODIACEAE		*Polyporina, Chenopodipollis*
CLUSIACEAE	*Calophylloxylon (Calophyllum)*	
COMBRETACEAE	*Terminalioxylon (Terminalia)*	*Heterocolpites (Lumnitzera)*
CTENOLOPHONACEAE		*Ctenolophonidites (Ctenolophon)*
DIPTEOCARPACEAE	*Dryobalanoxylon (Dryobalanops)* *Anisopteroxylon (Anisoptera)* *Hopenium (Hopea)* *Shoreoxylon (Shorea)*	*Dipterocarpuspollenites (Dipterocarpus)*
DROSERACEAE		*Ornatetradites (Drosera)* *Droseridites*
EBENACEAE	*Ebenoxylon (Diospyros - Maba)*	*Psilatricolporites ebenoides*
EUPHORBIACEAE		*Crotonoidaepollenites, Crototricolpites*
FABACEAE	*Cynometroxylon (Cynometra)* *Cassinium (Cassia)*	*Margocolporites (Caesalpinia, Peltophorum)* *Trisyncolpites (Poinciana, Caesalpinia)*

Family	Fossil wood & related modern genus	Fossil pollen & related modern genus
		Palaeocaesalpiniaceaepites
FLACOURTIACEAE	*Hydnocarpoxylon (Hydnocarpus)*	
HALORAGACEAE		*Haloragacidites (Myriophyllum)*
HIPPOCRATEACEAE		*Hippocrateaceaedites*
IRIDACEAE		*Iridacidites*
LAMIACEAE		*Restistephanocolpites neogenicus*
LEMNACEAE		*Spinamonoporites*
LORANTHACEAE		*Loranthipites (Dendraphthoe) ,Gothanipollis*
LYTHRACEAE		*Verrutricolporites rotundiporis (Crenea)*
MALVACEAE		*Malvacearumpollis, Hibisceaepollenites*
MENISPERMACEAE		*Retitricolporites operculatus (Cissampelos - Cocculus)*
MORACEAE		*Triporopollenites minimus (Artocarpus)*
MYRTACEAE		*Myrtacidites (Syzygium)*
OLACACEAE		*Anacolosidites (Anacolosa)*
OLEACEAE		*Retitrescolpites (Ligustrum)*
ONAGRACEAE		*Triorites (Jussieua)*
PLUMBAGINACEAE		*Warkallipollenites (Aegialitis)*
PROTEACEAE		*Proteacidites*
POACEAE		*Monoporopollenites*
POLYGALACEAE		*Psilastephanocolporites (Xanthophyllum)*
POTAMOGETONACEAE		*Retipilonapites (Potamogeton)*
RHIZOPHORACEAE	*Carallioxylon*	*Zonocostites (Rhizophora)*
RUBIACEAE		*Retitriporites (Randia), Cricotriporites (Randia) Palaeocoprosmadites (Coprosma)*
RUTACEAE	*Fagaroxylon (Fagara)*	*Retiticolporites rhombicus (Fagaropsis)*
SAPINDACEAE	*Euphorioxylon (Euphoria, Litchi, Otonephalium)*	*Talisipites, Cupaniedites (Cupania)*
SAPOTACEAE	*Sapotoxylon (Payena-Palaquium)*	*Sapotaceoidaepollenites (Madhuca, Manilkara)*
SONNERATIACEAE		*Verrutriporites perverrucatus (Duabanga)*
		Florschuetzia (Sonneratia)
STERCULIACEAE	*Heritieroxylon (Heritiera)*	
SYMPLOCACEAE		*Symplocoipollenites (Symplocos)*
THYMELIACEAE	*Gonystyloxylon (Gonystylus)*	*Clavaperiporites (Wikstroemia)*
TILIACEAE		*Lacrimapollis (Brownlowia), Intratriporopollenites (Brownlowia)*

Data collected from : Awasthi & Ahuja 1982; Awasthi & Panjwani 1984; Awasthi & Srivastava 1989, 1990, 1992a; Ramanujam 1972, 1987; Ramanujam & Rao 1973; Rao & Ramanujam 1978, 1982; Rao 1990; Kar 1992; Kar & Jain 1981; Raha *et al.* 1986, 1987; Srivastava & Awasthi 1994.

PALAEOCLIMATIC AND VEGETATIONAL CONSIDERATIONS

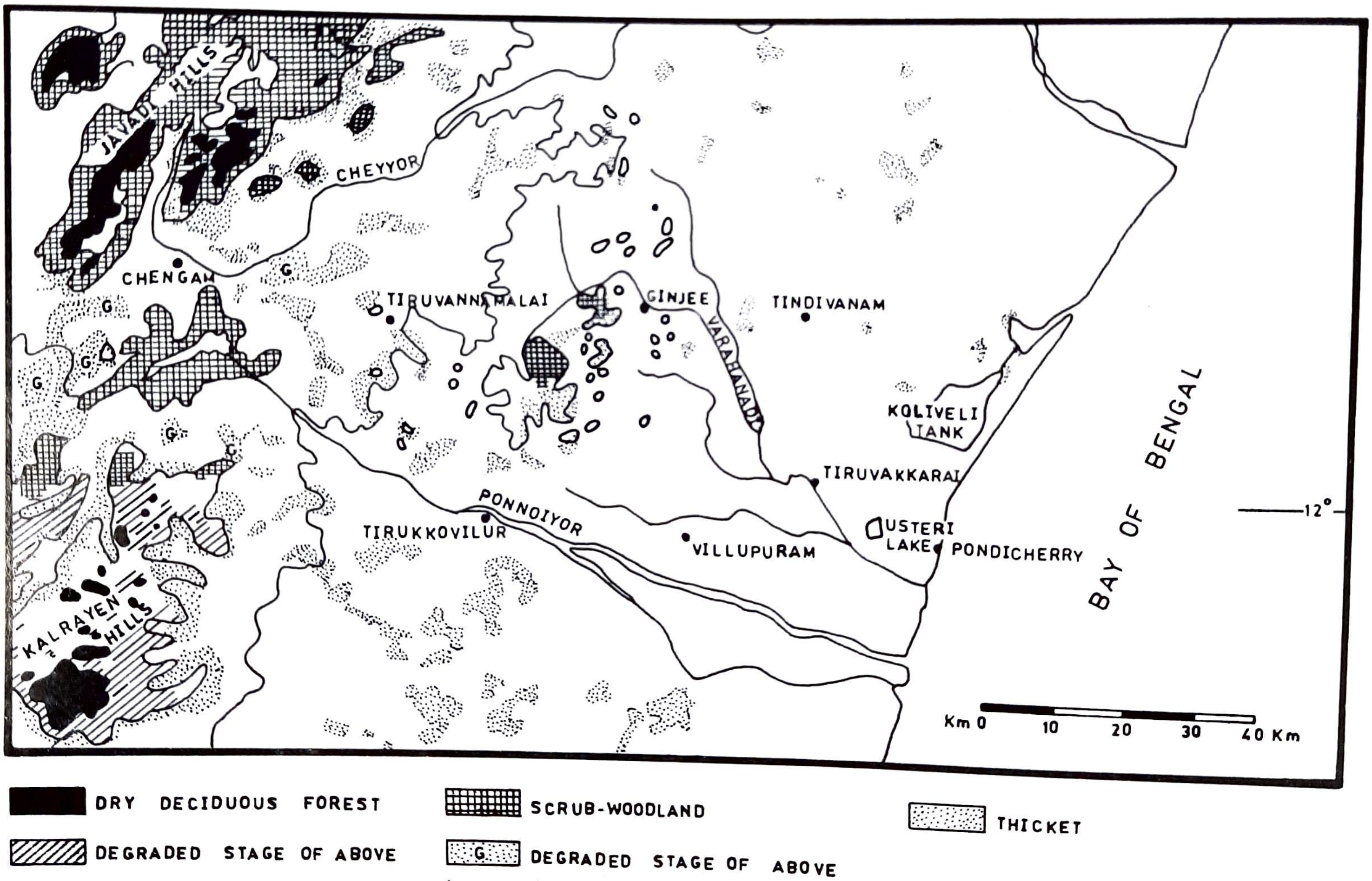
Fossil plants are reliable indicators (the thermometers) of past climates; particularly so if they are related and referable to modern taxa. This is attributable to the principle, that vegetational complexes of the past had environmental requirements similar to their modern counterparts, barring unforeseen imponderables. Environmental interpretations deduced from individual taxa become more convincing when the floristic complex includes a number of taxa with similar ecological requirements, thereby highlighting a characteristic natural biome.

The totality of the Tertiary floristic spectrum of southern India clearly indicates the occurrence of discrete pockets of brackish water or estuarine mangrove swamps adjacent to the coast line and tropical wet evergreen forests slightly away from the coastal belt (Ramanujam, 1982, 1990; Alpana Singh *et al.*, 1992). These two vegetational aspects are an expression of the prevailing ecological conditions. The mangrove swamps could be encountered in the littoral regions between low and high tides at the river mouths and mudflats of the sea coast where the soil is saline and essentially silty and clayey. *Rhizophora, Avicennia, Sonneratia, Barringtonia, Heritiera, Crenea, Nypa, Lumnitzera, Aegialitis, Excoecaria* and *Brownlowia* constitute the more important mangrove elements in the Tertiary floras of southern India.

Taxa which unequivocally point towards the prevalence of tropical wet evergreen vegetation, a product of excessive humid conditions because of heavy

Kerala basins show most of these climatic markers (see Tables 3 & 4).

The members of Arecaceae (Palms) in general are essentially coastal and occupy a position away from the storm tide dominating the sand beach flora. The deciduous taxa of the flora viz., *Terminalia, Lagerstroemia, Anogeissus, Albizia, Cassia, Acacia, Sterculia* etc., must have occupied the open areas in the evergreen forests apparently imparting a semi-evergreen look to these areas. When gaps or opennings are created in the evergreen forests accidentally, the deciduous members from the adjoining regions creep in and get established. These deciduous taxa are generally hardy and adjust to variable climates and co-exist with the evergreen ones occupying locally available relatively drier niches (Meher-Homji, 1978).



Text-fig. 2. Vegetational types in the vicinity of Pondicherry (Redrawn from Meher-Homji, 1974).

rainfall more or less all through the year include *Gluta, Swintonia, Bouea, Mangifera, Calophyllum, Mesua, Pentadesma, Symphonia, Dipterocarpus, Dryobalanops, Anisoptera, Hopea, Shorea, Diospyros, Ctenolophon, Cynometra, Artocarpus, Anacolosa, Alchornia, Duabanga, Litsea, Parinari, Syzygium, Cullenia, Palaquium, Hydnocarpus, Canarium* etc. The Neogene strata of the Cauvery and

The occurrence of water plants (hydrophytes) such as *Nymphaea, Potamogeton, Myriophyllum, Ceratopteris, Utricularia* etc. indicate prevalence of ponds and other fresh water bodies dotting the landscape. The temperate taxa such as *Symplocos, Ligustrum, Wikstroemia* etc. could have been the denizens of high lands in the vicinity of the depositional sites.

Though tropical humid climate is indicated by both the Palaeogene and Neogene floras, the respective floral compositions make it patently clear that the quantum of annual precipitation increased from Palaeogene to Neogene times.

The vegetation in the Cauvery basin, particularly in the South-Arcot sub- basin around Pondicherry is now made up of scrub jungle, thickets with many dry evergreen and deciduous elements (Meher-Homji, 1974, 1980). The hill ranges towards the west, not far from Pondicherry environs viz., Ginjee, Tiruvannamalai, Tirukkovilur, Javadi, Chengam, etc. are clothed with typical dry deciduous forests (Text-fig. 2). The annual rainfall is about 330 mm during June to September (south-west monsoon) and about 800 mm during October to January (north-east monsoon regime).

In contradistinction to the present day climatic and floristic scenario, the Neogene (Mio-Pliocene) climate and floristic complex was of an altogether different type with excessive humid conditions ± all through the year (due to heavy precipitation) and with little or practically no dry period. Naturally such a climate favoured the growth of a dense and luxuriant moist evergreen forests (rain forests) as exemplified by the fossils of the climatic markers mentioned (enumerated) above. Many of the ferns generously contributed to the undergrowth of these forests (Ramanujam, 1990; Ramanujam & Reddy, 1984).

The situation is somewhat different when we shift our attention to the west coast in the Kerala region. The rich Neogene flora of this basin shows remarkable similarity with that of Coromandel coast (both megafossils and microfossils bear testimony to this). The climate was similar; it was of tropical excessive humid type and the vegetational complex was of the same tropical moist evergreen type. In other words, the climate and vegetation were pretty uniform towards either coast of southern India during the Neogene times. However, whereas, the Coromandel coast experienced dramatic reduction in rainfall and concomittant desiccation during the post Mio-Pliocene times, resulting in a sharp change in the vegetational complex, one does not notice such a drastic change in the overall climatic pattern of Kerala region and the dense, wet evergreen forests seen in many parts of Kerala even now are perhaps a continuation of similar climatic and floristic regimes of the Neogene times. There does, however, seem to be some decline in the annual quantum of precipitation received now *vis-a-vis* the Mio-Pliocene times (Awasthi & Srivastava, 1990). This is clearly highlighted by the disappearance of such taxa as *Dryobalanops*, *Anisoptera*, *Swintonia* and *Gonystylus* from the present day Kerala forests. All these taxa require excessive humid conditions all through the year (with rainfall well over 3500 mm) with practically no dry period.

The occurrence of a wet evergreen forest in the Cauvery basin in the vicinity of Pondicherry region now at a latitudinal position of 12°N, could only be possible if this region was more nearer to the equatorial latitude in the Miocene period about 20 million years ago. It is an established dictum that climate is a function of the latitude. Palaeomagnetic studies of the Deccan trap highlighted the position of Nagpur 7° N during the Miocene compared to its present day latitudinal position of 21°N. Incidentally, as pointed out by Meher-Homji, the evidence from the rate of northward drift of the Indian plate as 5-6 cm per year if worked backwards puts southern India at the equator during Miocene age (see Meher-Homji, 1976, 1978, 1980).

Another probability that comes to mind when one deals with the drastic alteration in the climate along the Coromandel coast, concerns the uplift of Himalayas in the wake of the inexorable northward movement of the Indian plate. The final phase of the Himalayan uplift manifested sometime during Late Pliocene and Early Pleistocene (about 2-5 million years ago). It is during this final phase of Himalayan uplift that the monsoon pattern so peculiar to India must have been firmly established triggering the drastic reduction of rainfall towards the eastern margin of southern India (Meher-Homji, 1980). The above phenomena operating in tandem could have been responsible for the change of the climate of the Coromandel coast from a very humid type of the Miocene or Mio-Pliocene period to the present day relatively dry type which concomittantly brought a sea-change in the physiognomy and structure of the vegetation from a moist evergreen to a dry deciduous type and scrub jungle (Meher-Homji, 1974, 1978).

PHYTOGEOGRAPHIC CONSIDERATIONS

The Indian land mass is a clearly demarcated geographical regime, circumscribed by effective barriers like the seas and the lofty Himalayas. The diversity of its climates and its characteristic geographic position at the junction or meeting place of important floristic flows and migratory routes have facilitated the invasion or penetration of Malaysian, African and other floral elements into this country. This is exemplified by not only the modern floristic complexes but also those of the past.

Although the bulk of the taxa of the Tertiary floras of southern India continue to be encountered even now either towards its eastern or western flanks depending upon the annual quantum of precipitation, there are some significant fossils which are conspicuous by their absence in the modern floras of India. *Eugeissona (Quilonipollenites)* and *Sclerosperma (Trilatiporites)* of Arecaceae, *Anisoptera (Anisopteroxylon)* and *Dryobalanops* (*Dryobalanoxylon*) of Dipterocarpaceae, *Pentadesma* (*Pentadesmapites*) and *Symphonia (Pachydermites)* of Clusiaceae, *Swintonia (Swintonioxylon)* and *Bouea* of Anacardiaceae, *Sindora (Hopeoxylon)* of Leguminosae, *Gonystylus* (*Gonystylus*) of Thymeliaceae and, *Ctenolophon* (*Ctenolophonidites*) of Ctenolophonaceae recorded in the Tertiary strata are not found presently in India. *Eugeissona* is a coastal palm in southeast Asia and *Sclerosperma* is a tropical African palm. *Anisoptera* is now found in the evergreen forests of Chittagong (Bangladesh), Myanmar, Malayan peninsula, Sumatra, Borneo and New Guinea. *Dryobalanops* is presently restricted to the rain forests of Sumatra, Borneo and Malayan peninsula. Similarly, *Swintonia, Bouea* and *Gonystylus* are Malayan taxa; the latter is also found in Indonesian archipelago. *Pentadesma* and *Symphonia* are mostly confined to tropical Africa and *Ctenolophon* is now found in West Africa and southeast Asia (Malayan region and Philippines).

The Malaysian elements in the South Indian Neogene floras particularly seem to be quite impressive. The Malaysian taxa could have migrated to India after the Indian plate collided with Asia and established land connection, which seems to have happened during Early Miocene. This was also the time, when Dipterocarpaceae taxa which were totally absent in the Palaeogene entered into India from their original home, the Malaysia. From India this family continued its westward march ultimately reaching Africa (Ramanujam, 1968; Lakhanpal, 1970; Meher-Homji, 1980).

Almost all the wet evergreen taxa recorded from south Indian Tertiaries seem to have enjoyed more extensive geographical distribution during the Mio-Pliocene period, compared to their present day limited spread. As India moved from an equatorial position in Miocene to its present northern latitudinal slot, with the concomittant decline in rainfall, a number of these wet evergreens perished (Ramanujam & Reddy, 1984).

In conclusion one may pertinently observe, that an understanding of the floristic complexes of the geological past would add a new dimension and a new ethos to our studies of the modern floras. Perhaps we should all look upon fossil plants as "*Sermons in Stones*" for the posterity to think, meditate, interpret and understand what sight cannot see and ears cannot hear. I would not hazard to claim. I have covered everything that merits coverage. What has been depicted before you was a mere bird's eye view of the theme; if it has triggered your inquisitiveness I should feel highly satisfied.

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(Received 8.9.1995; Accepted 10.1.1996)