Evidence of Late Palaeocene-Early Eocene equatorial rain forest refugia in southern Western Ghats, India

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Equatorial rain forests that maintain a balance between speciation and extinction are hot-spots for studies of biodiversity. Western Ghats in southern India have gained attention due to high tropical biodiversity and endemism in their southern most area. We attempted to track the affinities of the pollen flora of the endemic plants of Western Ghat area within the fossil palynoflora of late Palaeocene-early Eocene (~55–50 Ma) sedimentary deposits of western and northeastern Indian region. The study shows striking similarity of extant pollen with twenty eight most common fossil pollen taxa of the early Palaeogene. Widespread occurrences of coal and lignite deposits during early Palaeogene provide evidence of existence of well diversified rain forest community and swampy vegetation in the coastal low lying areas all along the western and northeastern margins of the Indian subcontinent. Prevalence of excessive humid climate during this period has been seen as a result of equatorial positioning of Indian subcontinent, superimposed by a long term global warming phase (PETM and EECO) during the early Palaeogene. The study presents clear evidence that highly diversified equatorial rain forest vegetation once widespread in the Indian subcontinent during early Palaeogene times, are now restricted in a small area as a refugia in the southernmost part of the Western Ghat area. High precipitation and shorter periods of dry months seem to have provided suitable environment to sustain lineages of ancient tropical vegetation in this area of Western Ghats in spite of dramatic climatic changes subsequent to the post India-Asia collision and during the Quaternary and Recent times.

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1. Introduction

Tropical forests are known for their high biodiversity pattern (Groombridge 1992; Davis *et al.* 1997; Hooghiemstra and Van der Hammen 1998; Givnish 1999; Wright 2002) and have been studied extensively world wide from various tropical regions. Tropical rainforest vegetation has a complex geological history, having been severely affected in response to changing climatic conditions of the geological past. The most distinctive tropical rainforests presently are found on the separated fragments of Gondwanaland, once a supercontinent during Palaeozoic-Mesozoic, except for the South East Asian rain forest (Corlett and Primack 2006).

High species diversity of tropical forests was noted as early as 1878 by Alfred Wallace who suggested stable tropical climate as the key factor in explaining high diversity. Within the tropics, tree diversity tends to be higher where dry season is shorter or seasonality is low (Givnish 1999; Leigh 1999; Leigh *et al.* 2004). It has been seen that the tree diversity is the highest in those tropical regions where climate has varied the least during various geological periods and the lowest in those areas where tropical forests were most disrupted by the cyclic revolutions of climate, especially during the Pleistocene (Morley 2000). Diversification and extinction of various species of tropical rain forest over time reflect series of climatic and tectonic changes during various geological time spans (Hooghiemstra and Van der Hammen 1998). Fossil record shows that the diversification of tropical plant biome took place during Late Cretaceous and early Palaeogene times; hence their evolution is likely to be related with the plate tectonics (Givinish and Renner 2004) and long term climatic changes. Geological history of

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tropical rain forests of the Indian subcontinent is extremely significant in view of its northward movement from mid southern latitudes to the equatorial zone and consequent global climatic and tectonic changes. The fossil history of tropical rain forest of the Amazon basin suggests that the high tree biodiversity in the Amazon forest is a legacy of the Tertiary period rather than an evolutionary product of the Quaternary (Hooghiemstra and Van der Hammen 1998). The forest refugia hypothesis holds that the ancient rain forest elements are restricted in certain high precipitation pockets of Amazon basin and survived during the harsh Pleistocene environmental conditions of glacial climate (Haffer 1969; Prance 1987; Whitmore 1987; Hooghiemstra and Van der Hammen 1998).

The Western Ghats in the peninsular India have been a focus for alpha diversity and high degree of endemism (Ganesh *et al.* 1996; Ghate *et al.* 1998; Myers *et al.* 2000; Bossuyt *et al.* 2004). Large number of Gondwana faunal relics from the wettest region of Western Ghat area has provided clues about the evolutionary history and palaeobiogeography of tropical fauna (Biju and Bossuyt 2003; Bossuyt *et al.* 2004). Amongst the plants, the observed levels of endemism are truly astounding. More than 56% trees are monotypic and endemic to the Western Ghat area and are restricted to the evergreen forest of southern region between 8°-11° latitudes (Ramesh and Pascal 1997; Barboni *et al.* 2003) (figure 4). The wet climatic condition and the deeply dissected topography induces high precipitation (>8000 mm) in certain areas in this region that produces local variation in the habitat type and localized centers of endemism (Gunnel 1997). The biotic diversity of this region has been a subject of extensive study (Pascal 1982; Pascal 1986; Pascal 1988; Pascal 1991; Ganesh *et al.* 1996; Ghate *et al.* 1998; Bonnefille *et al.* 1999; Barboni and Bonnefille 2001; Barboni *et al.* 2003). Studies on Quaternary palynofloral diversity have also been performed by various workers (Vasanthy 1988; Farooqui *et al.* 2009).

Palynofloral characteristics of ancient tropical rain forests are widely documented from coal and lignite bearing deposits of early Palaeogene sedimentary successions from India (figure 1). In this paper we attempt to track the affinities of palynofloral components of the tropical rain forest vegetation during early Palaeogene times spanning Palaeocene Eocene Thermal Maxima (PETM) and early Eocene Climatic Optima (EECO) global warming events, with the extant tropical rain forest community of the Indian subcontinent. The study reveals that equatorial rain forests once widespread in the Indian subcontinent during early Palaeogene times, are now restricted to a small area as a refugia, in the southernmost part of the Western Ghat area (figure 3). High precipitation and low seasonality in Western Ghats must have provided suitable environment to sustain lineages of ancient tropical vegetation.

2. Global Climatic Events and early Palaeogene history of Indian subcontinent

The Cretaceous-Early Palaeogene time span is noted for radiation and expansion of angiospermous flora of tropical nature. The prolonged greenhouse conditions during the Cretaceous ended up with a brief pulse of cooling after the end Cretaceous event marked by bolide impact and extensive volcanism (Thomas *et al*. 2006). The earth subsequently experienced rapid and pronounced global warming episodes beginning with the PETM Event ~55.5 Ma and followed by EECO ~50 Ma, a time span of ~6 Ma characterized by continued warming interspersed with pulses of excessive warming (hyperthermal events) (Zachos *et al.* 2001; Thomas *et al.* 2006). The impact of this warming was far reaching on both terrestrial and marine global ecosystems. Excessive carbon dioxide released then in the atmosphere finds evidence in the carbon isotopic composition of both ocean and continental records with a decrease of δC^{13} by 3–4‰ (Koch *et al*. 1992). Amongst the various theories proposed, excessive carbon input at 55.5 Ma prior to Palaeocene-Eocene boundary is attributed to the rupturing of 2000Gt methane gas hydrate from the continental shelf and its subsequent oxidation to CO_2 (Dickens *et al.* 1995). The alternative hypotheses maintain that the equatorial convergence of Indian plate resulted in high influx of CO_2 during early Cenozoic times (Kent and Muttoni 2008), besides some other options (*see* Thomas *et al.* 2006). The impact of these events on terrestrial and marine biota was dramatic involving extinction as well as evolution, radiation and migration amongst several groups of organisms. PETM related climatic signals have been studied extensively from high to mid latitudinal regions, however, equatorial biotic records of this event are limited (*see* Schmidt *et al.* 2000; Wing *et al.* 2003; Prasad *et al.* 2006).

The Indian subcontinent uniquely represents the equatorial biotic records of extreme climatic events of the early Palaeogene (Prasad *et al.* 2006; Sahni *et al.* 2006; Garg *et al.* 2008). Equable climate leading to wet and evergreen tropical vegetation in both mid and high latitudinal regions was one of the most significant features of this event that has been documented from far and wide regions across the globe. With its unique palaeoequatorial setting (figure 2), the Indian subcontinent is considered to be a hotspot for tropical biodiversity and plays an important role in tracking the biogeography and evolution of tropical rain forest vegetation. Vegetation on Indian subcontinent underwent significant changes in comparison to other subcontinents as it crossed various palaeoclimatic belts after its breakup from Gondwanaland in the far southern hemisphere and subsequent collision with the tropical Asia in the northern hemisphere (Briggs 2003). Changing climatic conditions as a result of its rapid northward drift as well as geographical isolation played a major role in shaping the palaeovegetation on the Indian subcontinent. Fossil palynofloral records of

Figure 1. Palaeocene – Eocene lignite and coal deposits of India. (1) Vastan, (2) Rajpardi, (3) Panandhro, (4) Barmer, (5) Bikaner, (6) Kalakot, (7) Garo Hills, (8) Khasi Hills, (9) Jaintia Hills.

the Indian region during its northward journey, show great similarity with those from Africa, Australia and Madagascar (parts of Gondwanaland) at various successive periods and finally with Asia during post collision times. As evident from rich and diversified palynofloral fossil records, this journey resulted in an extensive exchange of floral traits between the adjoining landmasses, enriching the gene pool of the Indian subcontinent leading to a higher rate of evolution and speciation. Late Cretaceous-Early Palaeogene time span is most significant in the Indian geological history as it shows floral turnover from gymnospermous flora to newly evolved tropical angiospermic community. At the time of PETM event, Indian subcontinent occupied an equatorial position (Prasad *et al.* 2006). During this interval, a warm and humid climate is evident on the basis of the deposition of thick coal and lignite deposits in coastal low land areas on the Indian western and northeastern margins (figure 1). Palynofloras from these sedimentary successions reveal rich and diversified tropical rainforest vegetation. Subsequent to collision, rise of the Himalayas and setting up of the Asian monsoonal climate system modified the ever-wet tropical rainforest vegetation. The palynofloral records suggest that the Glacial-Interglacial periods of the Pleistocene, particularly the Last Glacial Maxima resulted in the extinction of most of the tropical rainforest lineages on the Indian subcontinent.

2.1 *Late Palaeocene-early Eocene Indian sedimentary successions*

The palaeogeographic reconstructions show that during the early Palaeogene northeastern and western marginal basins in the Indian subcontinent lay within the equatorial zone (figure 2). During this time span, widespread peat accumulation on the margins of the epicontinental seaways fringing the northeastern and western margins of the Indian subcontinent is a significant feature (figure 1). On the western margin (Barmer, Jaisalmer, Bikaner, Kutch, Gujarat), the sedimentary successions contain thick lignite deposits, whereas in the north (Jammu, Himachal Pradesh) and the northeastern region (Garo-Khasi-Jaintia Hills in Meghalaya) the successions are interspersed with coal measures characterized by thin, pinching and discontinuous but workable coal seams (figure 1). All these coal and lignite bearing successions are characteristically associated with overlying or underlying larger foraminifera rich carbonate horizons (limestone and marls), providing the main criterion for fixation of their age as early Eocene in the western sector and late Palaeocene in the northeastern sector. Lately, recovery of rich dinoflagellate cyst assemblages from these lignite and coal bearing sedimentaries has provided considerable refinement in the larger foram based age considerations. In the northeastern region, the main coal bearing units within the Lakadong Sandstone have been demonstrated to be latest Palaeocene-early Eocene (Late Thanetian-Sparnacian) age (Garg and

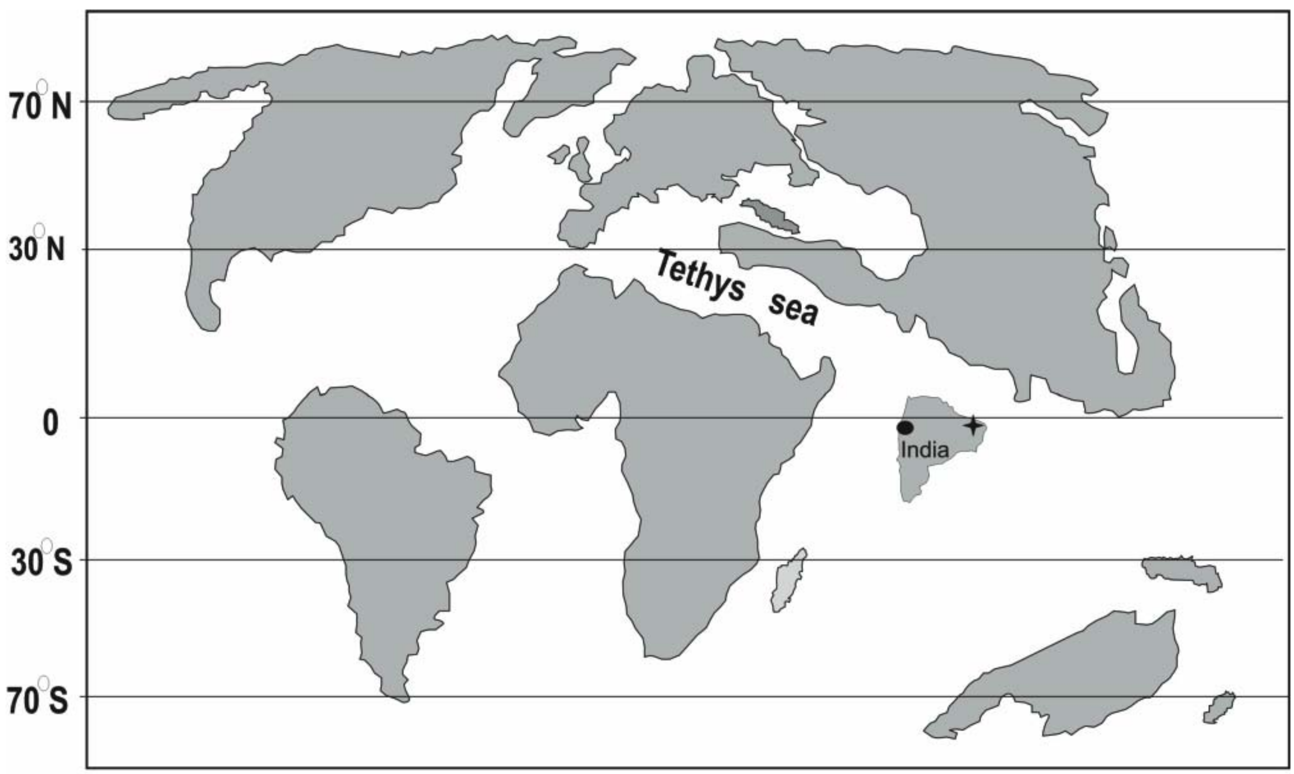

Figure 2. Paleogeographic reconstruction during late Palaeocene (after Scotese and Golanka, 1992; Crouch *et al.* 2003; Prasad *et al.* 2006) showing equatorial positioning of Indian subcontinent during late Palaeocene-early Eocene. ✦, PETM (Shillong Plateau, northeastern India); ●, EECO (Vastan, Gujarat).

Khowaja-Attequzzaman, 2000, Prasad *et al.* 2006). These successions were laid down during the "green house" world of early Palaeogene times which is characterized by globally recognized warming events i.e. Palaeocene Eocene Thermal Maxima (PETM) at ~55.5 Ma, and Early Eocene Climatic Optima (EECO) till about ~50 Ma. In northeastern region the PETM event is well demarcated (figure 2) with negative carbon isotopic excursion peak and the ubiquitous *Apectodinium* acme (dinoflagellate cyst) global phenomenon (Prasad *et al.* 2006). In the western sector, the lignite succession in Vastan is also dated to be latest Palaeocene-early Eocene (late Thanetian-Sparnacian) but is supposed to be lying in the post PETM interval (Garg *et al.* 2008) within the warming phase of EECO (figure 2). The succession underlying the Vastan lignite and its equivalents in the western Indian basins are supposed to fall within the PETM interval.

2.2 *Early Palaeogene palynoflora of western and northeastern India*

The coal and lignite bearing successions in northeastern and western Indian margin abound in terrestrial palynomorphs, exhibiting highly diverse and rich assemblages indicating a warm and exceptionally humid climate with a dense tropical rain forest in the vicinity of the depositional environment. The palynological evidences during the PETM interval in northeastern India indicate domination of tropical rainforest elements along with brackish mangrove, coastal vegetation (Prasad *et al.* 2006). The pollen records show well diversified lowland tropical rain forest vegetation. Palynological studies on late Palaeocene to early Eocene succession, identified as Cambay Shale, of Vastan lignite mine have been worked out by Mandal and Guleria (2006), Garg *et al.* (2008) and Tripathi and Srivastava (unpublished). Some significant works have also been carried out on equivalent strata exposed in Rajpardi (Kar and Bhattacharya 1992; Kumar 1996; Samant and Phadtare 1997) and Bhavnagar (Samant 2000). Palynofloras from these successions are diverse represented by pteridophytic spores and angiospermous pollen. Dominance of *Spinizonocolpites* spp. (*Nypa*) and dinoflagellate cysts at few selected levels in Vastan succession indicates lowland coastal environment of deposition. The assemblage is dominated by angiospermic pollen assignable to the families Arecaceae, Liliaceae, Bombacaceae, Euphorbiaceae, Rubiaceae and Rhizophoraceae. Of these, pollen having affinities with the family Arecaceae and Bombacaceae are recorded in high frequency. Pollen grains of the family Arecaceae have been assigned to different species of *Palmidites, Spinomonosulcites, Longapertites, Spinizonocolpites, Acanthotricolpites* and *Echimonoporopollis.* Pollen grains of the family Bombacaceae are ascribed to *Lakiapollis ovatus, Lakiapollis matanomadhensis* and *Dermatobrevicolporites dermatus*. *Lakiapollis ovatus* is abundantly recorded in almost all the Palaeocene-Eocene successions of western India. Palynofloras from Rajpardi lignite (early Eocene) shows most diverse tropical rain forest palynoflora belonging to a wide range of plant families (Samant and Phadtare 1997).

Palynofloras from early Eocene Naredi Formation, Kutch, Gujarat also show rich and diversified angiospermous pollen (Venkatachala and Kar 1969; Kar 1978, 1985). Many taxa recorded from bore-hole samples and open-cast lignite mine successions of Barmer, Rajasthan (Tripathi 1994, 1995; Tripathi *et al.* 2003, 2009) are also recorded from Vastan. These studies indicate similar palynofloral diversity pattern during Palaeocene-Eocene time span. The abundance and striking resemblance of palynoflora of western and northeastern Indian region during this time span indicates widespread, closed-canopy tropical rain forest cover over a vast expanse of the Indian subcontinent.

Palynological studies on early Palaeogene sediments of Meghalaya and Assam have been extensively carried out by many workers. These studies are on Tura Formation in Garo Hills (Sah and Singh, 1974; Singh 1977; Tripathi *et al.* 2000), Cherra Formation and Lakadong Sandstone (Dutta and Sah 1970; Kar and Kumar 1986), Therria Formation in Jaintia Hills (Tripathi and Singh 1984, 1985) and Mikir Formation in North Cachar Hills (Mehrotra 1981). Stratigraphic distribution shows varied palynofloral assemblages in these formations, some of which are dominated by pteridophytic spores while others are conspicuously rich in angiospermous pollen that show affinity with those of modern tropical rain forest elements. Some of these palynofossils are: *Albertipollenites* sp, *Foveotricolpites alveolatus, Dipterocarpuspollenites retipilatus, Tricolpites reticulates, Retimonosulcites ovatus*, *Longapertites* spp., *Quillonipollenites* spp., *Neocouperipollis* spp., *Dicolpopollis* spp., *Lakiapollis ovatus, Lakiapollis matanomadhensis, Monosulcites* spp., *Meliapollis* spp., *Polybrevicoporites* spp., *Polycolpites/Retistephanocolpites* spp., and *Retimonocolpites* spp.

3. Geomorphological evolution, climate and vegetation of the Western Ghats

Mantle plume activity and volcanism during the northward journey of the Indian subcontinent and massive outpouring of basaltic magma provided an extensive trap cover over much of the peninsular region. Regional upwarping is also conceived due to thermal expansion along the track of the hotspot (Radhakrishna 1993). Rifting and downfaulting of western margin led to the creation of Western Ghats and the scarps facing the Arabian Sea some time during the Eocene prior to the India-Asia collision. The Western Ghats are thus, precipitous western edge of an elevated Plateau (*see* Radhakrishna 1993), also known as Sahyadri Mountains.

In the Western Ghats, the Agasthyamalai Hills in the extreme south are believed to harbour the highest levels of plant diversity and endemism at the species level. Nearly 87% of the region's flowering plants are found south of the Palghat Gap (37% being exclusive to this sub-region); these figures decrease to about 5%, in the Nilgiri Hill.

Tropical diversity and endemism appear to be higher in the area that lies south of the Palghat Gap, a 30 km wide break that separates the high rain fall areas of the southern part from rest of the regions in the Western Ghats (figure 3). The climate is characterized by heavy precipitation in summer and dry season in winter. Southwest monsoon is the main contributor for rainfall in this region. Maximum rainfall occurs during May to September. According to bioclimatic maps of the Western Ghats (Pascal 1982), the annual rainfall from west to east decreases from >5000mm/yr to <2000 mm/yr and duration of the dry season increases from 3 to 7 months (figure 4). Temperature in the coldest months remains >23°C at 650 m elevation and <15°C at 1500 m elevation. Mountain chains that form crest in the western part with peaks at ca. 2600 m above mean sea level, triggers heavy precipitation (Ramchandran and Banerjee 1983). The mountain chains also limit the inland penetration of the rains. Starting from the south of the Western Ghats and progressing towards north and west, there is a significant decrease in precipitation, showing strong west to east and north to south decreasing rainfall gradient (Barboni *et al.* 2003). The monsoon always arrives from southern part of the Western Ghats and also retreats from there, hence rendering the area wet and humid for a considerable period of time during the year (Barboni *et al.* 2003) (figure 4). The length of dry period also varies in various parts of the Western Ghat area. The precipitation gradient in the Western Ghats is also reflected in modern pollen spectra of the surface sediments that provide evidence of differential distribution of wet evergreen and moist deciduous semi evergreen vegetation (Anupama *et al.* 2000; Barboni and Bonnefille 2001). It is considered that length of the dry season instead of high precipitation may be a more important determinant of distribution of wet, evergreen forest types in the Western Ghat area (Pascal 1988). Vegetational maps with floristic types along the latitudinal gradient in the Western Ghat area have been described by several workers (Pascal *et al.* 1982a, b 1984; Ramesh *et al.* 1998). Each floristic type was defined by occurrence of the most prominent plant families and genera within specific climatic regime (average rain fall received, total length of dry periods and elevation). Each floristic type is also marked by forest phenology. Southernmost region is covered by evergreen forest followed by semi-evergreen and deciduous forest towards north. Floristic type hence occupies different geographical areas of different climatic regimes (Pascal 1986) (table.1).

4. Materials and methods

The morphological comparison of the early Palaeogene palynoflora with the modern pollen for the purpose of drawing affinities is based on L M studies of selected taxa. Further studies backed by SEM are crucial for assessing species level affinities. In this study fossil palynomorphs recovered from the two well constrained Palaeocene–Eocene sedimentary successions from Jathang (Khasi Hills, northeastern India) and Vastan (Gujarat, western India) besides those known from published records, are compared with the extant pollen from the published literature of the Western Ghat area (BSIP Herbarium slides) and the Catalogue of pollen flora from the Western Ghats (Vasanthy 1988; Tissot *et al.* 1994).

5. Comparison of Palaeocene-Eocene pollen flora with extant pollen flora of the Western Ghats (table 2)

Albertipollenites kutchensis [Figure 5 (6–7)]: Pollen grains spheroidal in polar view, size range 70-80 μm, tricolpate. Colpi long, reaching almost up to the poles. Exine tectate, reticulate, lumina 1–2 μm across. Different species of this genus are recorded from most of the Palaeocene-Eocene successions of western and eastern regions of India. These taxa show morphological resemblance with pollen of extant genus *Dipterocarpus indicus.* Plants of this extant taxon, endemic to Western Ghats and restricted to south and central Sahyadris, are about 60m tall and form canopy in the evergreen forests.

Arengapollenites achinatus: Pollen grains subspherical to oval in shape, size range 30–40 μm, monocolpate. Exine tectate, spinose, spines arranged on margin of colpus, interspinal area psilate. A few species of the fossil genus *Arengapollenites,* recorded from the early Eocene successions of Cambay Basin, show great morphological resemblance with modern *Arenga* pollen especially in having the alternating arrangement of spines along the sulcus margin.

Clavaperiporites heteroclavatus: Pollen grains spheroidal in shape, size range 34–45 μm, pentoporate. Exine heteroclavate, clava of different sizes around the pores and rest of the pollen. Clavae heads form distinct crotonoid pattern. Fossil pollen grains, described from Rajpardi lignite, Cambay Basin, show close resemblance with the extant plants of *Garcinia travancorica.* These plants are endemic to the Western Ghats and are restricted to high rainfall areas.

***Cupanieidites* spp.** [Figure 6 (12)]: pollen grains triangular to subtriangular in shape, size range 20–28 μm,

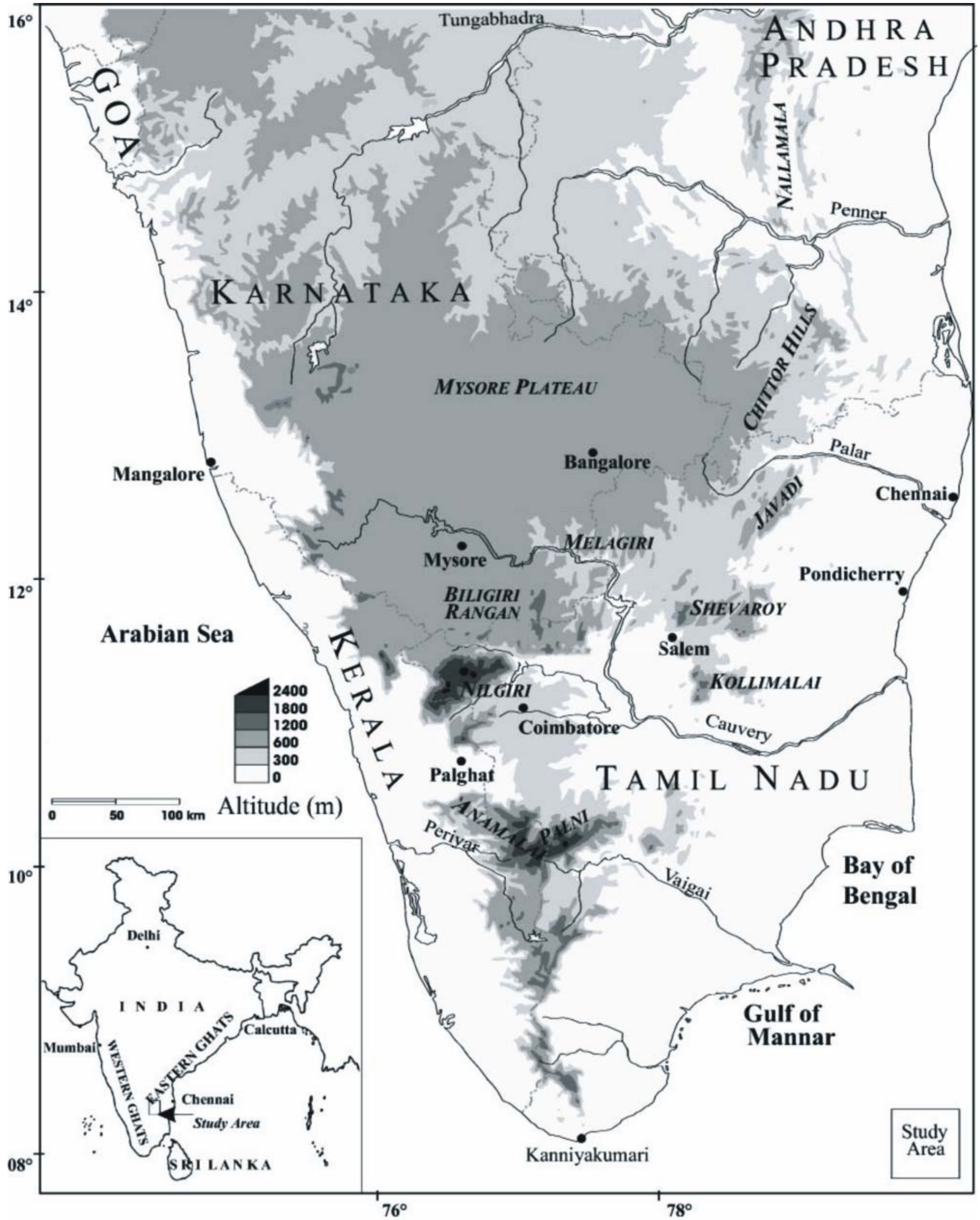

Figure 3. Map showing Western Ghats region of India (after Anupama *et al.* 2000).

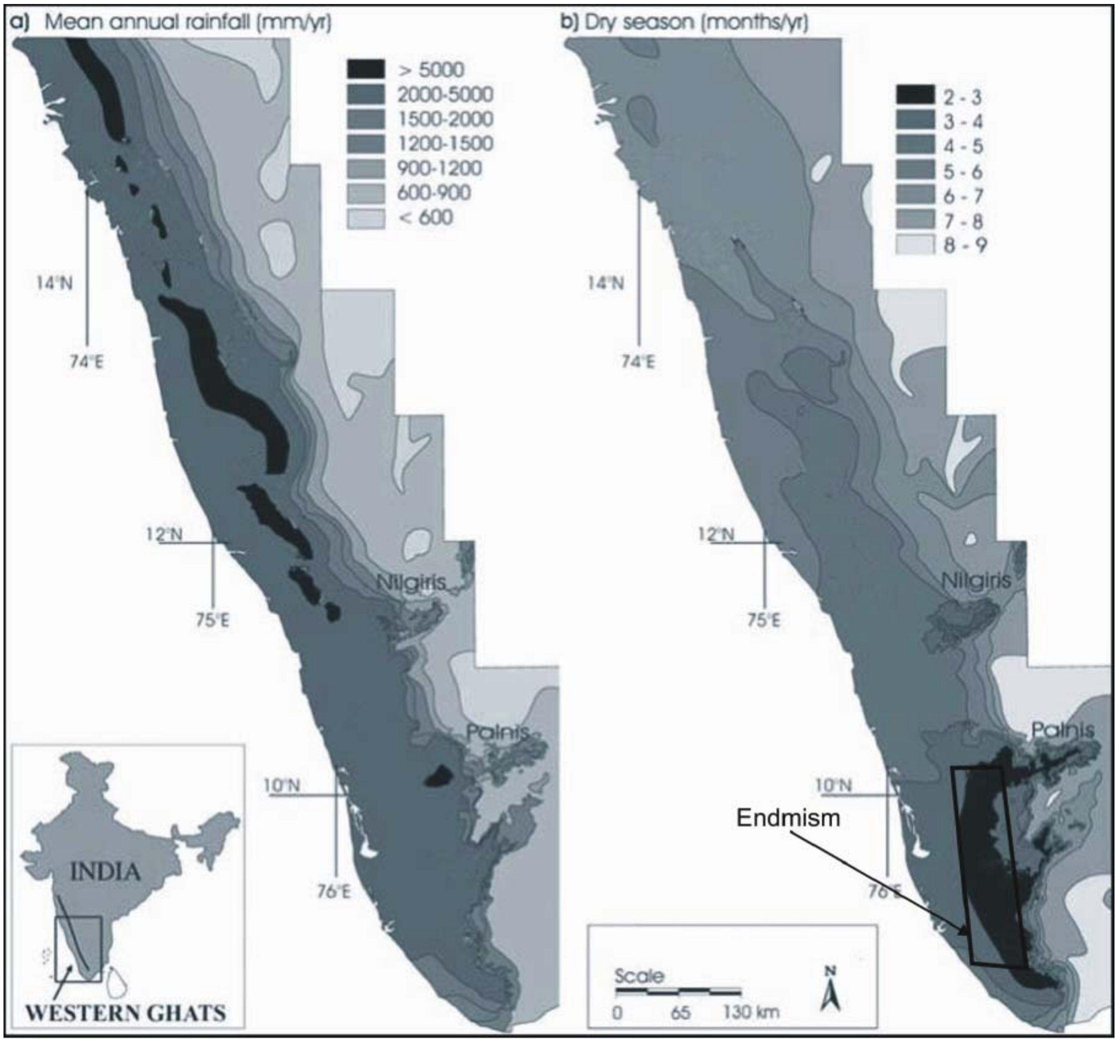

Figure 4. Map showing relative to mean annual rainfall and the length of the dry season in the Western Ghats, South India (after Pascal 1982; Barboni *et al.* 2003).

tricolporate, syncolporate, angulaperturate. Exine tectate, granulate to locally microreticulate. These fossil pollen grains are comparable to those of the extant species *Eugenia thwaitesii*, occurring as a shrub or small tree in south Kanara of the Western Ghat area.

***Dicolpopollis* sp.**: Pollen grains elliptic-bilobed in shape, size range 20–30 μm, dicolpate. Colpi short. Exine tectate, reticulate. Different species of the fossil pollen *Dicolpopollis* are well represented in palynological assemblages from Indian early Palaeogene sedimentary basins. These pollen show similar morphological characters that are exhibited in extant pollen of palm genus *Calamus* which occur as common tree in the Nilgiri and Travencore hills of the Western Ghats area.

Dipterocarpuspollenites retipilatus [Figure 5(8)]: Pollen grains sphaeroidal to subsphaeroidal in shape, size range 45–50 μm, tricolpate. Colpi long, prominent, wide apart in polar view, Exine reticulate. These palynomorphs are recorded from Cambay basin and Khasi Hills, Meghalaya and are comparable with those of extant plant *Vateria macrocarpa*. Trees of this species are 30m tall and form canopy in the wet and evergreen forests. It is endemic to Western Ghats.

Foveotricolpites alveolatus [Figure 5 (1–5)]: Pollen grains spherioidal to subspheroidal in shape, size range 60-70 μm, tricolpate. Colpi long, extending almost up to the poles. Exine retipilate, reticulations formed due to fusion of pila heads resulting into a foveolate appearance. Recorded from Khasi Hills, Meghalaya, this fossil species shows similarity with the pollen of extant *Dipterocarpus indicus* which is endemic to the Western Ghats area.

***Incrotonipollis* sp.** [Figure 5 (11)]: Pollen grains spheroidal in shape, size range 40–60 μm, inaperturate. Exine exhibiting crotonoid pattern. Two species of this fossil genus are reported in late Palaeocene-early Eocene

Table 1. Distribution of plant families and taxa according to relative mean precipitation and total number of dry months in Western Ghats (modified after Champion and Seth 1968; Tissot *et al*. 1994)

Forest type	Precipitation mm per ann.	Family	Genus	Species
Tropical Rain Forest	5000 and above, 2–3 months dry period	Anacardiaceae	*Gluta*	*travancorica*
		Annonaceae	*Goniothalamus*	*rhyncantherus*
		Asteraceae	*Vernonia*	*travancorica*
		Bombacaceae	*Cullenia*	*exarillata*
		Clusiaceae	*Calophyllum* *Garcinia* *Garcinia* *Poeciloneuron* *Mesua*	*austroindicum* *rubroechinata* *travancorica* *indicum*
		Ebenaceae	*Diospyros*	*barberi ferrea*
		Melastometaceae	*Memecylon*	*gracile*
			Memecylon	*subramanii*
		Podocarpaceae	*Podocarpus*	*wallichiana*
		Sapotaceae	*Palaquium*	*ellipticum*
	2500–5000, 4–5 months dry period	Anacardiaceae	*Gluta*	*travancorica*
			Holigarna	*arnottiana, beddomei,*
			Mangifera	*indica*
		Annonaceae	*Goniothalamus*	*thwaitesii*
			Polyalthia	*cerasoides, coffeoides, fragrans*
		Arecaceae	*Pinanga*	*dicksonia*
		Asteraceae	*Vernonia*	*travancorica*
		Bombacaceae	*Cullenia*	*exarillata*
		Burseraceae	*Canarium*	*strictum*
		Clusiaceae	*Calophyllum*	*austroindicum*
			Garcinia	*rubroechinata*
			Garcinia	*travancorica*
			Mesua	*ferrea*
		Dipterocarpaceae	*Dipterocarpus*	*indicus*
			Dipterocarpus	*turbinatus*
			Hopea	*glabra* and 8 species
			Shorea	*assamica* and 2 species
			Vateria	*macrocarpa*
		Ebenaceae	*Diospyros*	*barberi*
		Elaeocarpaceae	*Elaeocarpus*	*glandulosus*
		Euphorbiaceae	*Bischofia*	*javanica*
			Daphniphyllum	*neilgherrense*
			Mallotus	*ferrugineus*
			Croton	*malabaricus*
		Fabaceae		
		Gnetaceae	*Gnetum*	*ula*
		Malvaceae	*Kydia*	*calycina*
		Melastometaceae	*Memecylon*	*gracile*

Table 1. *(Continued)*

			Memecylon	*subramanii*
		Meliaceae	*Aglaia*	*barberi*
		Moraceae	Artocarpus	*communis*
		Myrtaceae	*Eugenia*	*caryophyllata*
		Myristicaceae	*Knema*	*attenuata*
			Myristica	*dactyloides, malabarica*
		Rubiaceae	*Ixora*	*arborea*
		Oleaceae	*Olea*	*dioica*
		Palmae	*Caryota*	*urens*
		Podocarpaceae	*Podocarpus*	*wallichiana*
		Rutaceae	*Clausena*	*indica*
		Sabiaceae	*Meliosma*	*pinnata* var. *barbatula*
		Sapotaceae	*Palaquium*	*ellipticum*
		Sterculiaceae	*Pterospermum*	*acerifolium, diversifolium, reticulatum, rubiginosum, suberifolium*
		Ulmaceae	*Trema*	*orientalis*
Semi-evergreen, to Moist Deciduous Forest	2500-3500, 5-6 months dry period	Celastraceae	*Lophopetalum*	*wightianum*
		Combretaceae	*Anogeissus*	*latifolia, acuminata*
		Cluseaceae	*Calophyllum*	*polyanthum*
		Euphorbiaceae	*Bridelia*	*airy-shawii*
		Dipterocarpaceae	*Hopea*	*Utilis* and 8 species
			Dipterocarpus	2 species
			Vateria	3 species
			Shorea	3 species
		Lythraceae	*Lagerstroemia*	*indica, microcarpa, lanceolata, thomsonii, parviflora, flos-reginae*
		Oleaceae	*Ligustrum*	*gamblei, robustum* subsp. *walkeri, travancoricum*
		Fabaceae	*Pteropcarpus*	*dalbergioides, marsupium, santalinus*
		Sterculiaceae	*Sterculia*	*urens* and 4 species
		Verbenaceae	*Tectona*	*grandis*
		Combretaceae	*Terminalia*	8 species
		Meliaceae	*Melia*	*dubia, azadirach*
			Toona / Walsura type	
		Myrsinaceae		
		Euphorbiaceae		
		Celastraceae		
		Sapindaceae	*Schleichera*	*oleosa*

Table 1. *(Continued)*

		Alangiaceae	*Alangium*	*salvifolium*
Dry Deciduous Forest	1000–2000, 6–7 months dry period	Anacardiaceae	*Buchanania*	*axillaries* and 5 species
		Alangiaceae	*Alangium*	*salvifolium*
		Arecaceae	*Arenga*	
			Pinanga	
		Araceae	*Calamus*	
		Apocynaceae		*Tabernaemontana*
		Caesalpinioideae	*Bauhinia*	*malabarica, racemosa*
			Cassia	*montana, fistula*
			Tamarindus	*indica*
		Dilleniaceae	*Dillenia*	*bracteata, pentagyna, retusa*
		Euphorbiaceae	*Emblica*	*officinalis*
			Agrostistachys	*indica*
			Phyllanthus	*polyphyllus*
			Dimorphocalyx	*beddomei*
		Fabaceae	*Hardwickia*	*binata*
		Fabaceae	*Butea*	*frondosa, monosperma*
		Icacinaceae	*Gomphandra*	*tetrandra*
		Meliaceae	*Azadirachta*	*indica*
		Moraceae	*Artocarpus*	*communis*
		Pedaliaceae	*Pedalium*	*murex*
		Rubiaceae	*Canthium*	*neilgherrense* and 5 species
		Rutaceae	*Chloroxylon*	*swietenia*
		Rutaceae	*Atalantia*	*monophylla*
		Sapindaceae	*Dodonaea*	*augustifolia*
		Sapotaceae	*Madhuca*	*bourdillonii*
		Ulmaceae	*Holoptelea*	*integrifolia*
		Xanthophyllaceae	*Xanthophyllum*	*arnottianum, favescens*

palynological assemblages from Rajasthan and Cambay basins. The inaperturate nature of these pollen grains having a crotonoid pattern of exine ornamentation is the most characteristic feature of this fossil genus. The pollen shows a close morphological similarity with those of the extant plant *Croton malabaricus* and *Dimorphocalyx lawianus* of family Euphorbiaceae. Both of these extant species occur in abundance in the Western Ghat area.

Intrareticulites brevis: Pollen grains subspheroidal to subtriangular in shape, size range 23–36 μm, tricolpate. Colpi distinct, long. Exine intra-reticulate. Fine reticulation and long colpi of this fossil species exhibit close resemblance with pollen grains of extant *Shorea.* Forests of these plants dominate in the southern part of the Western Ghat area and low land areas of South East Asia.

Lakiapollis ovatus [Figure 6 (8)]: Pollen grains subspheroidal in shape, size range 40–60 μm, tri-brevi-colporate. Exine psilate to weakly structured. It is the most widely distributed fossil pollen species of Palaeocene- Eocene time and is recorded in almost all palynological assemblages of sedimentary basins from Indian subcontinent. *Lakiapollis ovatus* shows close morphological similarity with the pollen of extant genus *Cullenia* of the family Bombacaceae. Plants of this modern genus are about 40 m tall evergreen trees and form canopy in medium elevations (600–1400 m). These are endemic to the Western Ghats occurring all along South Sahyadri and up to Wayanad in Central Sahyadri.

***Longapertites* spp.** [Figure 6 (15)]: Pollen grains elongatly oval in shape, size range 50–75 μm, monocolpate. Exine finely retic ulate.These pollen exhibit morphological resemblance with those of extant plant *Pinanga dicksonii* in having an extended sulcus. Different species of *Longapertites* are extensively recorded from Palaeocene-Eocene successions of India, of which, *Longapertites*

Table 2 Comparison of Fossil palynomorphs with the Extant pollen flora of the Western Ghats area

Sl. No.	Fossil genera	Locality	Extant genera	Family	Present day distribution
1	*Albertipollenites* spp (Srivastava 1969)	Kutch Rajasthan Meghalaya	*Dipterocarpus indicus*	Diptercarpaceae	Endemic to Western Ghat
2	*Arengapollenites achinatus* (Kar 1985)	Kutch Cambay basin West Bengal	*Arenga*	Arecaceae	Endemic to Western Ghat
3	*Clavaperiporites heteroclavatus* (Samant and Phadtare 1997)	Cambay basin	*Garcinia travancorica*	Clusiaceae	Endemic to Western Ghat
	Cupanieidites spp. (Cookson and Pike)	Cambay basin	*Eugenia thwaitesii*	Myrtaceae	Western Ghat and Sri Lanka
4	*Dicolpopollis fragilis* (Salujha *et al.*. 1972)	Cambay basin Rajasthan Meghalaya North-west Himalayas	*Calamus*	Araceae	Endemic to Western Ghat
5	*Dipterocarpuspollnites retipilatus* (Kar 1992)	Cauvery basin Meghalaya	*Vateria type*	Diptercarpace-ae	Western Ghat and other moist tropical forest
6	*Foveotricolpites alveolatus* (Mandal and Rao 2001)	Meghalaya	*Dipterocarpus indicus*		Endemic to Western Ghat
7	*Incrotonipollis burdwanensis* (Jansosius and Hills 1979)	Rajasthan Cambay basin	*Croton malabaricus*	Euphorbiace-ae	Endemic to Western Ghat
8	*Intrareticulites brevis* (Kar 1985)	Kutch Cambay basin Rajasthan Upper Assam Meghalaya	*Shorea type*	Diptercarpac-eae	Western Ghat and other moist tropical forest
9	*Lakiapollis ovatus* (Venkatachala and Kar 1969)	Cambay basin, Kutch Rajasthan Assam Meghalaya Himachal Pradesh Meghalaya	*Cullinia*	Bombacaceae	Endemic to Western Ghat
11	*Longapertites* (van Hoeken-Klinkenberg 1974)	Cambay basin, Meghalaya	*Pinanga*	Arecaceae	Endemic to Western Ghat
12	*Margocolporites sahnii* (Ramanujam, Venkatachala and Rawat 1973)	Rajasthan	*Agrostistachys meeboldii*	Euphorbiace-ae	Endemic to Western Ghat

Table 2. *(Continued)*

		Kutch			
		Assam			
13	*Meliapollis naveleii* (Kar 1978)	Cambay basin,	*Toona / Walsura type*	Meliaceae	Western Ghat and other moist tropical forest
		Kutch			
		Rajasthan			
		Assam			
		Meghalaya			
		Himachal Pradesh			
14	*Neocouperipollis achinatus* (Kar and Kumar 1987)	Cambay basin, Kutch	*Arenga*	Arecaceae	Endemic to Western Ghat
		Rajasthan			
		Assam			
		Meghalaya			
		Himachal Pradesh			
15	*Paripollis broachensis* (Samant and Phadtare 1997)	Cambay basin	*Lophopetalum wightianum*	Celastraceae	Western Ghats and tropical rain forest of Malaysia
16	*Pellicieroipollis langenheimii* (Kar 1978)	Kutch	*Alangium salvifolium*	Alangiaceae	Endemic to Western Ghat
		Cambay basin			
17	*Podocarpidites* spp. (Cookson ex Couper)	Cambay basin	*Podocarpus wallichiana*	Podocarpace-ae	Western Ghat and other moist tropical forest
18	*Polybrevicolporites cephalus* (Sah and Kar 1974)	Kutch	*Garcinia talbotii*	Clusiaceae	Western Ghat and Sri Lanka
		Cambay basin			
		Upper Assam			
		Rajasthan			
		Himachal Pradesh			
		West Bengal			
19	*Polybrevicolporites indistinctus* (Samant and Phadtare 1997)	Cambay basin	*Garcinia morella*	Clusiaceae	Western Penninsular region, Malaysia
20	*Polycolpites/ Retistephanocolpites* spp. (Couper 1953)	Meghalaya	*Pedalium*	Pedaliaceae	Endemic to Western Ghat
		Rajasthan			
		Cambay basin			
		Himachal Pradesh			
21	*Polygalacidites* spp. (Sah and Dutta 1966)	Cambay basin	*Xanthophyllum*	Polygalaceae	Endemic to Western Ghat
		Upper Assam			
22	*Pseudonyssapollenites* kutchensis (kar 1985)	Kutch	*Gomphandra coriacea*	Icacinacea	Western Peninsular region
22	*Quillonipollenites* sp. (Rao and Ramanujam)	Cambay basin,	*Pinanga dicksonii*	Arecaceae	Endemic to Western Ghat
23	*Retimonocolpites thanikaimonii* (Samant and Phadtare 1997)	Cambay basin	*Myristica malabarica*	Myristicaceae	Endemic to Western Ghat

Table 2. *(Continued)*

24	*Rhoipites* sp. (Wodehouse)	Rajasthan	*Nothopegia beddomei*	Anacaerdiac-eae	Endemic to Western Ghat
25	*Sastripollenites trilobatus* (Kar 1978)	Cambay basin	*Calophyllum polyanthum*	Clusiaceae	Western Ghat and other moist tropical forest
26	*Striacolporites* sp. (van der Hammen)	Cambay basin	*Bhesa indica*	Celastraceae	Western Ghat and other moist tropical forest
		Kutch			
		Rajasthan			
27	*Tetracolporopollenites brevis* (Samant and Phadtare, 1997)	Cambay basin	*Palaquim ellipticum*	Sapotaceae	Endemic to Western Ghat
28	*Tricolpites reticulates* (Jain *et al*. 1973)	Kutch	*Hopea* type	Dipterocarpa-ceae	Western Ghat and other moist tropical forest
		Rajasthan			

vaneedenburgii is most common in both western and northeastern regions.

The exine ornamentation in the pollen of *Pinanga dicksonii* and the fossil pollen genus *Quilonipollenites* [figure 6 (14)] are similar as both have coarse reticulations. Most of the species assigned to *Quilonipollenites* have been recorded from Miocene deposits of various Indian sedimentary basins. However, one species *Q. minutus* with smaller pollen size as compared to *Pinanga dicksonii*, is known from Palaeocene-Eocene deposits of Rajpardi lignite, Cambay basin (Samant and Phadtare 1997). Plants of *Pinanga dicksonii* are slender, delicate, shade-loving endemic palm of the Western Ghat area which grow gregariously in the swamps with *Myristica*. These plants are locally common in moist pockets in evergreen forests of the Western Ghats.

Margocolporites sahnii [Figure 6 (1)]: Pollen grains oblate to sub-oblate in shape, size range 40–60 μm, tricolporate, longicolpate, apocolpal area psilate. Exine reticulate. This fossil species, recorded from palynological assemblages of Rajasthan, Kutch and Assam, shows close similarity with the extant pollen of *Agrostistachys meeboldii* which is common in the moist evergreen forests occurring on the banks of streams in evergreen and wet deciduous forests of Indian western peninsular regions. *Agrostistachys meeboldii* is endemic to the Western Ghat area and forms small under storey trees up to 5m tall. These plants generally occur in low elevations of wet evergreen forests of south and central Sahyadris and Malayasia.

***Meliapollis* spp.** [Figure 6 (4)]: Pollen grains spheroid to sub-spheroid in shape, size range 36–58 μm, tri- to pentacolporate. Colpi long to short, ora distinct. Exine psilate to weakly intrastructured. Different species of *Meliapollis* abundantly occur in Indian Palaeocene-Eocene palynological assemblages indicating wide distribution of the family Meliaceae. These fossil pollen show close similarity with those of extant *Toona cilata* and *Walsura trifolia* which are restricted to Western Ghats and western peninsula of India respectively. *Toona* trees are about 28 m tall and form canopy in evergreen to semi-evergreen moist deciduous forests up to 1200 m height. These plants occur in wider regions of the Western Ghat area. *Walsura trifolia* are about 15 m tall trees occurring as under storey in wet evergreen to semi-evergreen forests up to 1200 m height in the south and central Sahyadris in the Western Ghats area.

***Neocouperipollis* spp.** [Figure 6 (13)]: Pollen grains sub-spheroid to ovoid in shape, size range 40–85 μm, monosulcate. Sulcus often long, sometimes obscured. Exine spinose, spines variable in shape. Different species of this fossil genus are well documented from the Indian sedimentary basins of late Palaeocene-early Eocene age. These forms have been ascribed to the family Arecaceae. Other monosulcate fossil pollen with spinose exine *(Echimonocolpites*, *Monosulcites)* are also common in many of the palynological assemblages recorded from sedimentary successions of Palaeocene-Eocene time indicating widespread distribution of the family Arecaceae during early Palaeogene in the Indian subcontinent. *Neocouperipollis* pollen shows close resemblance with the pollen of extant Palm genus *Arenga,* the plants of which are small to medium-sized (2–20 m high) and commonly occur at the steep slopes of low and medium elevations of wet evergreen tropical rainforests. These plants are endemic to Western Ghats.

Paripollis broachensis: Pollen grains found in tetrahedral tetrads, individual grains prolate in shape, tricolporate, fossaperturate. Colpi long, ora indistinct. Exine verrucate, verrucae around poles fused together forming psilate caps. This fossil form, recorded only from Rajpardi lignite of Cambay Basin, shows close resemblance with the extant pollen of *Lophopetalum wightianum* of the family Celastraceae. Plants of this modern species are common in Western Ghat area and also occur in rain forests of Malaysia.

Pellicieroipollis langenheimii: Pollen grains triangular to sub-triangular in shape, size range 55–66 μm, tricolporate, brevicolpate. Pores distinct, lalongate, generally with thickened margin. Exine tegillate, bacula forming negative reticulum. The comparable extant pollen grains belong to *Alangium salvifolium* which is a common low land plant in the Western Ghat area.

***Podocarpidites* spp**. [Figure 5(12)]: Pollen grains varable in size, bisaccate, sacci equatorially attached, exine psilate, sulcus indistinct. Fossil species of this genus abundantly occur in Palaeocene-Eocene palynological assemblages of Cambay Basin, northwest Himalaya and Khasi Hills, Meghalaya. The comparable extant pollen are produced by *Podocarpus wallichiana* occurring in the areas of highest rainfall region of Western Ghats.

***Polybrevicolporites* spp.**: Pollen grains spheroid in shape, size range 30–40 μm, polycolporate. Colpi short, ora indistinct. Exine scabrate to psilate. Two species of *Polybrevicoporites* [*P. cephalus*, figure 6 (3). and *P. indistinctus*] are recorded from almost all Indian sedimentary basins. *P. cephalus* shows close similarity with the extant pollen of *Garcinia talbotii* whereas, *P. indistinctus*, recorded from Cambay Basin, shows resemblance with the extant *Garcinia morella.* Both of these extant species are common in the Western Ghat area. *Garcinia talbotii* also occurs in Sri Lanka.

***Polycolpites/Retistephanocolpites* spp.** [Figure 6 (11)]: Pollen grains spheroid in shape, multi-lobed, size range 30–50 μm, polycolpate. Exine microreticulate. Different species of both of these genera widely occur in Palaeocene-Eocene successions of India. Morphological characters of these fossil forms show close resemblance with the pollen of extant genus *Pedalium* that is common in the evergreen forest of Western Ghat area.

***Polygalacidites* spp.** [Figure 6 (10)]: Pollen grains sub-spheroid in shape, size range 32–50 μm, polycolporate. Exine psilate. These pollen are recorded from western and northeastern Palaeocene-Eocene successions of India. Pollen of extant genus *Xanthophyllum* shows close resemblance with these fossil forms. Trees of *Xanthophyllum* occur in low-lying evergreen forests and are confined to the southern part of the Western Ghat area.

Pseudonyssapollenites kutchensis [Figure 6(9)]: Pollen grains triangular to sub-triangular in shape, size range 32–46 μm, triorate. Exine finely reticulate. This fossil pollen, described from western Indian basins, show morphological similarity with the extant genus *Gomphandra* of family Icacinaceae. However, the granulate exine in *Gomphandra* is a character which is not in conformity to the diagnosis of *Pseudonyssapollenites kuthensis*. *Gomphandra* is native of Western Ghat area and is also common in Sri Lanka.

Retimonocolpites thanikaimonii [Figure 6 (7)]: Pollen grains spheroidal in shape, size range 46–55 μm, monocolpate. Exine reticulate. This species is very common in Palaeocene-Eocene successions of Cambay Basin. Morphological features of this form show resemblance with the pollen of extant *Myristica malabarica.* The plant is endemic to the Western Ghats, occurring in the moist evergreen rainforest area.

***Rhoipites* spp**. [Figure 6 (6)]: Pollen grains broadly oval in shape, size range 25–36 μm, tricolporate. Colpi long, ora distinct. Exine finely reticulate/pitted. Recorded from the Meghalya and Cambay basin, these forms resemble with the extant *Nothopegia bedomeii*. The plant is endemic to the Western Ghats, occurring along streams in the evergreen and moist areas.

Sastripollenites trilobatus [Figure 6 (2)]: Pollen grains subspheroidal in shape, size range 40–60 μm, tricolporate, trilobed, apocolpal areas thickened, pores distinct. Exine coarsely reticulate. Recorded from the Cambay basin, these fossil pollen grains show similarity with extant *Calophyllum polyanthum* of the family Clusiaceae. The plant is common in the south and central Western Ghat areas and is also found in China and Malaysia.

Striacolporites striatus: Pollen grains subspheroidal in shape, size range 55–78 μm, tricolporate, trilobed, colpi long, ora faint. Exine striate. Striate pollen grains are commonly recorded from the Palaeocene-Eocene successions of western Indian basins. These striate forms with tricolporate aperture closely resemble with extant pollen of *Bhesa indica* of the family Celastraceae. Trees of this modern plant are about 30 m tall and form canopy in the wet-evergreen forests of south Sahyadri of the Western Ghats area. The genus is also well distributed in the Malaysian tropical rain forests.

Tetracolporopollenites brevis: Pollen grains subprolate in shape, trilobed, size range 40–60 μm, tetra- to pentacolporate, colpi slit like, ora elliptical. Exine psilate. These fossil pollen reported only from Rajpardi lignite of Cambay Basin, Gujarat show close resemblance with the extant pollen of *Palaquim ellipticum*, except for the smaller size of the latter. *Palaquim ellipticum* is endemic to the Western Ghats, occuring in the highest rainfall areas.

Tricolpites reticulatus [Figure 5 (9–10)]: Pollen grains spheroidal-subspheroidal in polar view, size range 40-45μm, tricolpate. Exine reticulate, meshes variable in size. These fossil pollen resemble with those of the extant genera *Sorea/Hopea* and are common in tropical evergreen forests of Western Ghats, India, Malaysia and Sri Lanka.

6. Discussion

The pioneering hypothesis by Alfred Russell Wallace (1878) for explaining the high tropical biodiversity states that high diversity of rain forest resulted from long periods of stable tropical climate. Almost a century later, forest refugia hypothesis (Hafffer, 1969) developed with a far reaching

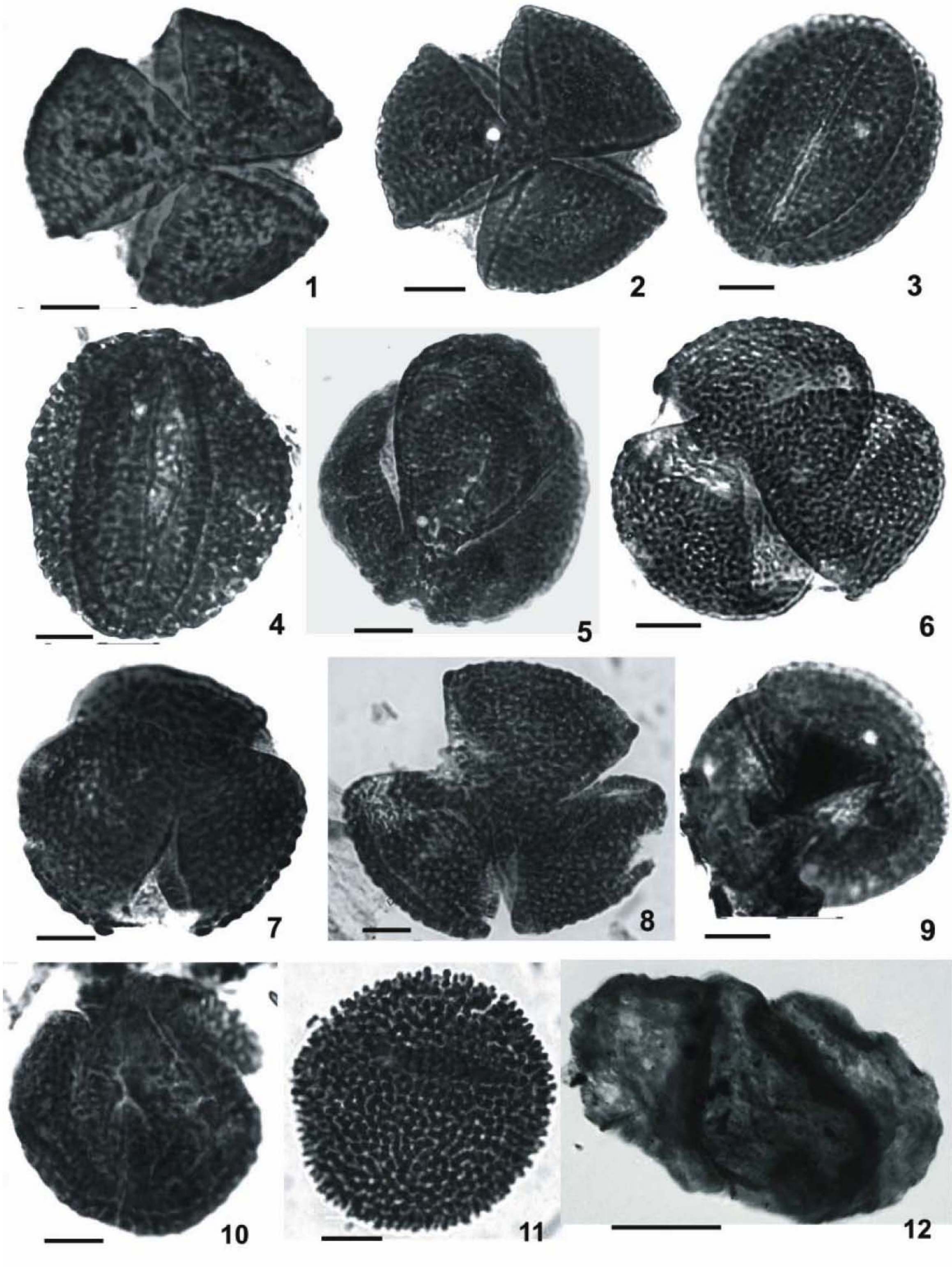

Figure 5. (1-5) *Foveotricolpites alveolatus*; (6, 7). *Albertipollenites kutchensis*; (8). *Dipterocarpuspollenites retipilatus*; (9, 10) *Tricolpites reticulatus*; (11) *Incrotonipollis* sp.; (12) *Podocarpidites* sp. (scale bar 10 μm).

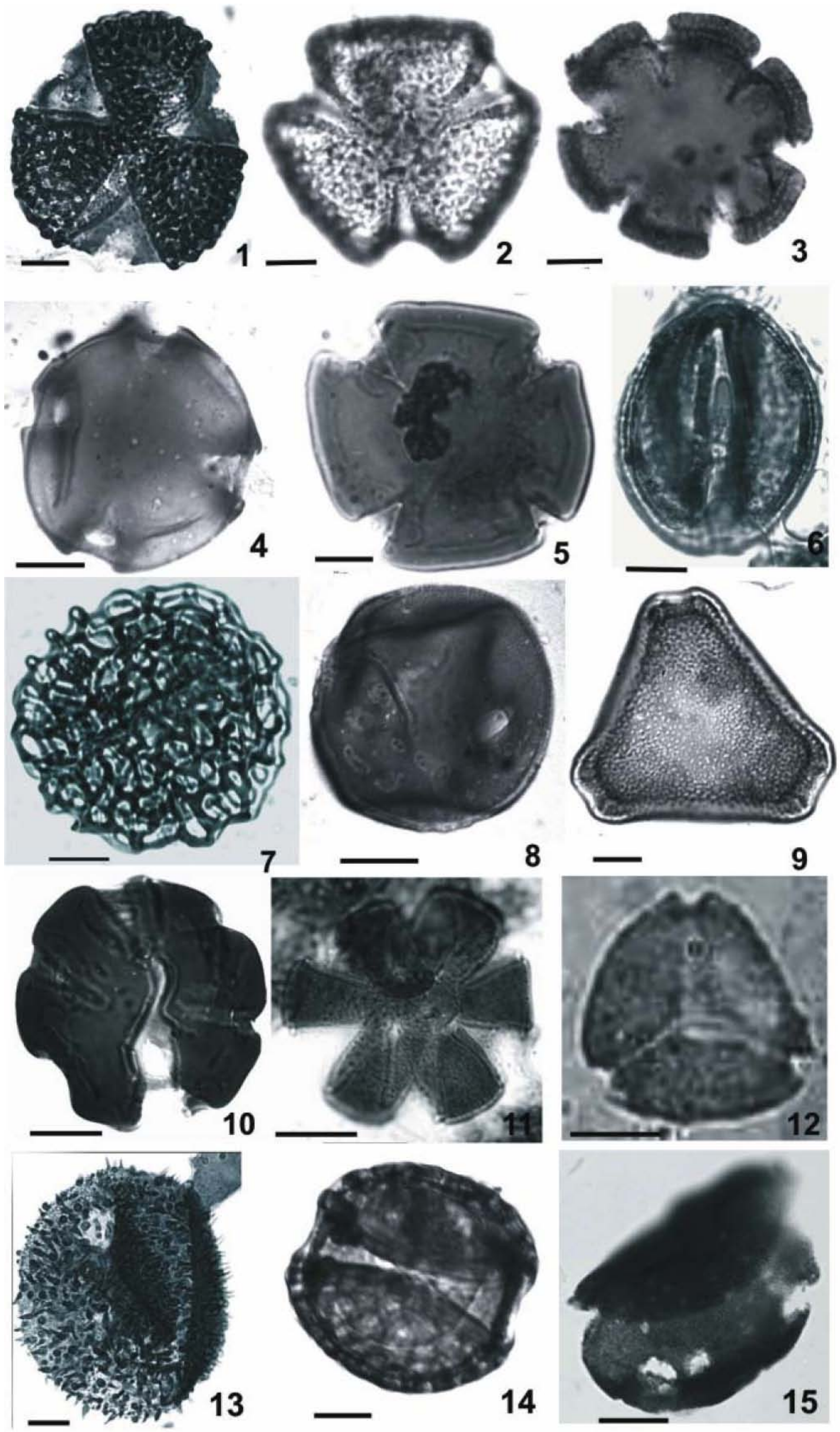

Figure 6. (1) *Margocolporites sahnii*; (2) *Sastripollenites trilobatus*; (3) *Polybrevicolporites cephalus*; (4) *Meliapollis* sp.; (5) *Meliapollis navalei*; (6) *Rhoipites* sp.; (7) *Retimonocolpites thanikaimonii*; (8) *Lakiapollis ovatus*;(9). *Pseudonyssapollenites kutchensis*; (10) *Polyglacidites* sp.; (11) *Polycolpites/Retistephanocolpites* sp.; (12) *Cupaiedites flabelliformis*; (13) *Neocouperipollis* sp.; (14) *Quilonipollenites* sp.; (15) *Longapertites* sp. (scale bar 10 μm).

concept that population of tropical rain forest become isolated in refugia during adverse climatic conditions of the geologic past. Haffer (1969) considered that this process was the principal speciation engine that had led to higher biodiversity. The areas outside such refugia experience so much reduction in precipitation that rain forest gets replaced by savanna type forest vegetation (Hooghiemstra and Van der Hammen 1998). Although the basis of refuge concept has been disputed, especially for the Neotropics (Colinvaux *et al.* 2001), it remains viable particularly for Africa, where severe climatic changes are evident during the Pleistocene ice age (Plana 2004).

In the present context, the geological records of the Western Ghats provide evidence of more or less consistent wet and humid climate during the distant past. Southern part of the Western Ghats has been the hotspot for tropical biodiversity with distinctive fauna and flora that displays high level of species endemism. It occupies only about 5% of the Indian penninsular region, but contains about 5000 species of flowering plants, including 857 tree species (Pascal 1986). There are also 58 endemic plant genera, 49 of which are monotypic (Ramesh *et al.* 1991). In the Western Ghats, occurrence of three plant community successions from west to east is a characteristic phenomenon. Under high mean rainfall (2500–5000 mm/yr), evergreen forests occur in the westernmost region while eastward on the plateau where rainfall is intermediate (1500–2000 mm/yr), moist deciduous forests replace evergreen forest. Further east, where the rainfall is sustained mainly by the summer monsoon, moist deciduous forest is replaced by dry deciduous forest vegetation (Barboni and Bonnefille 2001). Similar plant successions can be observed in the northward direction also.

The present study demonstrates that pollen of the evergreen vegetation in the high precipitation zone of south western part of the Western Ghats shows striking similarity with the fossil pollen of the late Palaeocene-early Eocene times (~55–50 Ma) recovered from northeastern and western parts of the Indian subcontinent. During this period of extreme global warming, India experienced excessive warm and humid climate with high precipitation (Prasad *et al.* 2006). The extant vegetation in this restricted zone of the Western Ghats, thus, represents the 'forest refugia' of the once widespread tropical rain forest that existed during early Palaeogene without undergoing much change subsequently during the geologic past. Outside the 'forest refugia', the vegetation got replaced by moist deciduous and subsequently further east by dry deciduous forest, as a result of post collision climate change and to a greater extent during more severe climate of the Pleistocene. This study provides evidence of a unique assemblage of early Palaeogene relic tropical rain forest vegetation in the southern Western Ghats that reinforces the conservation of the region at a time when biodiversity is being impacted on an unprecedented scale. It further substantiates the concept that high biodiversity of the modern tropical rain forest is a 'Tertiary legacy' (vide Hooghiemstra and Van der Hammen 1998), especially of the extreme global warming times of the early Palaeogene.

7. Conclusions

(1) Rich Palynofloral assemblages from coal and lignite bearing sedimentary successions of western and northeastern Indian region show existence of well diversified and widely distributed tropical rain forest community during late Palaeocene-early Eocene time interval.

(2) Palaeoequatorial positioning of Indian subcontinent and global warming phase of early Palaeogene (PETM and EECO) were instrumental in the development of excessive warm and humid climate over a wider expanse of the Indian subcontinent.

(3) The most common 28 fossil pollen of late Palaeocene-early Eocene times compare well with the extant pollen flora which are confined to the wet climatic zone of the Western Ghat area that receives 2500–5000 mm or even greater rainfall annually with only 2–3 months of dry season. Similar climatic conditions with very short dry seasons during late Palaeocene - early Eocene time interval over greater part of the Indian subcontinent are envisaged.

(4) Excessive wet climate and unique topographic setting of the Western Ghats provided more or less stable environmental conditions to sustain this ancient equatorial rain forest as refugia through the geological past.

(5) Present day high diversity of the Western Ghat area is a legacy of globally warm interval of the early Palaeogene when the tropical diversity was much higher than the present day and widespread over a greater part of the Indian subcontinent.

(6) High precipitation and low seasonality in climate of the low latitude equatorial region during early Palaeogene was the key factor in widespread distribution of the tropical rain forest community in the Indian subcontinent.

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