Some new carbonised woods from Neogene of Kerala coast and their bearing on palaeoclimate

N. Awasthi & Rashmi Srivastava

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Carbonised woods resembling extant species of *Hydnocarpus* (Flacourtiaceae), *Anisoptera* and *Hopea* (Dipterocarpaceae) and *Payena-Palaquium* (Sapotaceae) are recorded from the Neogene sediments of Varkala and Payangadi, Kerala coast. They have been named as *Hydnocarpoxylon keralaensis* sp. nov., *Anisopteroxylon varkalaensis* sp. nov., *Hopenium payangadiensis* sp. nov. and *Sapotoxylon prepayena* sp. nov., respectively. The modern equivalents of these woods are among the important elements of the tropical evergreen forest of Western Ghats, Burma and Malaysia indicating the prevalence of nearly equable warm climate and excessive humid conditions in the area at the time of their deposition during Mio-Pliocene.

Key-words—Carbonised woods, Dicotyledons, Kerala Coast, Neogene (India).

N. Awasthi & Rashmi Srivastava, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

सारांश

केरल तट के पश्चनूतन कल्प से कुछ नई कार्बनमय काष्ठें तथा पुराजलवायु में इनका महत्व

नीलाम्बर अवस्थी एवं रश्मि श्रीवास्तव

केरल तट पर वरकला एवं पयांगदी के पश्चनूतन अवसादों से **हिड्नोकार्पस** (फ़्लेकोर्शिएसी), **एँनाइसॉप्टेरा** एवं **होपिआ** (डिप्टेरोकार्पेसी) तथा **पयेना-पैलेक्वियम** (सैपोटेसी) की वर्तमान जातियों से मिलती-जुलती कार्बनमय काष्ठें अभिलिखित की गई हैं। इन्हें क्रमशः **हिड्नोकार्पोक्सीलॉन केरलायेन्सिस** नव जाति, **एँनाइसॉप्टेरॉक्सीलॉन वरकलायेन्सिस** नव जाति, **होपीनियम पयाँगदीयेन्सिस** नव जाति एवं **सैपोटॉक्सीलॉन प्रीपयेना** नव जाति से नामांकित किया गया है। इन काष्ठों के वर्तमान वर्गक पश्चिमी घाट, बर्मा एवं मलेशिया के उष्णकटिबन्धीय सदाहरित वनों के मुख्य अवयव हैं जो मध्यनूतन-अतिनूतन कल्प में इनके निक्षेपण के समय उष्ण जलवायु एवं अत्याधिक आर्द्र परिस्थितियों का होना इंगित करते हैं।

THE sedimentary sequence along the Kerala coast, classified as Warkalli beds of Mio-Pliocene age, contain rich deposits of carbonised woods. These are generally found associated with lignite, carbonaceous clays, sandy clays and white plastic clays. A number of dicotyledonous woods have been described earlier as *Calophyllum, Gluta, Swintonia, Diospyros, Dryobalanops, Cynometra, Terminalia, Gonystylus, Canarium* and a lauraceous member closely comparable to *Cinnamomum-Litsea* complex from Varkala cliff section and Payangadi Super Clay Mine by Awasthi and Ahuja (1982), Awasthi and Panjwani (1984) and Awasthi and Srivastava (1990).

The main objective of this study is to generate additional data for reconstruction of palaeoflora and palaeoclimate of the region and to trace out the history of the tropical evergreen forests of Western Ghats. The carbonised woods investigated from Varkala and Payangadi show close resemblance with those of *Hydnocarpus, Anisoptera, Hopea* and *Payena-Palaquium* complex of Sapotaceae.

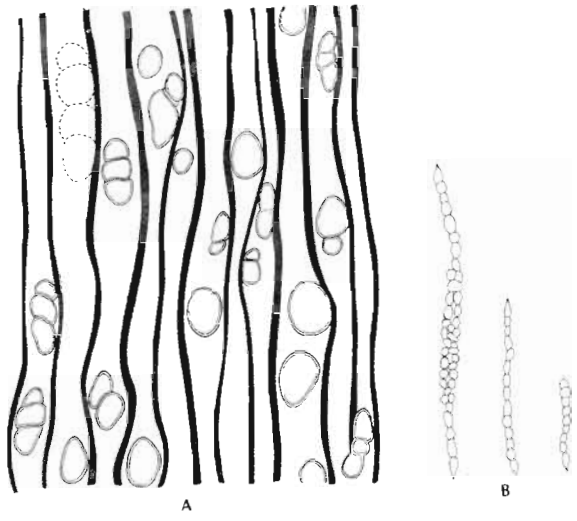
SYSTEMATIC DESCRIPTION

Family—Flacourtiaceae

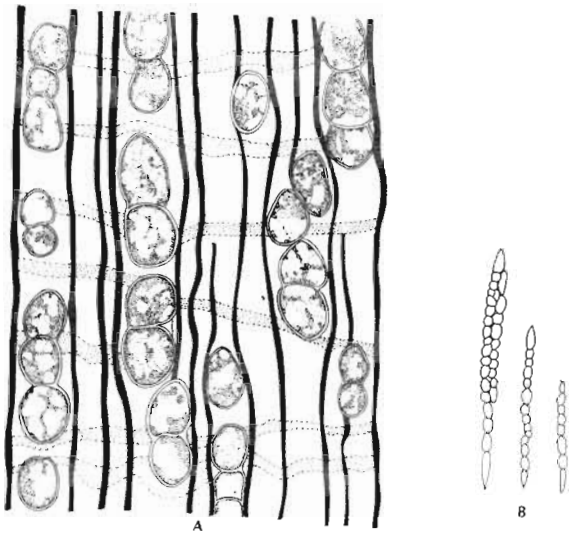
Genus—*Hydnocarpoxylon* Bande & Khatri 1980

Hydnocarpoxylon keralaensis sp. nov.
Pl. 1, figs 1-5; Text-figs A, B

Description—Wood diffuse-porous. *Growth rings* indistinct. *Vessels* solitary and in radial



Text-figure 1—*Hydnocarpoxylon keralaensis* sp. nov.—**A.** Cross section showing vessels, × 100; **B.** 1-3 Seriate heterocellular rays, × 100.



Text-figure 2—*Sapotoxylon prepayena* sp. nov.—**A.** Cross section showing distribution pattern of vessels tyloses in vessels and thin bands of apotracheal parenchyma, × 100, **B.** 1-2 seriate heterocellular rays, × 100.

multiple of 2-3, occasionally more, mostly small, rarely medium in size, oval or flattened due to compression, t.d. 32-96 μm, r.d. 48-175 μm; evenly distributed, about 20-30 vessels per sq mm, profusely tylosed; perforations scalariform with 18 22 horizontal bars, sometimes branched; vessel-members 175-800 μm long; inter-vessel pits not observed. *Parenchyma* absent. *Rays* 1-3 (mostly 1-2) seriate; uniseriate rays consisting of mostly upright cells, sometimes a few procumbent cells also occur in between, multiseriate rays consisting of procumbent cells in the median portion with uniseriate marginal extensions of upright cells at both the ends 10-45 cells or 160-1280 μm in height, crystalliferous; upright cells 24-48 μm in tangential height and 20-32 μm in radial length; procumbent cells 16-20 μm in tangential height and 40-60 μm in radial length. *Fibres* aligned in radial rows, semilibriform, septate.

Affinities—The present carbonised wood resembles closely that of the genus *Hydnocarpus* Gaertn. of the family Flacourtiaceae (Metcalfe & Chalk, 1950) in having important features, such as small to medium-sized tylosed vessels, scalariform perforations, absence of parenchyma, 1-3 (mostly 1 2) seriate, heterogeneous xylem rays and septate fibres. A detailed comparison of the fossil wood with a number of species of *Hydnocarpus* (Chowdhury & Ghosh, 1958; Desch, 1957; Pearson & Brown, 1932) revealed that it bears similarities with most of them. However, in having xylem rays 10-45 cells high and 18-20 bars in scalariform perforation plates the fossil shows closest affinities with the wood of *Hydnocarpus sumatrana*.

There is only one species of fossil wood of *Hydnocarpus*, *Hydnocarpoxylon mandalaensis* Bande & Khatri 1980 known so far, which is reported

PLATE 1 →

Hydnocarpoxylon keralaensis sp. nov.

1. Cross section showing nature and distribution of vessels, × 27; Slide no. BSIP 36383-I.
2. Cross section magnified to show shape and size of vessels, × 86; Slide no. BSIP 36383-I.
3. Scalariform perforation plate with bars in radial longitudinal section, × 340; Slide no. BSIP 36383-III.
4. Tangential longitudinal section showing rays, × 56; Slide no. BSIP 36383-II.
5. Radial longitudinal section showing heterocellular rays, × 86; Slide no. BSIP 36383-III.

Anisopteroxylon varkalaensis sp. nov.

6. Cross section showing nature and distribution of heavily tylosed vessels, × 30; Slide no. BSIP 36384-I.
7. Cross section magnified to show diffuse parenchyma, heavily tylosed vessels and solitary gum canals, × 85; Slide no. BSIP 36384-I(a).
8. Tangential longitudinal section showing multiseriate rays with sheath cells, × 120; Slide no. BSIP 36384-II.
9. Radial longitudinal section showing heterocellular rays, × 86; Slide no. BSIP 36384-III.

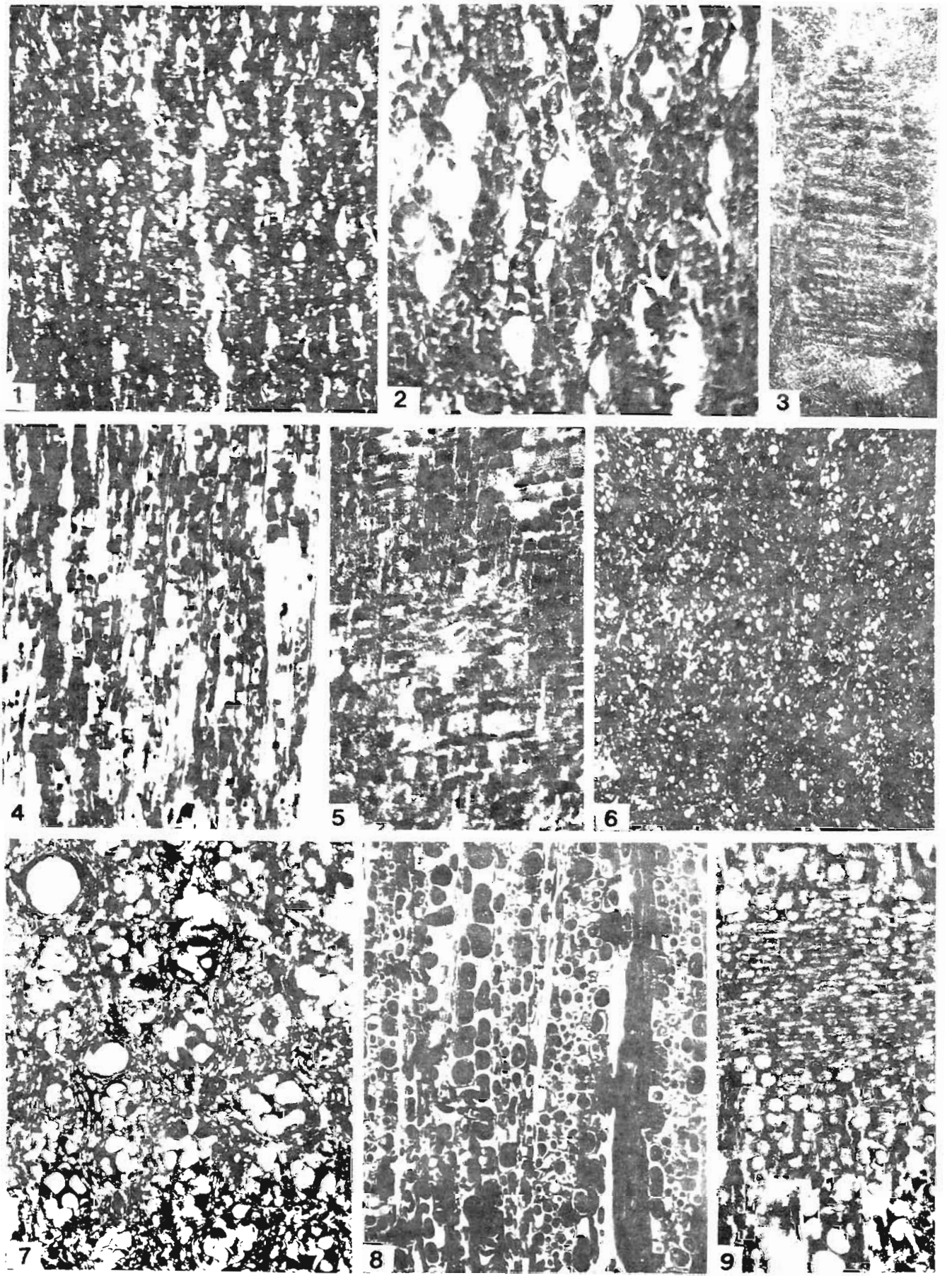


PLATE 1

from the Deccan Intertrappean beds of Mandla District. It differs from our fossil wood in having vessels in radial multiples of up to 11 with 40-60 per sq mm frequency. Besides, the height of xylem rays in *H. mandalaensis* is also more.

Holotype—Specimen no. BSIP 36383.

Locality—Varkala Cliff section, Varkala, Kerala.

Family—*Dipterocarpaceae*

Genus—*Anisopteroxylon Ghosh* & Kazmi 1958

Anisopteroxylon varkalaensis sp. nov.
Pl. 1, figs 6-9

Description—Wood diffuse-porous. *Growth rings* indistinct. *Vessels* mostly solitary, rarely in radial multiples of 2-3, small to medium in size, t.d. 80-160 μm, r.d. 64-192 μm, circular to oval, uniformly distributed, about 25-30 vessel per sq mm; heavily tylosed (Pl. 1, fig. 7); perforations simple; vessel-members 240-640 μm long with transverse to oblique septa; inter-vessel pits small to medium, alternate, 6-8 μm in diameter, vestured. *Vasicentric tracheids* present, intermingled with vasicentric parenchyma. *Parenchyma* paratracheal and apotracheal, paratracheal scanty; apotracheal parenchyma diffuse to diffuse-in-aggregate, sometimes forming uniseriate interrupted lines; cells 20 μm in diameter and 54-130 μm in length. *Rays* 1-7 (mostly 4-5) seriate, heterogeneous; uniseriate rays rare, 6-12 cells in height, consisting of upright cells only; multiseriate rays 2-7 cells or 40-160 μm broad and 16-120 cells or 350-2000 μm in height; heterocellular, consisting of procumbent cells and 2-10 marginal rows of square or upright cells at one or both the ends, sheath cells present, occurring throughout the flank of multiseriate rays; upright and square cells 20-44 μm in tangential height and 16-32 μm in radial length; procumbent cells 12-20 μm in tangential height and 20-32 μm in radial length. *Fibres* aligned in radial rows between two consecutive rays, 20-25 μm in diameter, nonseptate, libriform. *Gum canals* vertical, diffuse, mostly solitary, sometimes in pairs, 40-96 μm in diameter.

Affinities—Presence of vertical diffuse gum canals, heavily tylosed medium-sized vessels, paratracheal and apotracheal diffuse to diffuse-in-aggregate parenchyma, heterocellular xylem rays with upright cells completely sheathing multiseriate rays, suggests close similarity of the carbonised woods with that of the genus *Anisoptera* of Dipterocarpaceae. From a detailed comparison with a number of species of *Anisoptera* it was found that the anatomical features of the fossil wood collectively indicate its similarity with that of *A. polyandra* Bl.

Seven species of the genus *Anisopteroxylon* Ghosh & Kazmi are known from the Neogene sediments of India, viz., *Anisopteroxylon bengalensis* Ghosh & Kazmi, 1958 from west Bengal, *A. jawalamukhi* Ghosh & Ghosh 1958 from the Siwalik sediments near Jawalamukhi, *A. coromandalensis* Navale 1963 from the Cuddalore Sandstone near Pondicherry, *A. garoense* (Chowdhury) Prakash & Tripathi 1976 from the Tipam Sandstone of Hailakandi, Assam and Garo Hills, *A. kalagarhensis* Prakash 1978 and *A. oblongoides* Yadav 1989 from the Siwalik sediments of Kalagarh and *A. shantiniketanense* Ghosh & Roy 1980 from near Shantiniketan, west Bengal. Our fossil wood *A. varkalaensis* differs from all these species in having relatively smaller and more frequent vessels (t.d. 80-160 μm, r.d. 64-192 μm) and higher rays.

Holotype—Specimen no. BSIP 36384

Locality—Varkala Cliff section, Varkala, Kerala.

Genus—*Hopenium* Awasthi 1980

Hopenium payangadiensis sp. nov.
Pl. 2, figs 1-4, 9

Description—Wood diffuse-porous. *Growth rings* distinct, crowding of vessels at regular intervals indicates beginning of annual growth increment (Pl. 2, fig. 2), *Vessels* solitary and in radial multiples of 2-3, small to medium in size, t.d. 48-240 μm, r.d. 64-220 μm, round to oval when solitary and flattened at places of contact when in radial multiples, heavily tylosed, 23-28 vessels per sq mm; perforations simple; inter-vessel pits medium, 5-8 μm in diameter, vestured. *Vasicentric tracheids* present, not easily recognisable from parenchyma in cross section. *Parenchyma* paratracheal, vasicentric, most probably forming sheath of 1-3 cells around vessels; apotracheal parenchyma diffuse to diffuse-in-aggregate, cells sometimes scattered among fibres (Pl. 2, fig. 3). *Rays* 1-4 (mostly 3-4) seriate; ray tissue heterogeneous; uniseriate rays 2-12 cells or 80-288 μm in height and 8-16 μm broad, composed wholly of upright cells; multiseriate rays 2-4 seriate or 48-96 μm broad, heterocellular, consisting of procumbent cells through the median portion and 1-4 marginal rows of upright cells at both the ends (Pl. 2, fig. 4), crystalliferous square or upright cells interspersed among procumbent cells (Pl. 2, fig. 4), 8-38 cells or 200-600 μm in height; square or upright cells 24-48 μm in tangential height and 24-30 μm in radial length; procumbent cells 20-28 μm in tangential height and 28-45 μm in radial length. *Fibres* aligned

in radial rows between two consecutive rays (Pl. 2, fig. 3), 16-20 μm in diameter, non-septate, libriform *Gum canals* vertical, aligned in tangential rows forming concentric rings, circular to oval, 48-144 μm in diameter.

Affinities—Occurrence of vertical gum canals in concentric rings, heavily tylosed medium to small sized vessels, vasicentric tracheids, paratracheal as well as diffuse parenchyma and thick-walled fibres suggest its affinity with the woods of *Shorea, Parashorea, Pentacme, Balanocarpus* and *Hopea* of the family Dipterocarpaceae. However, in having crystalliferous upright or square cells interspersed among procumbent cells of multiseriate rays the carbonised wood resembles that of *Hopea* and can be differentiated from other genera.

Critical examination of wood slides of *Hopea plagata* Vidal, *H. pentanervia* Symington ex G. H. S. Wood, *H. intermedia* King, *H. parviflora* Bedd., *H. ferruginea* Parijs, *H. sangal* Korth., *H. beccariana* Burck and *H. mengarwan* Miq. has revealed that the present fossil resembles closely the wood of *H. parviflora*. The only difference between the two is that the vessels in *H. parviflora* are slightly smaller.

So far four species of fossil woods of *Hopea* are known, viz., *Hopenium pondicherriense* Awasthi 1980 from the Cuddalore Sandstone near Pondicherry; *H. neyveliense* Awasthi 1984 from the Neyveli lignite deposits, Tamil Nadu; *H. prenutansoides* Prasad & Prakash 1988 and *H. kalagarhensis* Prasad & Prakash 1988 from the Siwalik sediments, Kalagarh, Uttar Pradesh. All these species show some significant differences from our fossil wood *H. payangadiensis*. In *H. pondicherriense* and *H. neyveliense* the frequency of vessels is more, i.e., 25-75 and 30-50 vessels per sq mm respectively as against up to 30 vessels in our fossil. Moreover, in *H. neyveliense* the gum canals are exceptionally large and more frequent. The gum canals in *H. kalagarhensis* are also bigger and their concentric rings are closely placed. The vessels and gum canals in *H. payangadiensis* are relatively bigger than in *H. prenutansoides*.

Holotype—Specimen no. BSIP 36385.

Locality—Payangadi Super-Clay Mine, district Cannanore, Kerala.

Family—Sapotaceae

Genus—*Sapotoxylon* Felix 1882

Sapotoxylon prepayena sp. nov.
Pl. 2, figs 5, 8, 10; Text-figs A, B

Description—Wood diffuse-porous. *Growth rings* absent. *Vessels* small to medium-sized, solitary and mostly in radial multiples of 2-6, round to oval in shape, t.d. 48-96 μm, r.d. 64-160 μm, somewhat obliquely arranged in radial line, about 12-16 vessels per sq mm; tyloses abundant, completely plugging the vessels; perforations simple, vessel-members short 172-350 μm in height with truncate ends; inter-vessel pits small, 5-8 μm in diameter, bordered, alternate with minute aperture. *Vasicentric tracheids* present, intermingled with vasicentric parenchyma. *Parenchyma* both paratracheal and apotracheal, apotracheal parenchyma abundant, occurring in the form of 1-3 cells thick, wavy, continuous or broken lines, each separated by 6-15 rows of fibres, about 2-6 lines per mm. *Rays* fine, 1-2 (mostly uniseriate), heterocellular, consisting of both upright and procumbent cells, 2-27 cells or 250-380 μm in height, upright cells 30-35 μm in tangential height and 28-30 μm in radial length; procumbent cells 12-16 μm in tangential height and 32-64 μm in radial length. *Fibres* aligned in radial rows between two consecutive rays, interrupted by thin bands of apotracheal parenchyma; small, 10-12 μm in diameter, thick-walled; semilibriform, non-septate.

Discussion—The above features collectively indicate that the fossil wood belongs to the family Sapotaceae. The family Sapotaceae is homogeneous in wood structure and therefore on the basis of wood anatomy it is not always possible to easily distinguish most of its genera from each other. However, it can be done only in exceptional cases when all the xylotomical characters are taken into consideration collectively after critical assessment. Detailed anatomical studies of various sapotaceous woods from their description and photographs (Desch, 1954; Hayashi *et al.*, 1973; Henderson, 1953; Kribs, 1969; Metcalfe & Chalk, 1950; Miles, 1978; Normand, 1960; Pearson & Brown, 1932), as well as thin sections revealed that the present carbonised wood shows maximum similarity with those of *Palaquium* and *Payena*. Their similarity with each other can be seen in shape, size and distribution pattern and frequency of vessels and parenchyma lines. However, in having predominantly uniseriate rays the fossil appears to be more akin to *Payena*.

A number of fossil woods belonging to the family Sapotaceae are known from different parts of the world. These are: *Sapotoxylon taeniatum* (Felix, 1882) from the Tertiary of Bavaria, Germany; *Manilkaroxylon diluviale* (Hofmann, 1948) from the Quaternary deposits of South America; *M. crystallophora* and *Palaeosideroxylon flammula* (Grambast-Fessard, 1968) from Upper Miocene of Castellane in South East France; *Sapotoxylon pacltovae* and *Manilkaroxylon bohemicum* (Prakash *et al.*, 1974) from the Oligocene of Bohemia, Czechoslovakia; *Sapotoxylon multiporosum* (Prakash

et al., 1982) from the Mio-Pliocene of Blue Nile, Ethiopia; *Tridemostemon tertiarum* and *Chrysophyllum zairense* (Bande *et al.*, 1987) from the Miocene of Zaire, Africa; *Siderinium deomaliense* (Prakash & Awasthi, 1970) from the Mio-Pliocene of Deomali, Arunachal Pradesh; *Madhucoxylon cacharense* (Prakash & Tripathi, 1977) from the Tipam Sandstone, Assam and *Chrysophylloxylon pondicherriense* (Awasthi, 1977) from the Cuddalore Sandstone near Pondicherry.

In having xylem rays predominantly uniseriate to occasionally biseriate and vessel profusely tylosed, the present fossil wood can be easily differentiated from all the known species. It may be pointed out that in all the above species the xylem rays are always more than 2-seriate and the vessels are not so profusely tylosed.

Though the present carbonised wood has been shown to be similar to *Payena*, yet possibility of its being still closer to certain other species of *Palaquium*, particularly the Malayan species, cannot be ruled out. We may, therefore, regard it as a new sapotaceous wood having close similarity with those of *Payena* and *Palaquium*. Accordingly, it is placed under the genus *Sapotoxylon* Felix and named as *Sapotoxylon prepayena* sp. nov., indicating its affinity with *Payena*.

Holotype—Specimen no. BSIP 36386.

Locality—Payangadi Super-Clay Mine, district Cannanore, Kerala.

PRESENT DISTRIBUTION AND PALAEOCLIMATIC IMPLICATIONS

Occurrence of *Hydnocarpus, Anisoptera, Hopea* and *Payena-Palaquium* in the Warkalli beds furnishes additional data for elucidating the climate at the time of their deposition. Early Tertiary marks the oldest occurrence of *Hydnocarpus* Gaertn. in India. At present as many as 40 species, distributed in the Indo-Malayan region, are known (Willis, 1973). In India, it is represented by 7 species (Santapau & Henri, 1973), occurring in the evergreen forests of Western Ghats, Assam and Andaman Island. *Hydnocarpus sumatrana*, the nearest living counterpart of the fossil, is found in Sumatra, Java, Borneo, Celebes and Philippines in rain forests (Sleumer, 1954).

The genus *Anisoptera* Korth. had wider distribution during Neogene, but has totally disappeared now from India. However, it continues to flourish luxuriantly in the evergreen forests of Chittagong to the east and southward to Burma, Thailand, Malay Peninsula, Sumatra and Borneo. *Anisoptera polyandra* Bl., a closely comparable species with carbonised wood, is known to occur in New Guinea in the evergreen forests (Hooker & Jakson, 1946). Like other dipterocarps, *Hopea* was also widely distributed in India during Neogene. At present, it is restricted to Western Ghats, Assam and the Andaman Island. *H. parviflora* with which the carbonised wood resembles most occurs in the evergreen forest of Western Ghats, from South Kanara to further south up to 1,100 m altitude, common in both the moist and dry forests in Malabar and Travancore up to an elevation of 900 m (Chowdhury & Ghosh, 1958).

Of the two sapotaceous genera *Palaquium* Bl. and *Payena* A. Dc., the former is represented in India by four species, occurring in the evergreen forests of Western Ghats, Garo Hills, Khasi Hills and Jaintia Hills, while the latter exists no more in India but is widely distributed in similar type of forests of Southeast Asia and Malayasia (Willis, 1973).

The living counterparts of the carbonised woods belonging to *Calophyllum, Dryobalanops, Canarium, Swintonia, Gluta, Cynometra, Terminalia, Diospyros, Leea, Gonystylus, Cinnamomum-Litsea* known from the same deposits have a similar distribution pattern in the Indo-

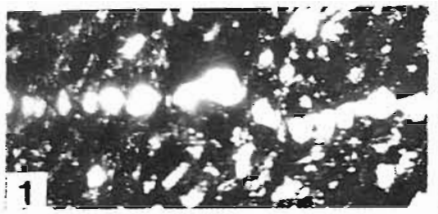
PLATE 2 →

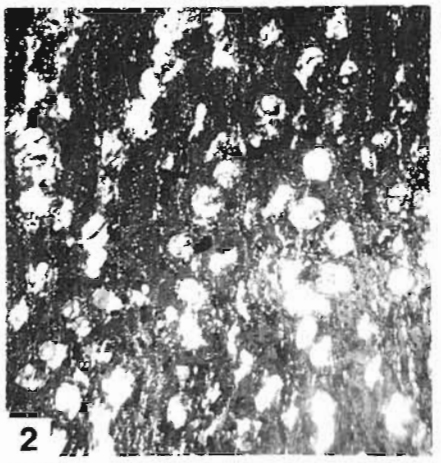
Hopenium payangadiensis sp. nov.

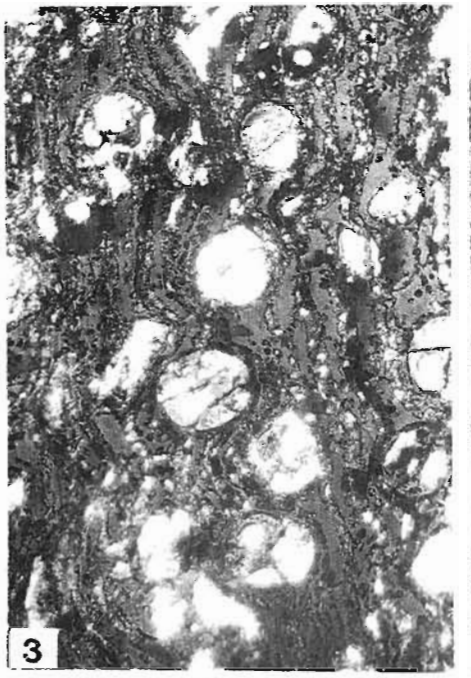
1. Cross section showing vertical gum canals in tangential row, × 27; Slide no. BSIP 36385-I(a).
2. Another cross section showing nature and distribution of vessels, × 27; Slide no. BSIP 36385-I(b).
3. Cross section magnified to show shape and size of vessels and distribution of parenchyma, × 86; Slide no. BSIP 36385-I(b).
4. Tangential longitudinal section showing heterocellular rays with upright cells interspersed amongst procumbent cells, × 86; Slide no. BSIP 36385-II.
9. Radial longitudinal section showing heterocellular xylem rays. × 86; Slide no. BSIP 36385-III.

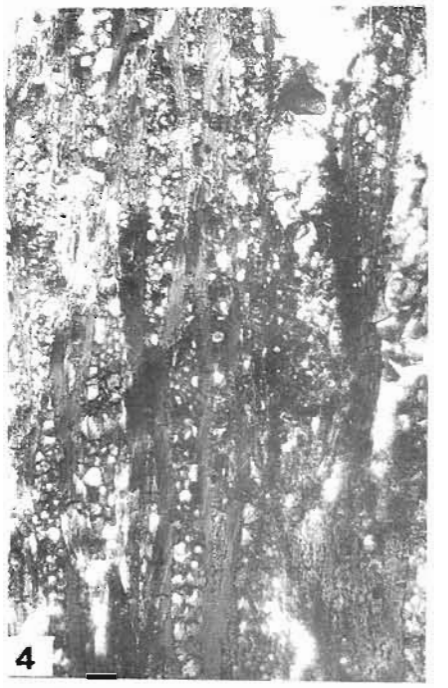
Sapotoxylon prepayena sp. nov.

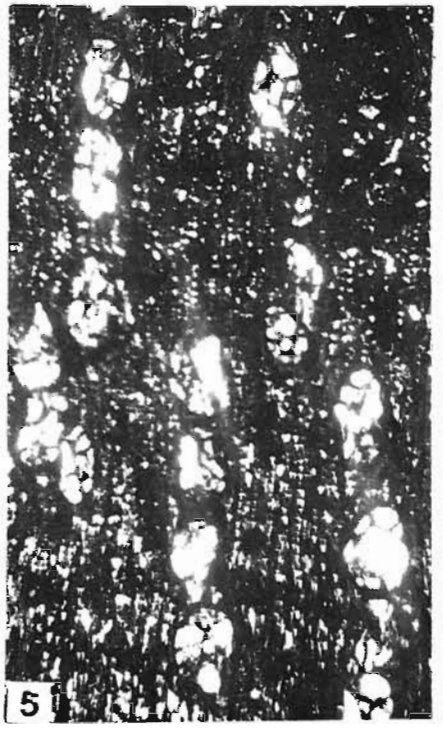
5. Cross section of carbonised wood showing distribution of vessels and parenchyma, × 80; Slide no. BSIP 36386-I.
6. Same section magnified to show shape and size of vessels and parenchyma, × 160; Slide no. BSIP 36386-I.
7. Tangential longitudinal section showing heterocellular uniseriate xylem rays, × 120; Slide no. BSIP 36386-II.
8. Radial longitudinal section showing heterocellular xylem rays, × 80; Slide no. BSIP 36386-III. 340.
10. Intervessel pits, × 340; Slide no. BSIP 36386-II.

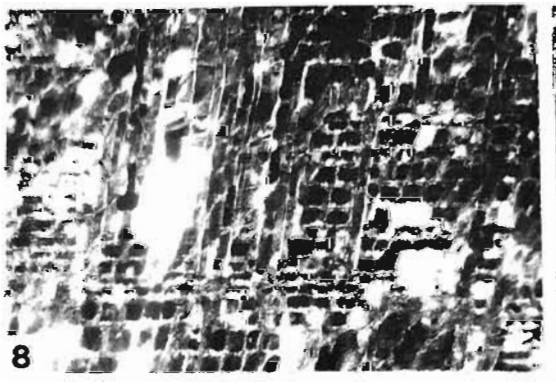












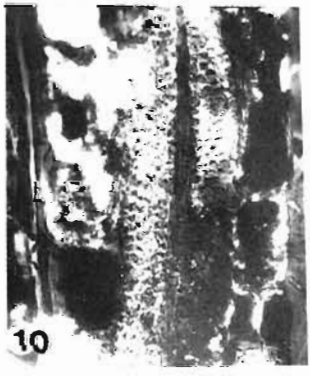


PLATE 2

Malayan region (Awasthi & Ahuja, 1982; Awasthi & Panjwani, 1984; Awasthi & Srivastava, 1989). Thus based on the collective evidence of the modern equivalents of megafossils, it may be inferred that the flora growing all along the Kerala coast during Mio-Pliocene was distinctly tropical with luxuriant forest vegetation dominated by evergreen elements. Further, presence of certain ecologically significant Malayan taxa, namely, *Dryobalanops*, *Anisoptera*, *Gonystylus*, *Payena* and certain species of *Hydnocarpus*, *Canarium*, *Swintonia* and *Leea* which totally disappeared from this region as well as from other parts of India during post Pliocene suggests the prevalence of excessive humid conditions as a result of higher rainfall throughout the year with a very short dry season. Disappearance of these taxa obviously reflects a considerable decrease in the annual precipitation, since in the tropical region it is mainly the rainfall which controls the distribution of plants.

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