INVESTIGATIONS OF SOME CARBONISED WOODS FROM THE NEOGENE OF VARKALA IN KERALA COAST*

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ABSTRACT

Carbonised woods associated with lignites and clays have been found in abundance in the Neogene sediments of Kerala Coast. Investigations of a number of such woods collected from the sea cliff section at Varkala of the Warkalli beds have shown that they belong to several genera of the dicotyledonous families. Out of the woods studied, seven are described in the present paper which show closest resemblance with those of *Calophyllum* (Guttiferae), *Dryobalanops* (Dipterocarpaceae), *Swintonia* (Anacardiaceae), *Cynometra* (Leguminosae), *Terminalia* (Combretaceae), *Diospyros* (Ebenaceae) and *Litsea-Cinnamomum* and allied genera of Lauraceae, respectively. The modern equivalents of these fossils are the important elements of the typical evergreen forests which unequivocally point towards the occurrence of tropical climate with plenty of rainfall in this region of Kerala during the Neogene times.

INTRODUCTION

The Tertiary rocks in Kerala are extended all along the coast from Cape Comorin in the south to Manjeshwar bordering the Mangalore District of Karnataka in the north They rest directly upon the Archaeans and are overlain by a variable thickness of recent to sub-recent marine and estuarine sediments. The details of geology of these sediments have been given by KING (1882) and further observations have been made by KUMAR AND PICHAMUTHU (1933), JACOB AND SASTRI (1952), DEY (1952), MENON (1967a, 1967b) and POULOSE AND NARAYANASWAMY (1968). KING classified the Tertiary sediments of Kerala into two : (1) The Lower Quilon beds consisting of fossiliferous limestone, carbonaceous clays, calcareous clays and sands, and (2) The Upper Warkalli beds(also spelt as Varkala beds) are of variegated sands, white plastic clays, carbonaceous clays and associated seams of lignite. They are very rich in plant remains. The age of Varkala beds, according to POULOSE AND NARAYANASWAMY (1968), is late Miocene or Miocene-Pliocene, and they are considered to be equivalent to the Cuddalore Sandstones.

Palaeobotanical study of Varkala lignite dates back to 1953 when VIMAL reported the pollen and spores from the lignite. Later, detailed palynological investigation of the lignite was made by RAMANUJAM (1960, 1972), RAMANUJAM AND RAO (1973, 1977), JAIN AND GUPTA (1972), JAIN AND KAR (1979) and KAR AND JAIN (1981) who described excellently preserved fungal spores, fungal fruiting bodies, pteridophytic spores, and pollen grains referable to several monocotyledonous and dicotyledonous families.

Although these palynological studies have revealed the occurrence of a large number of plant taxa, the affinities of most of them are not exactly known beyond the family level. For precise ecological and phytogeographical interpretation of the flora, identification of its components with modern ones, at least up to the generic level, is prerequisite, which can be done through the study of megafossils. So, in order to

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build up the Tertiary flora of Kerala Coast and to reconstruct its environment we have undertaken the studies of megafossils.

The material for the present study comprises carbonised woods collected by one of us (N. A.) during early 1971 from the carbonaceous clays exposed in the sea cliff section at Varkala belonging to the Warkalli beds. The sections of the woods were cut with the help of microtome. In the case of fragile material before sectioning it was dehydrated by keeping in different grades of alcohol and transferred to xylol, and then finally embedded in paraffin wax. A large number of pieces of carbonised woods were investigated and found to belong to several genera of the dicotyledonous families. The affinities of a few have been confirmed with the modern woods of *Calophyllum, Dryobalanops, Swintonia, Cynometra, Diospyros, Terminalia* and those of *Litsea-Cinnamomum* and allied genera of Lauraceae. They are described here in detail.

SYSTEMATIC DESCRIPTION

Family—GUTTIFERAE

Genus—**Calophylloxylon** Lakhanpal & Awasthi, 1965

Calophylloxylon sp.
Pl. 1, Figs. 1-3

Description—Wood diffuse-porous. *Growth rings* not seen. *Vessels* small to large, exclusively solitary, 6-8 per sq mm, appearing more or less round to oval, mostly compressed radially as well as tangentially, about 60-280 μm in diameter ; Vessel-members 160-360 μm in length, with truncate ends ; perforations simple ; pits leading to contiguous vasicentric tracheids, small, 5-6 μm in diameter, with slit-like aperture ; tyloses present, often completely occluding vessels (Pl. 1, Figs. 1 & 2). *Vasicentric tracheids* occurring around vessels or vessel groups. *Parenchyma* apotracheal, in concentric tangential wavy bands, being regular, about 4-5 per cm, each 3-5 cells in width ; cells probably round to oval, about 15-35 μm in diameter. *Rays* very fine, uniseriate to rarely biseriate due to pairing of procumbent cells, closely placed (Pl. 1, Fig. 3), about 36 μm in width ; rays heterocellular, consisting of procumbent cells through the median portion and 1-3 marginal rows of upright cells at both the ends, up to 25 cells in height. *Fibres* oval to angular, nonseptate, moderately thick-walled.

Affinities wih modern woods—The above anatomical features of the carbonised wood clearly indicate that it belongs to the modern genus *Calophyllum* L. of the family Guttiferae. With a view to identify it further up to specific level, thin sections of a number of modern species of *Calophyllum* were examined and literature consulted. The specific xylotomical differences taken into consideration in distinguishing the species of *Calophyllum* from one another are the shape, size, frequency and distribution or orientation of vessels, thickness and frequency of apotracheal parenchyma bands and sometimes the height of rays. But, since all the specimens of the carbonised wood are compressed exhibiting no definite shape, size and the arrangements of vessels, we find it difficult in ascertaining which of the species of *Calophyllum* could be its nearest modern equivalent.

However, in view of its close resemblance with the woods of *Calophyllum*, the present carbonised wood is placed under the genus *Calophylloxylon* Lakhanpal & Awasthi (1965).

Comparison with fossil species—There are a few fossil woods of *Calophyllum* known

so far from India and abroad, viz. *Calophylloxylon indicum* and *C. cuddalorense* (LAKHANPAL & AWASTHI, 1965) from the Cuddalore Series near Pondicherry ; *C. eoinophyllum* (PRAKASH, 1966, PRAKASH & AWASTHI, 1971) from the Tipam Series near Hailakandi, Assam and Dupitila Series of Deomali, Arunachal Pradesh ; *C. bengalensis* (GHOSH & ROY, 1979) from the Miocene of Birbhum District, West Bengal ; *C. garcinioides* (LEMOIGNE, 1978) from the Neogene of Ethiopia and *Calophylloxylon* sp. cf. *C. indicum* Lakhanpal & Awasthi (KRAMER, 1974) from the early Quaternary of Java. Besides, there is one more species, *Calophylloxylon dharmendrae* (BANDE & PRAKASH, 1980) from the Deccan Intertrappean beds near Shahpura in Mandla District, Madhya Pradesh, whose affinities with *Calophyllum* appear to be doubtful. All these species show general similarity with our fossil, but due to the reasons stated above it is very difficult to decide whether it could be a different species of *Calophylloxylon*. Hence we prefer to name it as *Callophylloxylon* sp.

Specimen—B.S.I.P. Museum no. 36035

Family—DIPTEROCARPACEAE

Genus—**Dryobalanoxylon** Den Berger, 1923

Dryobalanoxylon keralaensis sp. nov.
Pl. 1, Figs. 4-6

Description—Wood diffuse-porous. *Growth rings* not seen. *Vessels* appearing as crowded dots to the naked eye in cross section, medium to large, t.d. 100-240 μm, r.d. 120-280 μm, circular to oval (Pl. 1, Fig. 5), exclusively solitary, evenly distributed, 15-20 per sq mm; due to heavy tyloses it is difficult to recognise and measure the length of vessel-members individually ; pits bordered, alternate, large, 8-10 μm, vestured. *Vasicentric tracheids* indistinguishable in cross section due to compression of the material, however, can be recognised in tangential section by the presence of bordered pits arranged in double rows. *Parenchyma* paratracheal and aportracheal ; paratracheal parenchyma vasicentric ; apotracheal parenchyma associated with concentric rings of gum canals ; cells circular to oval in shape in cross-section, 13-36 μm in diameter. *Rays* fine to broad, 1-5 seriate, mostly 3-5 seriate (Pl. 1, Fig. 6), 6-8 per mm ; ray tissue heterogeneous; uniseriate rays rare in comparison to multiseriate rays ; multiseriates up to 45 cells in height, usually with single or sometimes up to 4 marginal rows of upright cells at one or both the ends ; sheath cells occasionally present, *Fibre-tracheids* nonseptate, thick-walled with distinct bordered pits (Pl. 1, Fig. 4). *Gum canals* vertical, arranged in tangential rows, embedded within parenchyma (Pl. 1, Fig. 5), oval to flattened, t.d. 60-180 μm, r.d. 100-120 μm.

Affinities with modern woods—In having the important anatomical features, such as exclusively solitary vessels, vasicentric tracheids, thick-walled fibres with distinct bordered pits and concentric rows of vertical gum canals, the present fossil wood shows close similarity with the woods of *Dryobalanops* Gaertn. f. of the family Dipterocarpaceae.

Detailed comparison of the fossil was made with the thin sections of the modern woods of *Dryobalanops*, viz. *D. aromatica* Gaertn. f., *D. beccarii* Dyer, *D. lanceolata* Burck, *D. keithii* Symington, *D. rappa* Becc. and *D. oblongifolia* Dyer. It was found that the fossil shows similarity, in general, with all these species. However, considering the shape, size, frequency and arrangement of vessels, the amount of tyloses and parenchyma, it does not appear to be identical to any of the species examined. In these modern species the paratracheal parenchyma is sometimes diffuse in addition to occurring around gum canals

forming tangential bands and the tyloses are relatively less, whereas in the present fossil the paratracheal parenchyma is less, forming narrow vasicentric sheath; the frequency of vessels is much more and they are heavily tylosed.

Comparison with fossil species—the genus *Dryobalanoxylon* was instituted by DEN BERGER (1923) to include the fossil woods having close resemblance with that of the genus *Dryobalanops* of the family Dipterocarpaceae. Till now 14 species of this genus have been described, out of which *Dryobalanoxylon indicum* and *D. holdeni* (AWASTHI, 1971) are from the Miocene-Pliocene beds near Pondicherry, India, and the remaining 12 species, viz. *Dryobalanoxylon tobleri, D. spectabile, D. javanense, D. sumatrense, D. borneense, D. mirabilis, D. bangkoense, D. neglectum, D. musperi, D. rotundatum, D. khmerinum* and *D. tambouense*, are from the Neogene deposits of Java, Sumatra, Borneo, Cambodia and Viet-Nam (DEN BERGER, 1923, 1927 ; SCHWEITZER, 1958 ; SERRA, 1981).

Although the present fossil shows general similarity with all the above species in having all the basic characters of the genus *Dryobalanops*, yet considering the hitherto described features collectively it can be easily differentiated from them. The differences observed are in the size, frequency of vessels and gum canals, amount of parenchyma and tyloses, and the width, length and frequency of multiseriate as well as uniseriate rays which enable us to place the present fossil wood under a new species, *Dryobalanoxylon keralaensis.*

Specific Diagnosis—Wood diffuse-porous. *Growth rings* not seen. *Vessels* t.d. 100-240 μm, r.d. 120-280 μm, circular to oval, exclusively solitary, evenly distributed, 15-19 per sq mm, heavily tylosed ; pits leading to contiguous tracheids about 6-8 μm, bordered, alternate, vestured. *Vasicentric tracheids* present. *Parenchyma* paratracheal, vasicentric ; apotracheal parenchyma associated with concentric rings of gum canals. Rays fine to broad, 1-5 (mostly 3-5)seriate, 6-8 per mm, ray tissue heterogeneous, uniseriate rays rare, multiseriate rays up to 45 cells in height, usually single or sometimes up to 4 upright cells present at one or both the ends, sheath cells also present. *Fibre-tracheids* nonseptate, thick-walled, with distinct bordered pits occurring in a row. *Gum canals* vertical, arranged in tangential rows, seemingly oval, t.d. 60-180 μm, r.d. 100-120 μm.

Holotype—B.S.I.P. Museum no. 36036

Family—ANACARDIACEAE

Genus—**Swintonioxylon** Prakash & Tripathi, 1968

Swintonioxylon tertiarum sp. nov.
Pl. 1, Fig. 7 ; Pl. 2, Figs. 8-11.

Description—Wood diffuse-porous. *Growth rings* not seen. *Vessels* small to medium, t.d. up to 170 μm, r.d. up to 180 μm, mostly solitary, also in radial multiples of 2-3, sometimes in double rows, heavily tylosed ; vessel-members short to medium with tailed ends ; perforations simple ; intervessel pits oval to orbicular, large, 8-20 μm in diameter with lenticular aperture (Pl. 2, Fig. 11). *Parenchyma* both paratracheal and apotracheal ; paratracheal parenchyma vasicentric, forming 1-2 seriate sheath around vessels ; apotracheal parenchyma occurring in the form of 1-3 seriate closely placed lines or bands (Pl. 1, Fig. 7 ; Pl. 2, Fig. 8), about 3-4 per mm. *Rays* two types, simple and fusiform ; simple rays 1-3 seriate, mostly biseriate, 20-44 μm in width, heterocellular, consisting of procumbent cells in the middle portion and 1-5 marginal rows of upright or square cells at one or both the ends (Pl. 2, Fig. 9), solitary crystal present in both

procumbent as well as in upright cells, 5-26 cells high ; fusiform rays up to 8 cells wide and 50 cells in height with single gum canal in the centre (Pl. 2, Fig. 10) ; upright ray cells 12-80 μm in tangential height, 16-32 μm in radial length ; procumbent cells up to 16 μm in tangential height and up to 120 μm in radial length. *Fibres* aligned in radial rows, thick-walled, nonseptate. *Gum canals* horizontal, solitary, occurring in broad fusiform rays, about 16-32 μm in diameter.

Affinities with modern woods—Presence of two types of xylem rays, simple and fusiform with horizontal gum canal, large inter vessel pits, vasicentric as well as closely placed lines of parenchyma obviously suggests close affinity of the present fossil wood with the genus *Swintonia* Griff. of the family Anacardiaceae (METCALFE & CHALK, 1950). Detailed comparison of this fossil was made with the woods of modern species of *Swintonia*, viz. *S. floribunda* Griff., *S. foxworthyi* Elmer and *S. pierrei* Hance from their thin sections as well as published anatomical description and figures (GAMBLE, 1920 ; PEARSON & BROWN, 1932 ; CHOWDHURY & GHOSH, 1958 ; LECOMTE, 1926). It was found that the present fossil shows closest resemblance with *Swintonia foxworthyi* in having same frequency of parenchyma lines and the size and distribution of vessels.

Comparison with fossil species

Since the present fossil wood is closely allied to the modern woods of *Swintonia*, it is being placed under the genus *Swintonioxylon* Prakash & Tripathi (1968) which was instituted for the fossil woods of *Swintonia*. *Swintonioxylon hailakandiense* is the only species representing the genus described by PRAKASH AND TRIPATHI (1968, 1969) from the Tertiary of Assam. Although this fossil shows general similarity with our fossil in the nature and distribution of vessels, parenchyma and rays, there are some significant differences between the two. In *S. hailakandiense* the vessels are medium to large in size, paratracheal parenchyma is vasicentric to aliform-confluent and the apotracheal parenchyma bands are widely placed whereas in our specimen the vessels are small to medium, paratracheal parenchyma is vasicentric and the apotracheal lines are closely placed. We, therefore, describe the present fossil as *Swintonioxylon tertiarum* sp. nov.

Specific Diagnosis—*Wood* diffuse-porous. *Growth rings* not seen. *Vessels* small to medium, t.d. up to 170 μm, r.d. up to 180 μm, mostly solitary, also in radial multiples of 2-3, sometimes in short double rows, heavily tylosed ; vessel-members short to medium with tailed ends, perforation simple, intervessel pits large, 8-20 μm in diameter, alternate, oval to orbicular with lenticular aperture. *Parenchyma* paratracheal, vasicentric, forming 1-2 seriate sheath around the vessels ; apotracheal in the form of 1-3 seriate closely placed lines, about 3-4 lines per mm. *Rays* simple and fusiform ; simple rays 1-3 seriate, mostly biseriate, heterocellular, consisting of procumbent cells and 1-5 marginal rows of upright cells at one or both the ends, solitary crystal present in procumbent as well as in upright cells, 5-26 cells high ; fusiform rays up to 8 cells wide and 50 cells in height with single gum canal in the centre. *Fibres* aligned in radial rows, thick-walled, nonseptate. *Gum* canals horizontal, occurring singly in multiseriate fusiform rays, about 16-32 μm in diameter.

Holotype—B.S.I.P. Museum No. 36037

Family—LEGUMINOSAE

Genus—**Cynometroxylon** Chowdhury & Ghosh, 1946

Cynometroxylon holdeni (Gupta) Prakash & Bande, 1980

Pl. 2, Figs. 12-13.

Description—*Wood* diffuse-porous. *Growth rings* not seen. *Vessels* small to medium, t.d. 45-75 μm, r.d. 65-120 μm, solitary and in radial multiples of 2-4, occasionally up to 8, evenly distributed, 5-9 per sq mm ; perforations simple ; intervessel pits bordered, alternate with orbicular aperture, vestured ; tyloses absent, vessels filled with dark contents. *Parenchyma* banded, bands alternating regularly with fibre bands of almost equal width, enclosing vessels completely (Pl. 2, Fig. 12), about 6-8 bands per mm each about 4-12 cells wide. *Rays* 1-3 seriate, mostly 2-seriate (Pl. 2, Fig. 13), heterocellular, consisting of procumbent cells and 1-2 marginal rows of upright cells at one or both the ends, 8-12 per mm, about 8-20 cells in height. *Fibres* banded, bands alternating with parenchyma bands, thick-walled, nonseptate.

Affinities with modern woods—The above features of the fossil are characteristics of the modern woods of *Cynometra* Linn. and hence it is identified as *Cynometra*. Fossil wood resembling *Cynometra* are known to be abundantly found in the Neogene deposits of India, Southeast Asia and Africa. Most of them are named as *Cynometroxylon holdeni* (Gupta) Prakash & Bande (1980). As there is not much difference between the present fossil and the already known species, it is also being placed under the same species.

Specimen—B.S.I.P. Museum No. 36038

Family—COMBRETACEAE

Genus—**Terminalioxylon** Schönfeld, 1947

Terminalioxylon varkalaensis sp. nov.
Pl. 3, Figs. 14, 16-18.

Description—*Wood* diffuse-porous. *Growth rings* scarcely distinct, when present delimited by somewhat smaller vessels. *Vessels* small to medium, nearly circular in shape (Pl. 3, Figs. 14, 17), t.d. 60-160 μm, r.d. 60-180 μm, plugged with pale lemon yellow or brown contents, solitary and also in radial multiples of 2-3, evenly distributed, about 28-30 per sq mm ; vessel-members 420-820 μm long, with truncate ends ; perforations simple, horizontal to oblique; intervessel pits bordered, alternate and vestured, about 8-10 μm in diameter. *Parenchyma* scanty paratracheal, forming incomplete to complete, narrow sheath of 1-2 cells wide around vessels, occasionally extending side ways uniting with that of adjacent vessels (Pl. 3, Fig. 17), cells 18-22 μm in diameter. *Rays* extremely fine, uniseriate (Pl. 3, Fig. 18), rarely biseriate due to pairing of procumbent cells in the median portion, homocellular to heterocellular, consisting of procumbent and upright to square cells (Pl. 3, Fig. 16), upright to square cells 40-45 μm in tangential height, up to 22 μm in radial length ; procumbent cells 24-32 μm in tangential height, 36-100 μm in radial length, 4-28 (135-675 μm) cells high and 9-13 μm wide. *Fibres* small, 6-20 μm in diameter, radially arranged, thick-walled (Pl. 3, Fig. 16), nonseptate.

Affinities with modern woods—The above structural details of the fossil wood bring out certain typical diagnostic features which help in its identification. The small to medium-sized vessels with vestured pits, paratracheal parenchyma forming incomplete to complete narrow sheath of 1-2 cells around the vessels, occasionally extending sideways uniting with that of adjacent vessels ; rays uniseriate rarely biseriate due to pairing of procumbent cells through the median portion, homocellular to heterocellular ; fibres thick-walled nonseptate. These are the characters which give clear indication that the present fossil wood belongs to the genus *Terminalia* Linn. of the family Combretaceae (METCALFE & CHALK, 1950 ; PEARSON & BROWN, 1932).

Detailed comparison of the fossil was made with the thin sections of a number of species of *Terminalia*, out of which *T. chebula* Retz. *T. myriocarpa* Heurk. & Muell. Arg. and *T. travancorensis* W. & A. show close resemblance with our fossil in having less parenchyma. However, *T. myriocarpa* can be differentiated from the fossil in having very large vessels and septate fibres. The remaining two species are closest to our fossil in having nearly identical anatomical details.

Comparison with fossil species—The genus *Terminalioxylon* was instituted by SCHÖNFELD (1947) for the fossil woods showing resemblance with that of *Terminalia*. Since then a number of fossil woods of *Terminalia* were described from India and abroad. In 1973, MÄDEL-ANGLLIEWA AND MULLER-STÖLL amended the diagnosis of *Terminalioxylon* to include all the fossil woods of *Terminalia* as well as those resembling *Combretum* and *Anogeissus* of the Combretaceae. However, PRAKASH (1979) did not agree to it and suggested the retention of two fossil genera, *Terminalioxylon* and *Anogeissusoxylon* Navale (1964), on the basis of some minor anatomical differences. In *Anogeissus* the crystals are usually found in the ray cells while in *Terminalia* they occur both in parenchyma and ray cells.

So far, 31 species of the genus *Terminalioxylon* have been described from India and abroad. A list of 25 species has been given by MÄDEL-ANGLLIEWA AND MULLER-STÖLL (1973). The remaining 6 species are, *Terminalioxylon kratiense* Serra (1966) from the Tertiary or Quaternary of Cambodia, *T. welkitii* Lemoigne & Beauchamp (1972) from the Miocene of Welkite, Ethiopia, *T. tunesense* Duperon Laudoueneix (1973) from the Upper Oligocene of Tunisia, *T. densiporosum* Kramer (1974) from the Miocene of Sumatra and *Terminalioxylon* sp. Kramer (1974) from the Mio-Pliocene of Java and Sumatra.

After comparison with all the above mentioned 31 species of *Terminalioxylon* it was found that our fossil is quite different from some of them in not having terminal parenchyma while the other species differ in possession of abundant aliform confluent parenchyma which is relatively less in our specimen. Therefore the present fossil wood is named as *Terminalioxylon varkalaensis* sp. nov.

Specific Diagnosis—*Wood* diffuse-porous. *Growth rings* scarcely distinct, when present delimited by somewhat smaller vessels. *Vessels* small to medium, t.d. 60-160 μm, r.d. 60-180 μm, solitary and also in radial multiples of 2-3, evenly distributed, about 28-30 per sq mm; vessel-members 420-820 μm long, truncate ; perforations simple, horizontal to oblique ; intervessel pits bordered, alternate, vestured, about 8-10 μm in diameter. *Parenchyma* paratracheal, scanty, forming incomplete to complete, narrow sheath of 1-2 cells around vessels, occasionally extending sideways uniting with that of adjacent vessels. *Rays* extremely fine, closely placed, 14-18 per mm, uniseriate, very rarely biseriate ; homo-to heterocellular, consisting of procumbent and 1-2 marginal rows of upright or square cells, 4-28 cells high, tetra- to hexagonal crystals present in the ray cells. *Fibres* thick-walled, nonseptate, pits simple, small, about 4-5 μm in diameter.

Holotype—B.S.I.P. Museum no. 36039

Family—EBENACEAE

Genus—**Ebenoxylon** Felix, 1882

Ebenoxylon obliquiporosum sp. nov.
Pl. 4, Figs. 20-22

Description—*Wood* diffuse-porous. *Growth rings* not seen. *Vessels* medium to large, t.d. 120-180 μm, r.d. 130-248 μm, solitary as well as in radial multiples of 2-6 (mostly 3), arranged obliquely along radial lines (Pl. 4, Figs. 20-21,) 4-7vessels per sq mm; perforations simple ; vessels plugged with dark contents, vessel-members up to 648 μm long with truncate ends ; intervessel pitting alternate, bordered, orbicular, 5-8 μm in diameter with lenticular aperture. *Parenchyma* paratracheal and apotracheal ; paratracheal associated with the vessels, apotracheal parenchyma forming closely placed uniseriate tangential lines (Pl. 4, Fig. 21), about 8-11 lines per mm; cells circular to flattened in shape, 22-45 μm in diameter. *Rays* fine, closely placed, 20-22 per mm, uniseriate, rarely biseriate due to pairing of procumbent cells in the median portion (Pl. 4, Fig. 22), 7-20 cells high, heterocellular, consisting of procumbent cells and 1-3 marginal rows of upright cells at both the ends. *Ray cells* upright and procumbent ; upright cells 21-45 μm in tangential height and up to 18 μm in radial length ; procumbent cells 18-36 μm in tangential height and 54-90 μm in radial length, brownish black infiltration present. *Fibres* aligned in radial rows, semilibriform, nonseptate, thick-walled, 4-8 μm in thickness.

Affinities with modern woods—Taking into consideration all the important anatomical features collectively the present fossil wood shows a close similarity with those of *Diospyros* Linn. and *Maba* Forst. of the family Ebenaceae (METCALFE & CHALK, 1950). In order to find out its nearest modern equivalent about 50 species of *Diospyros* and 2 species of *Maba* were examined critically and it was found that *D. microphylla* Bedd. and *D. melanoxylon* Roxb. resemble the fossil in almost all the characters, such as in the shape, size, oblique or zig-zag arrangement of pores, exclusively uniseriate or rarely biseriate rays and the frequency of parenchyma lines.

Comparison with fossil species—So far 21 fossil woods have been referred to Ebenaceae from India and abroad (Table-1). However, the wood under invesigation

Table-1—Fossil woods referred to Ebenaceae

1. *Ebenoxylon ebenoides* Schenk, 1883 ; Kaiser, 1890	Libyan desert (Near Regenfeld)	Upper Cretaceous
2. *E. diospyroides* Felix, 1882, 1883 ; Kaiser, 1890	Antigua	Tertiary
3. *E. speciosum* Platen, 1908	California	Tertiary
4. *E. tenax Beck* 1886, Kaiser, 1890 ; Schonfeld, 1930	Saxony	Oligocene
5. *E. tunetanum* Fliche, 1888; Edwards, 1931	Tunisia (Ain Cherichira) ..	Pliocene
6. *Ebenoxylon* sp. Fliche, 1898	Mytilene (Orthymnos) ..	Tertiary
7. *E. boreale* Platen, 1908	Alaska	Tertiary (Oligocene)
8. *E. aegypticum* Kräusel, 1939	Egypt	Tertiary
9. *E. knollii* Hofmann, 1944 ; Greguss, 1956	Prambachkirchen Darno-Berges (Kom. Heves), Hungary.	Oligocene
10. *E. hofmannae* Greguss, 1956	Darno-Berges, Hungary ..	Oligocene
11. *Diospyroxylon* sp. cf. *D. ebenaster*, Greguss, 1967	Ipolytarnoc, Hungary ..	Miocene
12. *Diospyroxylon* sp. Greguss, 1967 ..	Helveti of Erd-Torokbalint, Hungary.	Miocene
13. *Diospyros washingtonia* Prakash & Barghoorn, 1961	Columbia Basalts	Miocene
14. *Diospyros* sp. Siljper, 1932	Holland	Pliocene
*15. *Ebenoxylon indicum* Ghosh & Kazmi, 1958	Assam	Miocene-Pliocene
16. Wood cf. *Diospyros* & *Maba* Navale, 1968	Neyveli lignite South India ..	Miocene

Table 1—(*Contd.*)

17. *Ebenoxylon kartikcherriense* Prakash & Tripathi, 1970	Tipam Sandstones, Cachar Distt., Assam		Upper Miocene
18. *Ebenoxylon arcotense* Awasthi, 1970 ..	Cuddalore Series, Tamil Nadu ..		Miocene-Pliocene
*19. *Ebenoxylon mohgaoense* Chitaley & Patil, 1972	Mohgaon Kalan ..	..	Early Tertiary
20. *Ebenoxylon miocenicum* Prakash, 1978 ..	Kalagarh (L. Siwalik)	..	Upper Miocene
21. *E. siwalicus* Prakash, 1982	Kalagarh (L. Siwalik)	..	Upper Miocene

*Affinities doubtful.

is quite different from all the species in the nature and distribution of vessels. The vessels in our fossil are characteristically and somewhat obliquely arranged along the radial lines. This type of arrangement of vessels is not seen in any of the known ebenaceous fossil woods. Hence a new specific name, *Ebenoxylon obliquiporosum*, is given to it. The specific name denotes the oblique arrangement of vessels.

Specific Diagnosis—Wood diffuse-porous. *Growth rings* not seen. *Vessels* medium to large, t.d. 120-180 μm, r.d. 130-250 μm, solitary as well as in radial multiples of 2-6 (mostly 3), arranged obliquely along radial lines forming zig-zag pattern, about 4-7 per sq mm ; perforations simple ; intervessel pits alternate, bordered, orbicular, 5-8 μm in diameter with lenticular aperture. *Parenchyma* both paratracheal and apotracheal ; paratracheal parenchyma represented by a few cells associated with vessels ; apotracheal parenchyma forming uniseriate tangential lines, about 8-11 per mm. *Rays* fine, 20-22 per mm, uniseriate, rarely biseriate due to pairing of procumbent cells in the median portion, 7-20 cells high, heterocellular, consisting of procumbent cells and 1-3 upright cells at one or both the ends. *Fibres* aligned in radial rows, semilibriform, nonseptate, thick-walled, 4-8 μm in thickness.

Holotype—B.S.I.P. Museum no. 36040.

Family—LAURACEAE

Genus—**Laurinoxylon** Felix, 1883

Laurinoxylon varkalaensis sp. nov.
Pl. 4, Figs. 23-24.

Description—Wood diffuse-porous. *Growth rings* not seen. *Vessels* medium to large, a few small, t.d. 80-240 μm, r.d. 128-280 μm, round to oval in shape, solitary and mostly in radial multiples of 3-4, heavily tylosed (Pl. 4, Fig. 93), closely placed ; vessel-members 224-288 μm in length with truncate ends; perforations simple; intervessel pits bordered with orbicular aperture. *Parenchyma* paratracheal, 2-3 seriate, forming narrow sheath round the vessels, sometimes gummy infiltration present in some parenchyma cells. *Rays* 1-3 seriate, mostly biseriate, 12-28 μm wide, 12-45 cells high, heterocellular, consisting of procumbent cells and 1-2 marginal rows of upright cells with oil cells at one or both the ends. *Fibres* semilibriform to libriform, septate. *Oil cells* abundant, scattered among the fibres and also occur at one or both the ends of rays (Pl. 4, Figs. 23-24).

The characteristic features of the present fossil wood are the presence of oil cells among the fibres as well as at the end of xylem rays, and septate fibres. This combination of characters clearly indicates the affinities of the fossil wood with those of the family Lauraceae. Xylotomically the woods of different genera of this family are not easily

distinguishable. However, taking into consideration various characters together they can be grouped into different combination of more than two genera.

While comparing the present fossil wood with the thin sections of several woods of the family Lauraceae it was found that our fossil wood shows close similarity with those of *Litsea-Cinnamomum* and allied genera, especially with *Cinnamomum zelanicum* Breyn. and a few species of *Litsea* Lamk. in the nature and distribution of parenchyma, oil cells and xylem rays.

Comparison with fossil species—In 1882, FELIX instituted the form genus *Laurinoxylon* to include the fossil woods having close similarity with the woods of the family Lauraceae. Since then a number of fossil woods have been referred to this genus from India and abroad. From outside India about 37 spp. have been described as listed by PRAKASH AND TRIPATHI (1974). They all show some significant differences from our fossil wood. From India four species of *Laurinoxylon* have been reported so far, viz. *Laurinoxylon tertiarum* (PRAKASH & TRIPATHI, 1974) from the Tipam Series near Hailakandi, Assam ; *L. namsangensis* and *L. deomaliensis* (LAKHANPAL *et al.*, 1982) from the Namsang beds near Deomali, Arunachal Pradesh, and *L. deccanensis* (BANDE & PRAKASH, 1980) from the Deccan Intertrappean beds near Shahpura in Mandla district, M.P. These also differ significantly from our fossil wood. *L. tertiarum* differs in having scalariform perforations. *L. namsangensis* and *L. deomaliensis* can also be differentiated in having bigger vessels and less parenchyma, and, moreover, in the former the oil cells are present only in rays while in the latter they are present only in the parenchyma. *L. deccanensis* shows marked difference in having exclusively solitary vessels and broader xylem rays. The present fossil wood is, therefore, described as a new species, *Laurinoxylon varkalaensis*.

Specific Diagnosis—Wood diffuse-porous. *Growth rings* not seen. *Vessels* medium to large, few small, t.d. 80-250 μm ; r.d. 128-280 μm, oval to round in shape, solitary, mostly in radial multiples of 3-4, heavily tylosed, closely distributed; perforations simple; intervessel pits bordered with orbicular aperture. *Parenchyma* paratracheal, 2-3 seriate, forming narrow sheath round the vessels, sometimes aliform ; oil cells scattered, gummy infiltration present in some parenchyma cells. *Rays* 1-3 seriate, mostly biseriate, 12-45 cells high, heterocellular, oil cells present at one or both the ends. *Fibres* semilibiform to libriform, septate. *Oil cells* abundant, scattered among the fibres and also occur at one or both the ends of rays.

Holotype—B.S.I.P. Museum no. 36041.

DISCUSSION

The present assemblage of carbonised woods, although very small, consisting of only seven species, may be considered to be of great value in deciphering the palaeoecology of this region. For critical evaluation of palaeoclimate and phytogeography it is necessary to mention here the distribution of modern counterparts of the fossils.

The genus *Calophyllum* consists of about 60 species (WILLIS, 1973) distributed in tropics of both the hemispheres having wider distribution in South-east Asia. In South India, about which we are concerned, there are three species, viz. *Calophyllum apetalum* Wall., *C. tomentosum* Wight and *C. inophyllum* L. occurring in the evergreen forests of Western Ghats from North Kanara to Travancore. The latter is generally found along the coast from Konkan southward above high water-marks (CHOWDHURY & GHOSH, 1958).

As compared to its fossil species, the genus *Dryobalanops* is small having survived with 9 species, restricted in its distribution to only the evergreen forests of Sumatra, Borneo and Malay peninsula. It is totally absent from the evergreen forests of the Indian sub-continent. Similarly the genus *Swintonia* is also confined to the Malayan region. Out of 14 species of the genus only one species, *Swintonia floribunda* whose fossil wood has already been found in the Tipam sandstones near Hailakandi, Assam, is now confined to the evergreen forests of Chittagong (Bangladesh) and Lower Burma. None of its species has been reported from South India. *Swintonia foxworthyi*, a closely related living species of Varkala fossil, is known to occur in the evergreen forests of Philippine.

The genera *Cynometra*, *Terminalia* and *Diospyros* have gained much popularity on account of their rich deposits as petrified and carbonised woods in the Neogene rocks of India and elsewhere. *Cynometra* consists of about 60 species, widely distributed mostly in the evergreen forests throughout the tropics. Six species are reported from India out of which four species, viz. *Cynometra beddomei* Prain, *C. bourdilloni* Gamble, *C. travancorica* Bedd. and *C. ramiflora* Linn., are found in the evergreen forests of Western Ghats, while *Terminalia* is a large genus having about 250 species of very large trees, widely distributed in the tropical regions of both the hemispheres. *Terminalia chebula*, the nearest modern counterpart of the fossil described here, is found throughout India and Burma. In the Western Ghats it occurs on dry slopes. *Diospyros* is still a larger genus consisting of about 500 species, widely distributed throughout tropical and sub-tropical regions of both the hemispheres. In South India, it is represented by 24 species mainly growing in the evergreen forests. *Diospyros microphylla* and *D. melanoxylon*, the closest modern equivalent of the fossil, are important elements of the evergreen forests of Western Ghats, occurring from North Kanara to Travancore and extending further to Waynaad and Anamalais and ascending to 900 m. The former is also known to have a wider distribution in the tropical evergreen forests of Malay peninsula.

The lauraceous wood recovered belongs to either of the species of *Cinnamomum* or *Litsea*, both are still found along with other members of the family in the evergreen forests of Western Ghats.

It is thus evident that the broad climatic setting of the flora of Varkala beds has been somewhat like that of the flora of the Western Ghats. Except *Dryobalanops* and *Swintonia* all other members of the present assemblage still continue to exist in this region. Absence of *Swintonia* from South India and total disappearance of *Dryobalanops* from the Indian sub-continent poses an enigmatic problem as to what could be the reasons. The latter was luxuriantly growing in South India during the Neogene as evidenced by its rich deposits of silicified woods in the Cuddalore sandstones near Pondicherry (AWASTHI, 1970). Apart from many other factors determining the distribution of plants, the rainfall or the annual precipitation plays an important role. Some of the plants are so sensitive to the environment that they fail to regenerate even if the amount of annual rainfall or the humidity is slightly lowered. *Swintonia* and *Dryobalanops* seem to belong to a category of such plants which are surviving today only in the rain-forests where there is high precipitation and rain falling almost every day. We may, therefore, broadly conclude that during the Neogene times this part of the country was recepient of more rainfall than today. Based on palynofossils recovered from the Varkala and Quilon lignites referable to several tropical evergreen families of angiosperms and a large number of spores and fungal fruiting bodies, RAMANUJAM (1977) had drawn similar conclusions regarding the palaeoenvironments of this region. Since

the investigation of the megafossils from several localities of Kerala Coast is in progress, more data are expected to be available soon which will enable us to discuss more precisely the ecological and phytogeographical implications of the Neogene flora of Kerala Coast.

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EXPLANATION OF PLATES

PLATE 1

Calophylloxylon sp.

1. Cross sectoin showing nature and distribution of vessels and parenchyma. ×6. B.S.I.P. Museum slide no. 6704.
2. Cross section magnified to show details of vessels and parenchyma band. ×45. B.S.I.P. Museum slide no. 6704.
3. Tangential longitudinal section showing rays. ×100. B.S.I.P. Museum slide no. 6705.

Dryobalanoxylon keralaensis sp. nov.

4. Fibre-tracheids in tangential longitudinal section showing bordered pits. ×450. B.S.I.P. Museum slide no. 6707.
5. Cross section showing vessels, parenchyma and tangential row of gum canals. ×40. B.S.I.P. Museum slide no. 6706.
6. Tangential longitudinal section showing rays. ×100. B.S.I.P. Museum slide no. 6707.

Swintonioxylon tertiarum sp. nov.

7. Cross section showing vessels and apotracheal parenchyma lines. ×30. B.S.I.P. Museum slide no. 6708.

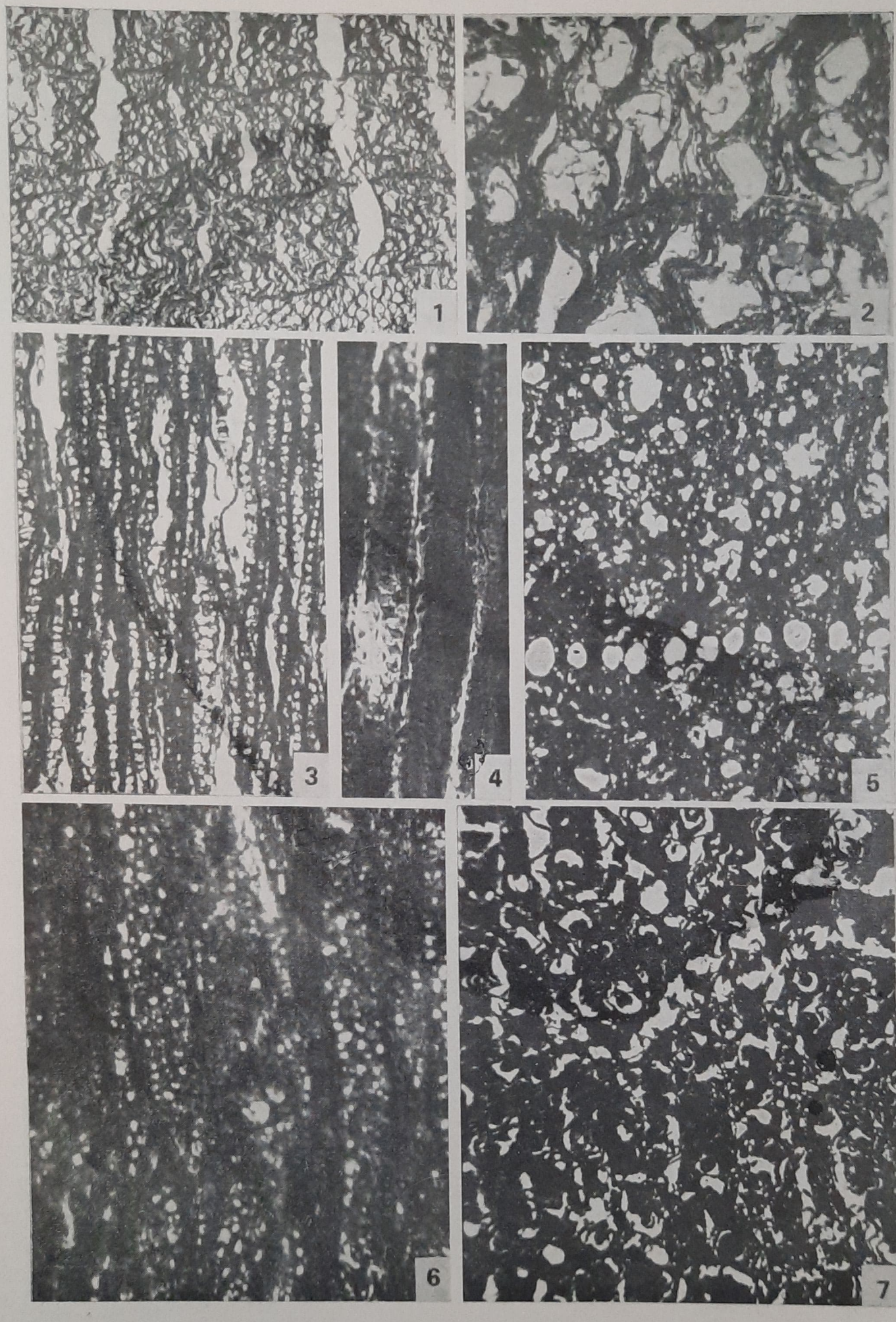
PLATE 2

Swintonioxylon tertiarum sp. nov.

8. Cross section magnified to show vasicentric parenchyma and apotracheal parenchyma lines. ×100. B.S.I.P. Museum slide no. 6708.
9. Tangential longitudinal section showing 1-2 seriate simple rays. ×100. B.S.I.P. Museum slide no. 6709.
10. A portion of tangential longitudinal section magnified to show multiseriate ray with horizontal (radial) gum duct. ×135. B.S.I.P. Museum slide no. 6709.
11. Intervessel pits. ×480. B.S.I.P. Museum slide no. 6709.

Cynometroxylon holdeni (Gupta) Prakash & Bande

12. Cross section showing vessels and parenchyma bands. ×45. B.S.I.P. Museum slide no. 6710.
13. Tangential longitudinal section showing rays. ×110. B.S.I.P. Museum slide no. 6711.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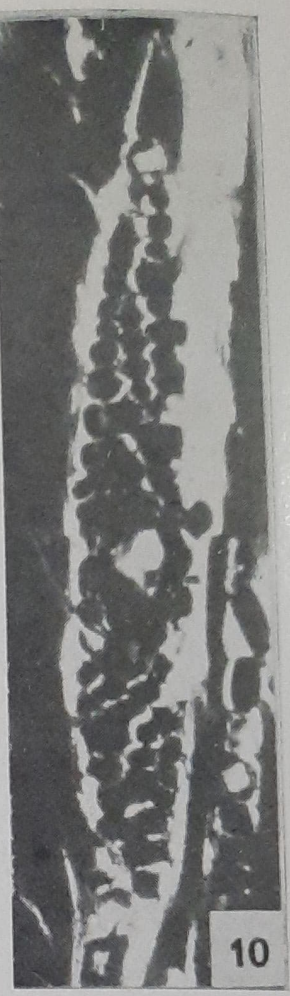
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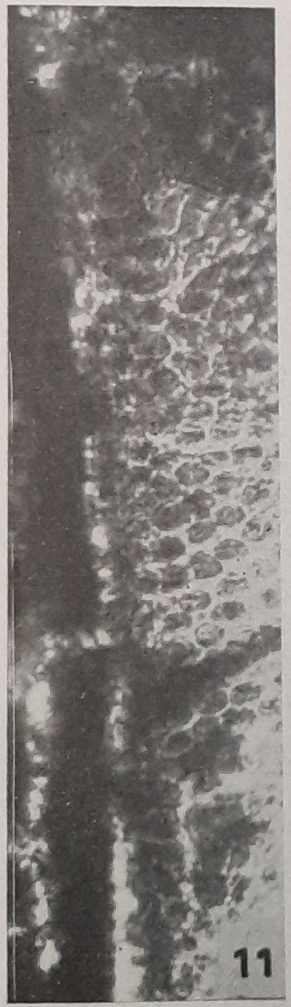
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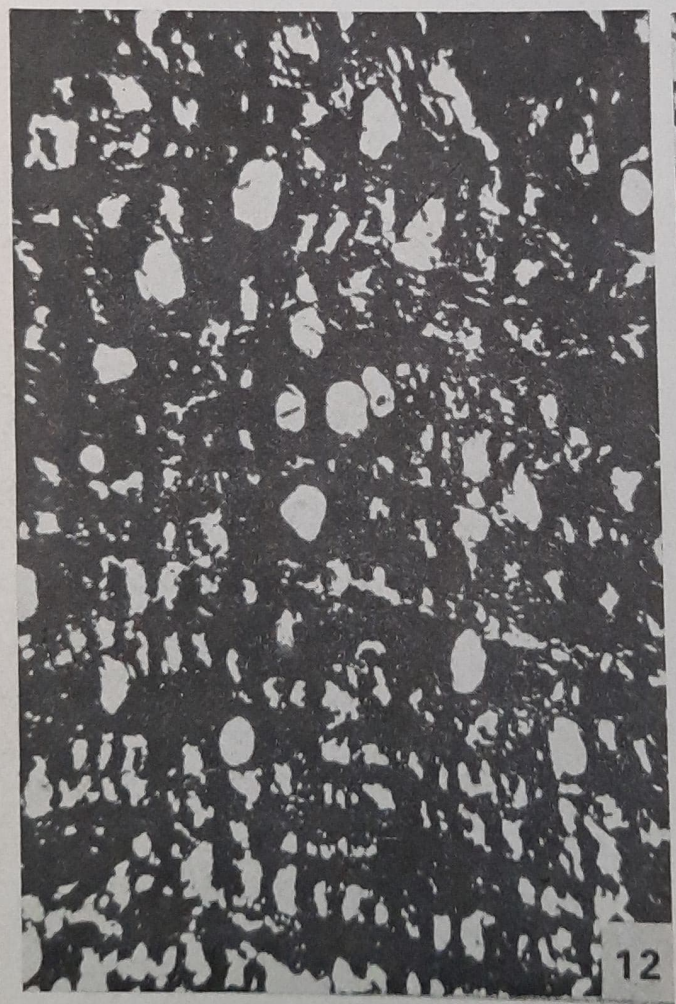
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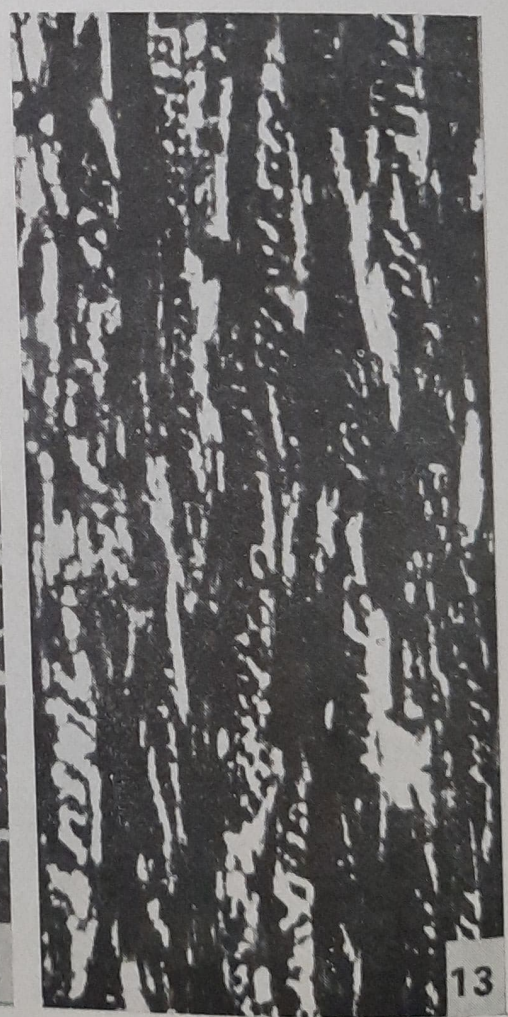
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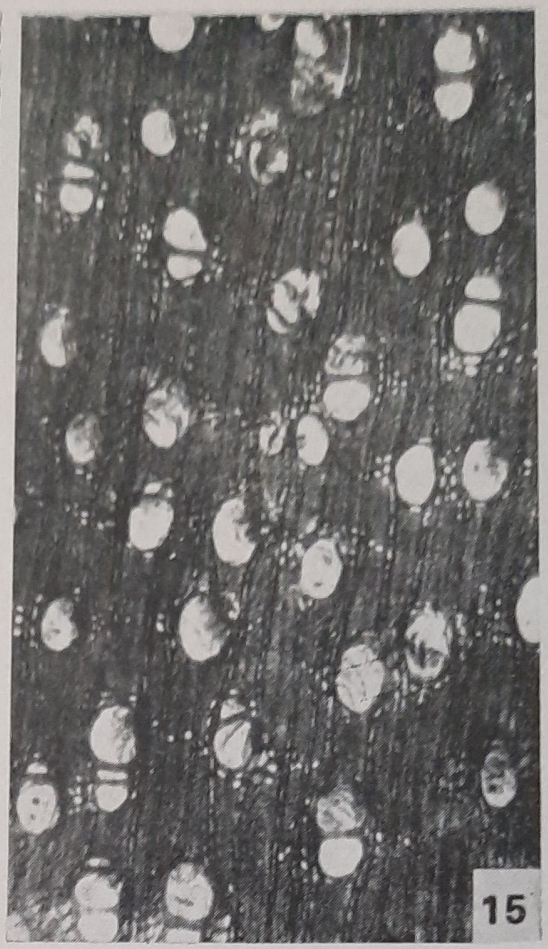
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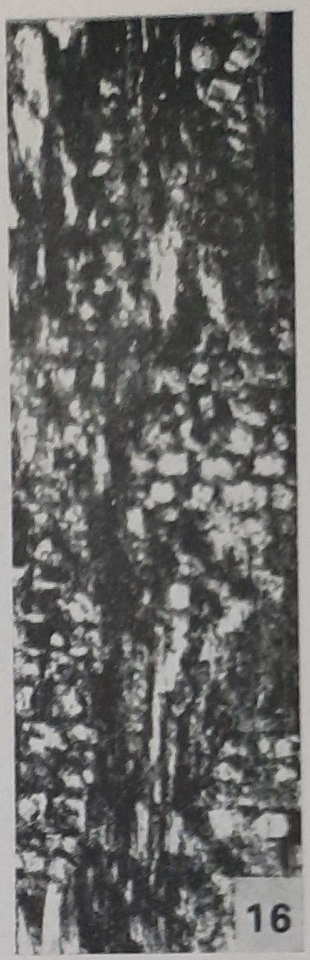
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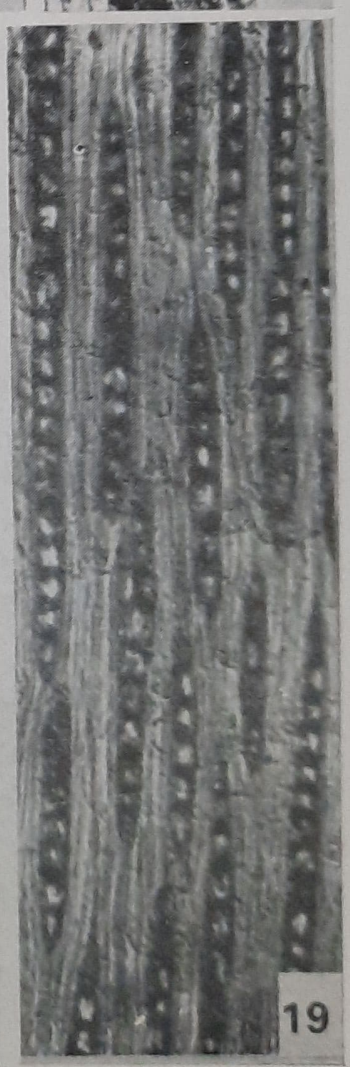
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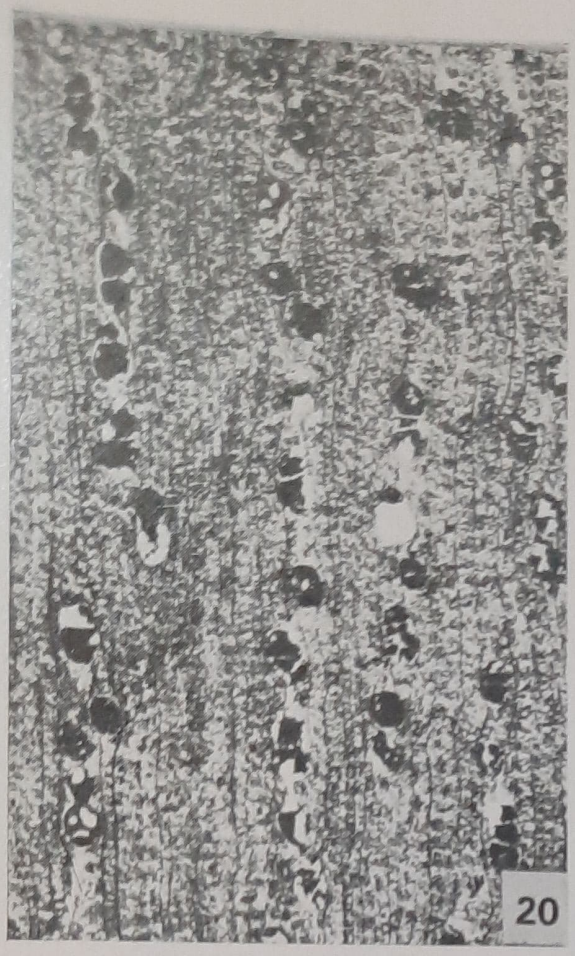
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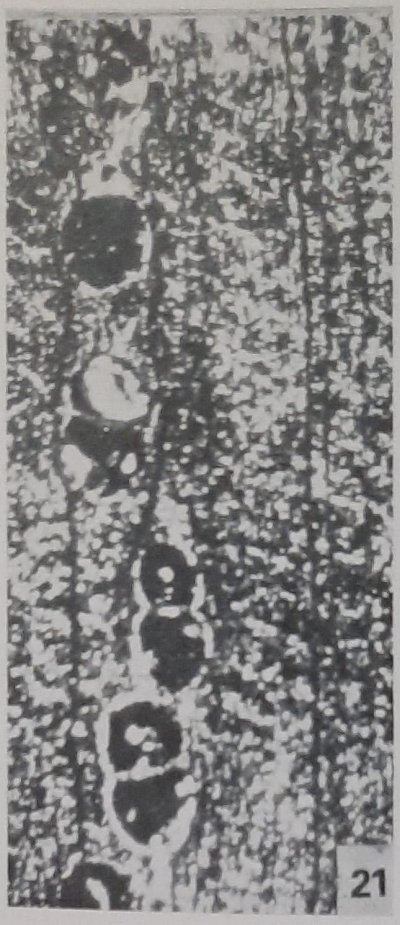
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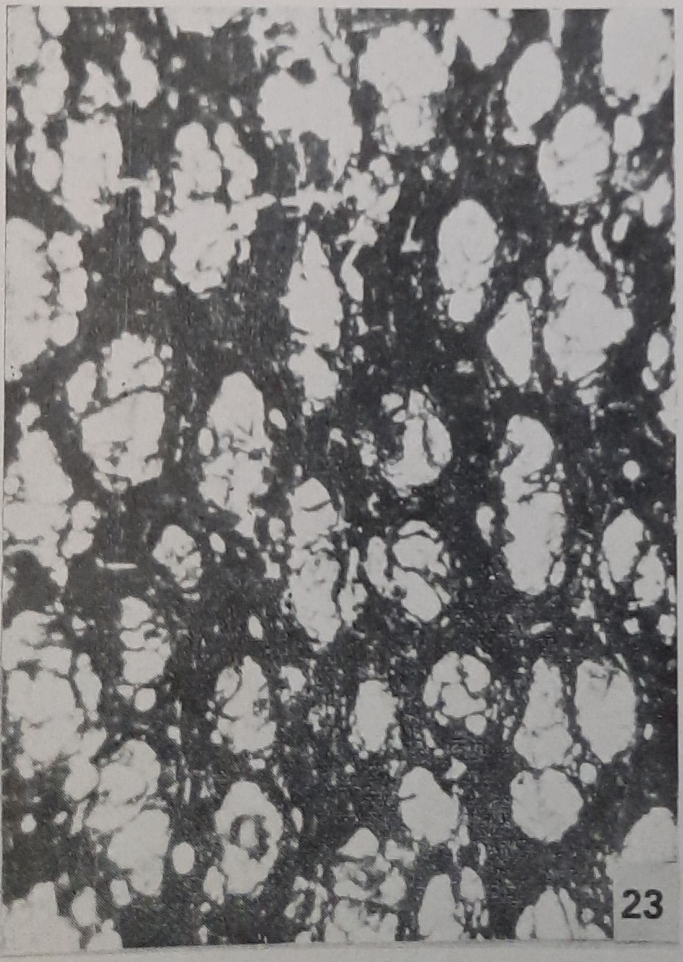
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PLATE 3

Terminalioxylon varkalaensis sp. nov.

14. Cross section showing vessels and paratracheal parenchyma. ×40. B.S.I.P. Museum slide no. 6712.

Terminalia chebula

15. Cross section showing similar type and distribution of vessels and parenchyma as shown in fig. 13. ×40.

Terminalioxylon varkalaensis sp. nov.

16. Radial longitudinal section showing homocellular to heterocellular rays. ×100. B.S.I.P. Museum slide no. 6714.
17. Cross section magnified to show vasicentric parenchyma. ×100. B.S.I.P. Museum slide no. 6712.
18. Tangential longitudinal section showing xylem rays. ×100. B.S.I.P. Musuem slide no. 6713.

Terminalia chebula

19. Tangential longitudinal section showing similar type of rays as in fossil shown in fig. 17. ×100.

PLATE 4

Ebenoxylon obliquiporosum sp. nov.

20. Cross section showing distribution of vessels and parenchyma. ×7. B.S.I.P. Museum slide no. 6715.
21. Cross section magnified to show vessels and uniseriate parenchyma lines. ×37. B.S.I.P. Museum slide no. 6714.
22. Tangential longitudinal section showing rays. ×100. B.S.I.P. Museum slide no. 6716.

Laurinoxylon keralaensis sp. nov.

23. Cross section showing distribution of vessels, parenchyma and oil cells. ×40. B.S.I.P. Museum slide no. 6717.
24. Tangential longitudinal section showing rays with oil cells. ×100. B.S.I.P. Museum slide no. 6718.