Study of fossil wood from the Middle–Late Miocene sediments of Dhemaji and Lakhimpur districts of Assam, India and its palaeoecological and palaeophytogeographical implications

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In order to reconstruct the palaeoclimate, a number of fossil wood pieces were collected and investigated from two new fossil localities situated in the Dhemaji and Lakhimpur districts of Assam. They belong to the Tipam Group considered to be of Middle–Late Miocene in age and show affinities with *Gluta* (Anacardiaceae), *Bischofia* (Euphorbiaceae), *Bauhinia, Cynometra, Copaifera-Detarium-Sindora, Millettia-Pongamia*, and *Afzelia-Intsia* (Fabaceae). The flora also records a new species of *Bauhinia* named *Bauhinia miocenica* sp. nov. The assemblage indicates a warm and humid climate in the region during the deposition of the sediments. The occurrence of some southeast Asian elements in the fossil flora indicates that an exchange of floral elements took place between India and southeast Asia during the Miocene.

1. Introduction

The Assam state, situated in the northeast corner of India, is bounded by Bhutan and Arunachal Pradesh in the north and northeast, Nagaland and Manipur in the southeast, Mizoram and Tripura in the south and Bangladesh as well as Meghalaya in the southwest and west (figure 1). Six geological groups, namely Disang (Eocene), Barail (Oligocene), Surma as well as Tipam (Miocene), Dupitila (Mio-Pliocene) and Dihing (Pliocene) are found there (Karunakaran 1974) and their detailed lithostratigraphic succession has been presented in the form of a table (table 1). The fossil wood logs are known to occur from the Tipam and Dupitila Groups and a number of them have been described from various localities of Assam (Mehrotra *et al* 2005). Recently, two new localities have been discovered in the Dirpai riverbeds in north Lakhimpur (27.13°N; 94.7°E) of the Lakhimpur District and Subansiri riverbeds in Dhemaji (27.48°N; 94.58°E) of the Dhemaji District of Assam. The outcrop is characterized by coarse to gritty, false bedded ferruginous sandstone and conglomerate. The upper part in the section is conglomeratic, while the lower part is sandy in nature (figure 2c) and embeds fossil wood. Till date, no plant (mega or micro) remains have been recorded from these districts which experience the predominant influence of the southwest monsoon having 73–90% relative humidity. The annual rainfall varies from 2600 to 3200 mm, while the maximum temperature reaches up to 37°C during July to August and the minimum temperature goes down to 10°C during the month of January. About 35 fossil wood pieces which have been collected either from the section or as scattered pieces lying on the riverbeds (figure 2a–b), belong to the Tipam

Keywords. Tipam Group; Anacardiaceae; Euphorbiaceae; Fabaceae; palaeoclimate; fossil wood; Miocene; Assam.

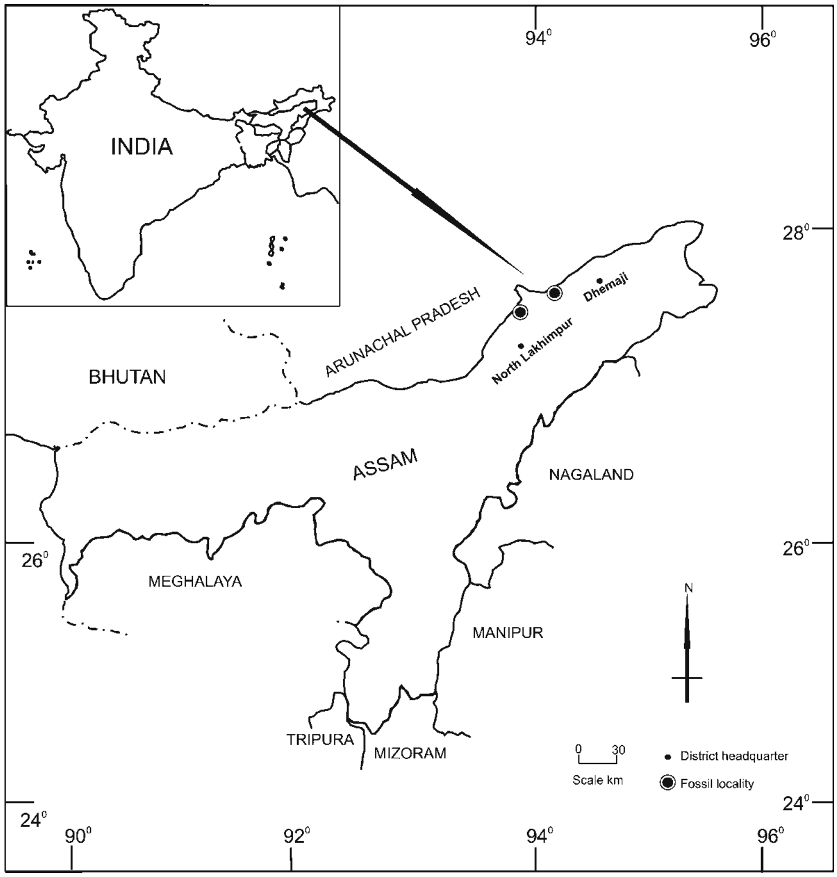

Figure 1. Map showing fossiliferous localities.

Group considered to be Middle–Late Miocene in age. These wood pieces are silicified and well preserved to reveal the structural details. Silicified wood material is the most informative mode of preservation in which molecule by molecule replacement of the original substance takes place in such a manner that even the microscopic details of the original are preserved (Schoph 1975). In order to reconstruct the palaeoenvironment of the region they have been investigated in detail and found to be of seven types, namely *Glutoxylon burmense* (Holden) Chowdhury of the Anacardiaceae, *Bischofia palaeojavanica* Awasthi of the Euphorbiaceae, *Bauhinia miocenica*, *Cynometroxylon holdenii* (Gupta) Prakash and Bande, *Hopeoxylon assamicum* Lalitha and Prakash, *Millettioxylon pongamiensis* Prakash and *Pahudioxylon deomaliense* Prakash of the Fabaceae.

2. Materials and methods

The wood material used in the present study is fragmentary varying in size from about 10–18 cm and collected from the bigger logs after breaking them in the field. Out of 35 samples, two were collected from the section, while the rest were picked up from the riverbeds. The samples picked up from the riverbeds belong to the same section of the Tipam Group as there is no other outcrop in the nearby areas. They are generally light yellow to dark brown in colour. Their slides were prepared by the standard method of cutting, grinding and polishing using different grades of carborundum powder and mounted in resin. Eleven of the samples were found ill preserved to reveal any structural detail. The slides as well as specimens are housed in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow (India). Terminology of wood anatomical characters follows the recommendations of the IAWA list (IAWA Committee 1989).

3. Systematic description

Family: Anacardiaceae
Genus: *Glutoxylon* Chowdhury (1934)
Glutoxylon burmense (Holden) Chowdhury (1952)
(figure 3a–f)

Description: Wood diffuse porous (figure 3a). Growth rings present, delimited by thick walled fibres. Vessels mostly large but occasionally small to medium, t.d. 55–275 μm, r.d. 55–495 μm (sometimes it becomes difficult to measure correct r.d.

Table 1. *Generalized lithostratigraphic sequence in Assam (after Karunakaran 1974).*

Age	Group	Formation	Lithology
Recent	Unclassified	Low level alluvium	Clay, sand, silt and shingle
		Unconformity	
Pleistocene	Unclassified	High level alluvium	Clay, coarse sand, shingle, gravel and boulder deposit
		Unconformity	
Pliocene	Dihing	Dihing	Pebble bed, soft sandy clay, clay, conglomerate, grit and sandstone
		Unconformity	
Mio-Pliocene	Dupitila	Dupitila (Surma Valley) and Namsang (Upper Assam)	Sandstone, mottled clay, grit and conglomerate; locally, with beds of coal conglomerate and poorly consolidated sand with layers and pockets of pebbles
		Unconformity	
Miocene	Tipam	Girujan	Mottled clay, sandy shales and subordinate, mottled, coarse to gritty sandstone
		Tipam Sandstone	Bluish grey to greenish, coarse to gritty, false bedded, ferruginous sandstone, clay, shale and conglomerate
	Surma	Bokabil	Shale, sandy shale, siltstone, mudstone and lenticular, coarse, ferruginous sandstone
		Bhuban	Alternations of sandstone, sandy shale and thin conglomerate and shaly in the middle part
		Unconformity	
Oligocene	Barail	Rengi	Massive and bedded sandstones; its equivalent, the Tikak Parbat Formation, in upper Assam is marked by thick coal seams at the basal part
		Jenam	Shale, sandy shale and carbonaceous shale with interbedded hard sandstone; its equivalent, the Baragolai Formation, in upper Assam is marked by numerous thin coal seams
		Laisong	Well bedded, compact, flaggy sandstone and subordinate shale; its equivalent, the Naogaon Formation, in upper Assam is marked by thin bedded, hard sandstone, and interbedded shale
Eocene	Disang (not divided)		Splintery dark grey shales and thin sandstone interbeds
	Jaintia	Kopili	Shale, sandstones, and marl
		Shella	Sylhet sandstone member-sandstone, clay and thin coal seam Sylhet limestone member-fossiliferous limestone
		Unconformity	
Pre-Cambrian	Shillong		Quartzite, phyllite and schist
		Unconformity	
Archaean	Archaean		Complex metamorphic group of Ortho- and Para- gneisses and schists; metasediments, later intruded by acidic and basic intrusives

due to the presence of tyloses destroying walls of the vessels in the radial multiples), solitary and in radial multiples of 2–4, round to oval, sometimes variously shaped due to compression, evenly distributed, 4–9 per mm^2, heavily tylosed (figure 3a–b); vessel members truncate, 80–110 μm in height; perforations simple; intervessel pits ill preserved due to heavily tylosed vessels, bordered, alternate, 5–14 μm in diameter, circular to oval (but appearing hexagonal due to crowding) with linear to lenticular apertures (figure 3f). Parenchyma both paratracheal and apotracheal; paratracheal scanty to thin vasicentric; apotracheal in the form of thin bands, 2–4 cells wide and 1–4 per mm (figure 3a–b); cells about 14 μm in diameter and 14–28 μm in height. Xylem rays 12–14 per mm, simple as well as fusiform, made up of procumbent cells only; simple ones uniseriate, rarely biseriate due to pairing of cells, 14–22 μm in width and 5–25 cells or 165–550 μm in height; fusiform rays rare, 2–3 seriate, containing solitary horizontal gum canal, about 110 μm in width and 4–21 cells or 300–460 μm in height (figure 3c–d); ray tissue homogeneous (figure 3e); ray cells crystalliferous,

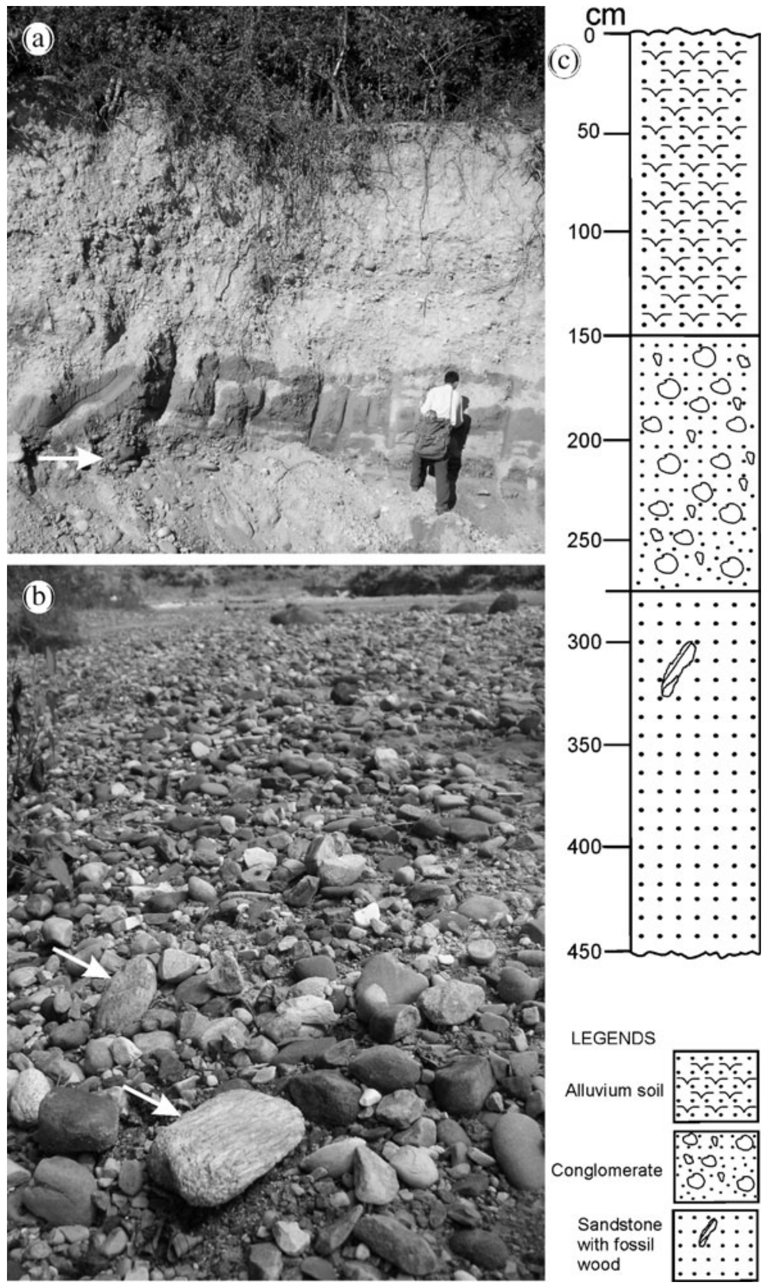

Figure 2. Field area, **(a)** Dhemaji section of the Tipam Group (arrow indicating wood containing zone, **(b)** fossil wood (marked by arrows) lying on the ground, and (**c**) lithostatigraphy of the fossil locality.

56–84 μm in radial length and 16–28 μm in tangential height (figure 3e). Fibres angular in cross section, moderately thick walled, nonseptate, 11–19 μm in diameter (figure 3b, d). Gum canals normal, horizontal, present in fusiform rays, t.d. 35–65 μm and r.d. 20–37 μm (figure 3d).

Figured specimen: Specimen no. BSIP39838.
No. of specimens: 3.
Horizon: Tipam Group.
Locality: Subansiri riverbeds in Dhemaji, Dhemaji District, Assam.
Age: Middle–Late Miocene.

Remarks: The diagnostic features of the fossil, *viz.*, diffuse porous wood, mostly large vessels occluded with tyloses and radial gum canals suggest its close resemblance with the family Anacardiaceae (Ghosh and Purkayastha 1963). The occurrence of profusely tylosed vessels, simple perforation plates, thin apotracheal bands of parenchyma, predominantly uniseriate xylem rays with occasional presence of fusiform rays, homogeneous ray tissue and nonseptate fibres strongly indicate affinities with *Gluta* Linn. among various genera of the family (Pearson and Brown 1932; Metcalfe and Chalk 1950; Kribs 1959; Ghosh and

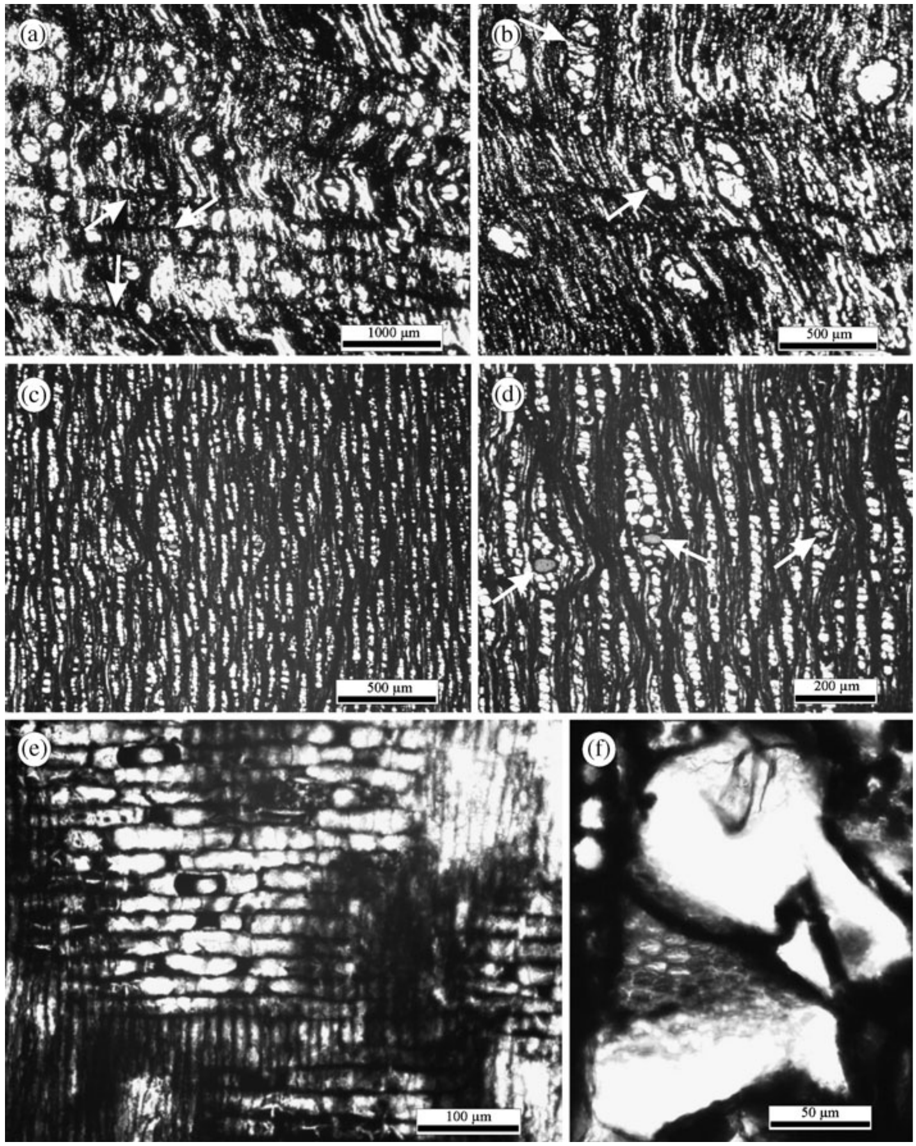

Figure 3. *Glutoxylon burmense* (Holden) Chowdhury, **(a)** diffuse-porous wood showing shape, size and distribution of vessels and parenchyma bands (marked by arrows), **(b)** fossil wood showing parenchyma bands and vessels plugged with tyloses (marked by arrows), **(c)** showing structure of xylem rays, **(d)** showing fusiform xylem rays having radial gum canals (marked by arrows), **(e)** showing homogeneous ray tissue, and **(f)** intervessel pits.

Purkayastha 1963; Miles 1978; Ilic 1991). Ghosh and Purkayastha (1963) have made detailed xylotomical study of various species of *Gluta* known from India and adjoining countries and have found that it is difficult to differentiate them on the basis of wood anatomy only. Therefore, it becomes difficult to trace the affinities of the fossil at the specific level.

Chowdhury (1934, 1936) for the first time erected the genus *Glutoxylon* (Holden) for the fossil wood resembling *Gluta* and those species of *Melanorrhoea* Wall. which have thin apotracheal bands of parenchyma. Prakash and Tripathi (1969) emended the diagnosis of *Glutoxylon* (Holden) Chowdhury on the basis of their study on the modern wood of *Gluta* and *Melanorrhoea*. According to them, the fossil wood having thin apotracheal bands (usually 2–4 cells wide) should be named *Glutoxylon*. They created a new genus *Melanorrhoeoxylon* (Prakash and Tripathi 1976) for those having thicker bands (usually 3–8 cells). Hou (1978) had merged the genus *Melanorrhoea* into *Gluta* on the basis of their taxonomic similarities. Under the circumstances, *Melanorrhoeoxylon* Prakash and Tripathi became invalid or superfluous to the already published *Glutoxylon* (Holden) Chowdhury. Therefore, Guleria (1984b) renamed two already known species of *Melanorrhoeoxylon*, namely *M. cacharense* (Prakash and Tripathi 1976) and *M. garbetaense* (Roy and Ghosh 1981) as *G. cacharense* (Prakash and Tripathi) Guleria and *G. garbetaense* (Roy and Ghosh) Guleria, respectively.

Five valid species of the genus *Glutoxylon* known so far from various parts of the world are: *Glutoxylon burmense* (Holden) Chowdhury (1952), *G. cuddalorense* Awasthi (1966), *G. cacharense* (Prakash and Tripathi) Guleria (1984b), *G. garbetaense* (Roy and Ghosh) Guleria (1984b) and *G. symphonoides* Lemoigne (1978). Except the last one which was described from the Tertiary of Ethiopia, all other species are known from various Tertiary exposures of India (Mehrotra *et al* 1999). After detailed comparison with the above species, it has been found that our fossil is identical to *G. burmense* and accordingly, has been kept under the same.

Gluta of the Anacardiaceae is a genus of small to very large evergreen trees and consists of about 30 species distributed in Madagascar, India, Myanmar, Thailand, Indo-China, China and throughout Malaysia (Ghosh and Purkayastha 1963; Hou 1978). In the Indian subcontinent it is distributed either in the coastal forests of Tenasserim, Tavoy and Mergui or in the evergreen forests of Kerala and Tamil Nadu.

Family: Euphorbiaceae
Genus: *Bischofia* Bl.
Bischofia palaeojavanica Awasthi (1989)
(figure 4a–f)

Description: Wood diffuse porous (figure 4a). Growth rings absent. Vessels small to medium, rarely very small, t.d. 42–112 μm, r.d. 70–168 μm,

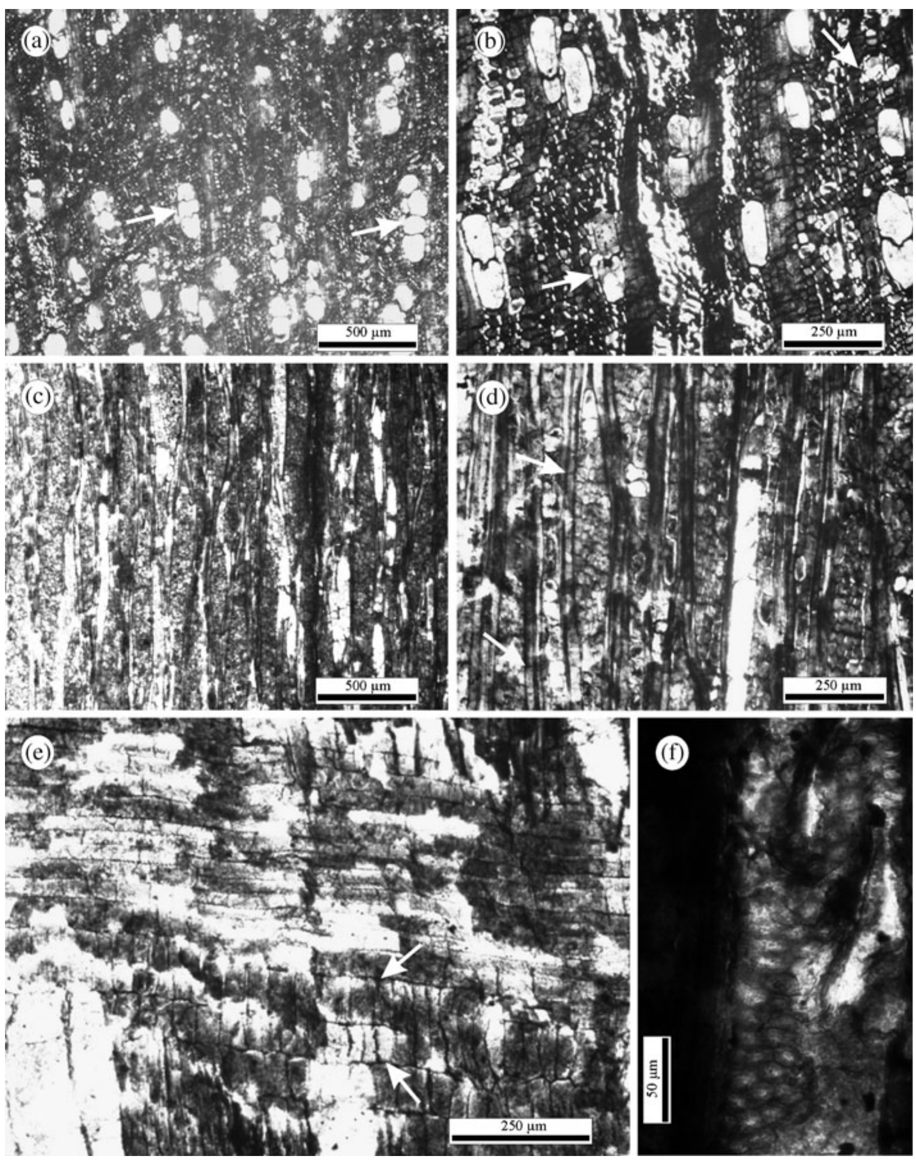

Figure 4. *Bischofia palaeojavanica* Awasthi, **(a)** diffuse-porous wood showing vessels in radial multiples (marked by arrows), **(b)** fossil wood showing vessels occluded with tyloses (marked by arrows), **(c)** showing distribution of xylem rays, **(d)** showing septate fibres (marked by arrows) and structure of xylem rays having crystals in some of the ray cells (marked by arrows), **(e)** showing heterogeneous ray tissue (arrows indicating upright cells), and **(f)** intervessel pits.

solitary and in radial multiples of 2–3 (rarely 4), sometimes in tangential pairs or clusters, circular to oval, evenly distributed, 11–18 per mm^2, plugged with tyloses (figure 4b); vessel members truncate, 84–238 μm in height; perforations simple; intervessel pits occasionally preserved due to tyloses, bordered, alternate, large, 8–14 μm in diameter, circular to oval (appearing hexagonal due to crowding) with lenticular apertures (figure 4f). Parenchyma mostly absent, rarely 1–2 cells associated with vessels. Xylem rays 5–7 per mm, 1–5 seriate, uniseriates made up of upright cells, 28–36 μm in width and 6–9 cells or 196–224 μm in height, multiseriates made up of procumbent cells in the median portion with 1–5 marginal rows of upright cells, 61–98 μm in width and 20–72 cells or 770–2200 μm in height (figure 4c–d); ray tissue heterogeneous (figure 4e); ray cells crystalliferous (figure 4d); procumbent cells 70–98 μm in radial length and 28–42 μm in tangential height; upright cells 28–56 μm in radial length and 56–84 μm in tangential height (figure 4e). Fibres angular in cross section, semilibriform, septate, crystalliferous, 27–55 μm in diameter and 550–935 μm in length (figure 4d).

Figured specimen: Specimen no. BSIP39839.
No. of specimens: 2.
Horizon: Tipam Group.
Locality: Subansiri riverbeds in Dhemaji, Dhemaji District, Assam.
Age: Middle–Late Miocene.

Remarks: The diagnostic features of the fossil, *viz.*, diffuse porous wood, simple perforation plates, restricted parenchyma and septate fibres strongly indicate its affinities with the family Euphorbiaceae (Pearson and Brown 1932). Among various genera of the family the fossil shows maximum resemblance with *Bischofia* Blume in having tylosed vessels, scanty paratracheal parenchyma, 1–5 seriate xylem rays and heterogeneous ray tissue (Pearson and Brown 1932; Metcalfe and Chalk 1950; Kribs 1959; Ilic 1991). Although the modern genus is represented by two species, namely *B. javanica* Bl. and *B. polycarpa* (Lévl) Airy Shaw, only the former is available for comparison. The fossil is identical to it as it shows similarities with our fossil in almost all the features.

Ramanujam (1960) erected the genus *Bischofioxylon* for the fossil wood similar to that of *Bischofia* and described *Bischofioxylon miocenicum* Ramanujam from south India. Mädel (1962) after suggesting its affinities with *Bridelia* merged it into another genus *Bridelioxylon* Mädel. Therefore, Bande (1974) instituted *Bischofinium* for the fossil wood resembling *Bischofia* and described *B. deccanii* from the Deccan Intertrappean beds of India. After the critical re-examination of the type slides of both these genera, Awasthi (1989) found that none of them belongs to *Bischofia* or *Bridelia*. While describing a fossil wood resembling *Bischofia* from the Namsang beds exposed near Deomali in Arunachal Pradesh, he placed his fossil directly under the extant genus and created a new species *Bischofia palaeojavanica*. Since then the same species has been reported from many parts of India (Awasthi and Mehrotra 1990; Agarwal 1994; Srivastava and Awasthi 1996; Guleria and Srivastava 2001; Guleria *et al* 2002). As our fossil is also identical to it, it has been placed under the same.

The genus *Bischofia* of the Euphorbiaceae consists of only two species and of which only *B. javanica* is found in India. It is a large deciduous tree widely distributed in the Indo-Malayan region ranging from the western Peninsula eastward through Myanmar and Thailand to Cochin-China (South Vietnam), the Philippines, Formosa and Polynesia and southward into Malaysia (Willis 1973; Mabberley 1997). In India it occurs in Lower Himalaya up to 300 m and sub-Himalayan tract from the Jamuna river eastwards, through Uttar Pradesh to Bengal and Assam; southward to Bihar and Orissa, Tirunelveli and Madurai and on the west coast from Konkan to the Nilgiris.

Family: Fabaceae
Genus: *Bauhinia* Linn.
Bauhinia miocenica sp. nov.
(figure 5a–h)

Specific diagnosis: Wood diffuse porous. Growth rings absent. Vessels t.d. 66–165 μm, r.d. 99–302 μm, solitary and in radial multiples of 2–3 (–4), 4–8 per mm^2, tyloses not observed; vessel members storied, 190–600 μm in height; perforations simple; intervessel pits bordered, alternate, about 4–7 μm in diameter, vestured. Parenchyma banded, bands regular, continuous, alternating with fibre bands, broader than fibres; cells storied. Xylem rays exclusively uniseriate, rarely biseriate, irregularly storied, made up of both procumbent and upright cells, 5–15 cells in height; ray tissue weakly heterogeneous; ray cells crystalliferous. Fibres appearing storied at places, nonseptate, 11–22 μm in diameter and about 330–550 μm in length. Ripple marks present due to storied vessel elements, parenchyma cells and storied rays.

Description: Wood diffuse porous (figure 5a). Growth rings absent. Vessels small to large, mostly medium, t.d. 66–165 μm, r.d. 99–302 μm, solitary and in radial multiples of 2–3 (–4), round to oval, occasionally elongated, evenly distributed, 4–8 per mm^2, tyloses not observed (figure 5a–b); vessel members truncate, storied, 190–600 μm in

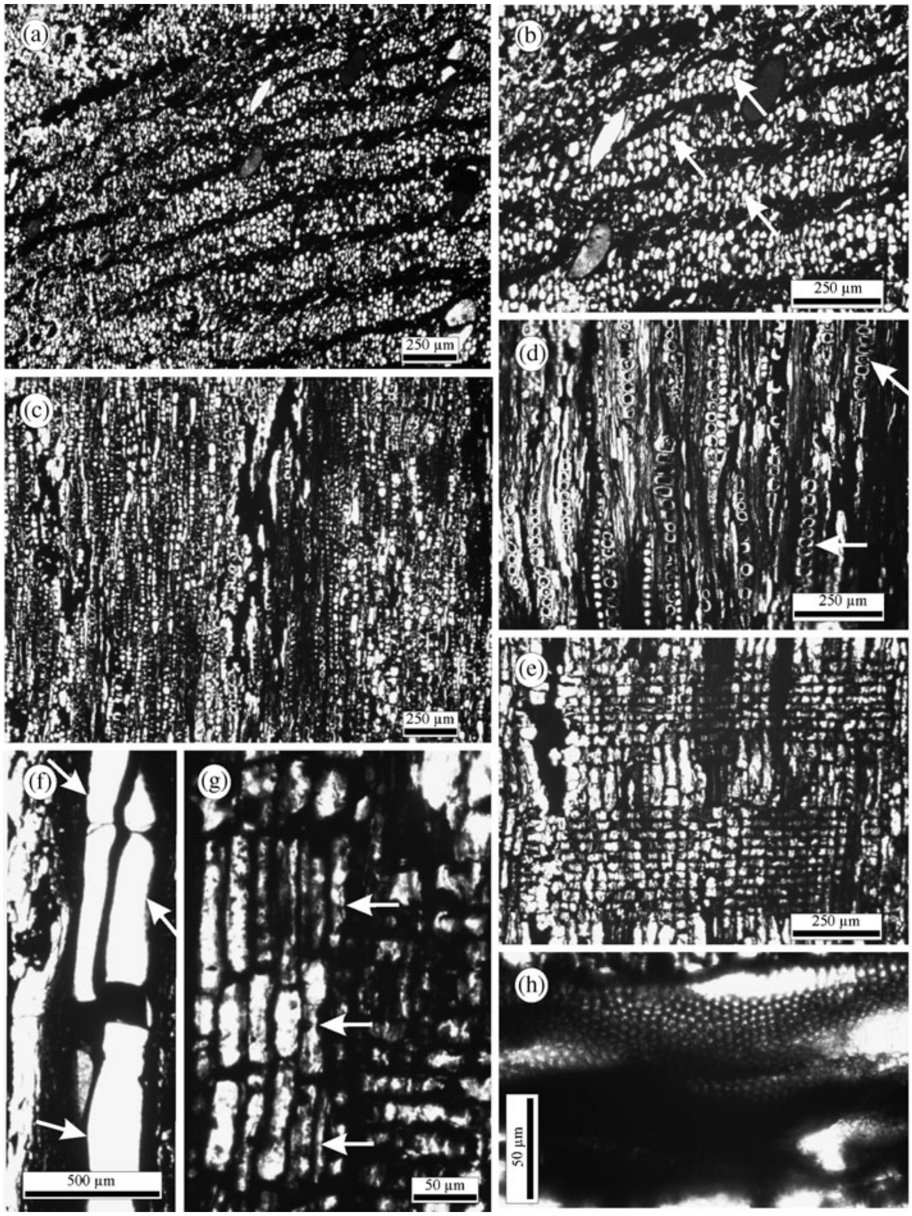

Figure 5. *Bauhinia miocenica* sp. nov., **(a)** showing shape, size and distribution of vessels and parenchyma pattern, **(b)** showing parenchyma bands (marked by arrows) alternating with fibre bands, **(c)** showing structure of xylem rays, **(d)** showing storied nature of xylem rays (marked by arrows), **(e)** showing homogeneous ray tissue, **(f)** storied vessel elements (marked by arrows), **(g)** storied parenchyma cells (marked by arrows), and **(h)** vestured intervessel pits.

height (figure 5f); perforations simple; intervessel pits bordered, alternate, about 4–7 μm in diameter, circular to oval, vestured (figure 5h). Parenchyma banded, bands regular, continuous, alternating with fibre bands, broader than fibres, 3–8 cells or 135–330 μm wide (figure 5a–b); cells storied, 14–28 μm in diameter and 56–140 μm in height (figure 5g). Xylem rays 7–10 per mm, exclusively uniseriate, rarely biseriate, irregularly storied, made up of both procumbent and upright cells, 16–38 μm in width and 5–15 cells or 192–550 μm in height (figure 5c–d); ray tissue weakly heterogeneous (figure 5e); ray cells crystalliferous; procumbent cells 56–84 μm in radial length and 22–42 μm in tangential height; upright cells 45–47 μm in radial length and 56–84 μm in tangential height (figure 5e). Fibres angular in cross section, appearing storied at places, moderately thick walled, nonseptate, 11–22 μm in diameter and about 330–550 μm in length (figure 5b, d). Ripple marks present due to storied vessel elements, parenchyma cells and storied rays.

Holotype: Specimen no. BSIP39840.
No. of specimens: 2.
Derivation of name: The specific epithet is after its age (Miocene).
Horizon: Tipam Group.

Locality: Subansiri riverbeds in Dhemaji, Dhemaji District, Assam.
Age: Middle–Late Miocene.

Remarks: The noteworthy features of the fossil, *viz.,* diffuse porous wood, vestured intervessel pits, simple perforation plates, abundant paratracheal parenchyma, and fine xylem rays indicate its affinities with the family Fabaceae (Pearson and Brown 1932; Ramesh Rao *et al* 1972). Among various genera of the family, the fossil shows maximum resemblance with *Bauhinia* Linn. in having small to large open vessels, storied vessel elements, parenchyma cells and xylem rays, continuous and broad parenchyma bands alternating with fibre bands, almost exclusively uniseriate xylem rays and nonseptate fibres (Pearson and Brown 1932; Metcalfe and Chalk 1950; Kribs 1959; Ramesh Rao *et al* 1972; Ilic 1991; Gupta 2007). Ramesh Rao *et al* (1972) studied wood of *Bauhinia* from India and found that only six of its species, namely *B. foveolata* Dalzell, *B. malabarica* Roxburgh, *B. purpurea* Linn., *B. racemosa* Lamarck, *B. retusa* Hamann, and *B. variegata* Lamarck attain tree size. Except the last two where ripple marks are absent, the rest of the species are xylotomically very similar. Our fossil, having storied elements, shows similarities with these four species. Pearson and Brown (1932, p. 420) observed that in *B. malabarica*, middle rings of the parenchyma bands are wider than the bands of fibres and t.d. of the vessels is <230 μm. As parenchyma bands in the present fossil are wider than fibre bands and t.d. of the vessels is not more than 165 μm, it shows maximum resemblance with the above species.

Fossil wood showing affinities with *Bauhinia* was first reported by Rawat (1965) from the Siwalik of Mohand (Saharanpur District) under the generic name *Bauhinioxylon*. The genus was not considered valid due to the absence of any description and illustration, therefore, Trivedi and Panjwani (1986) established a new genus *Bauhinium* for the fossil wood of *Bauhinia*. Awasthi and Prakash (1987) placed their fossil resembling *Bauhinia* directly under the modern genus. The fossil woods belonging to *Bauhinia* commonly occur during the Neogene in India and are: *Bauhinium miocenicum* (Trivedi and Panjwani 1986) and *B. palaeomalabaricum* (Prakash and Prasad 1984) from the Siwalik sediments of Uttar Pradesh, *Bauhinia deomalica* (Awasthi and Prakash 1987) from the Namsang beds of Deomali, Arunachal Pradesh and Tipam Group of Udaipur, South Tripura District, Tripura (Mehrotra *et al* 2006) and *B. tertiara* (Awasthi and Mehrotra 1990) from the Tipam Group of Mon District, Nagaland. In addition one more wood, cf. *Bauhinia* is described from the Cuddalore sediments of Cauvery Basin, south India (Ramanujam and Rao 1966). After detailed comparison with all of them it has been found that the fossil shows near resemblance with *B. palaeomalabaricum* (Prakash and Prasad). However, the present fossil differs from it in radial arrangement of vessels and height of the xylem rays. As parenchyma bands are broader than fibrous bands in the present fossil, a character not observed in any of the above fossil species, it is being described as a new species, *Bauhinia miocenica* sp. nov.

Bauhinia is a large genus comprising about 300 species distributed throughout the tropics of the world and about 30 of its species are found in India and Myanmar. *B. malabarica* is a small to moderate-sized tree widely distributed in almost all the states of India, especially in the moist deciduous forests (Ramesh Rao *et al* 1972; Mabberley 1997).

Genus: *Cynometroxylon* Chowdhury and Ghosh (1946)
Cynometroxylon holdenii (Gupta) Prakash and Bande (1980)
(figure 6a–f)

Description: Wood diffuse porous (figure 6a). Growth rings absent. Vessels small to large, t.d. 56–140 μm, r.d. 56–224 μm, solitary as well as in radial multiples of 2–3, round to oval, evenly distributed, 6–12 per mm^2 (figure 6a–b), tyloses absent but occasionally filled with dark coloured gummy deposits; vessel elements truncate, 165–465 μm in height (figure 6c); perforations simple; intervessel pits bordered, alternate, 3–6 μm in diameter, circular to oval (but appearing hexagonal due to crowding) with lenticular apertures, vestured (figure 6d). Parenchyma paratracheal, in the form of broken to continuous bands, each 4–8 cells wide, occasionally vasicentric (figure 6a–b); cells 19–28 μm in diameter and 35–125 μm in height. Xylem rays 7–10 per mm, 1–3 (mostly 2) seriate, usually made up of procumbent cells, uniseriate rays 28–33 μm in width and 5–6 cells or 140–196 μm in height, multiseriate rays 42–56 μm in width and 13–28 cells or 308–605 μm in height (figure 6c, e); ray tissue weakly heterogeneous (figure 6f); ray cells crystalliferous; procumbent cells 56–84 μm in radial length and 22–33 μm in tangential height; upright/square cells 20–33 μm in radial length and 28–33 μm in tangential height (figure 6f). Fibres angular in cross section, thick walled, nonseptate, 5–8 μm in diameter and about 500 μm in length (figure 6b–c).

Figured specimen: Specimen no. BSIP39841.
No. of specimens: 3.
Horizon: Tipam Group.

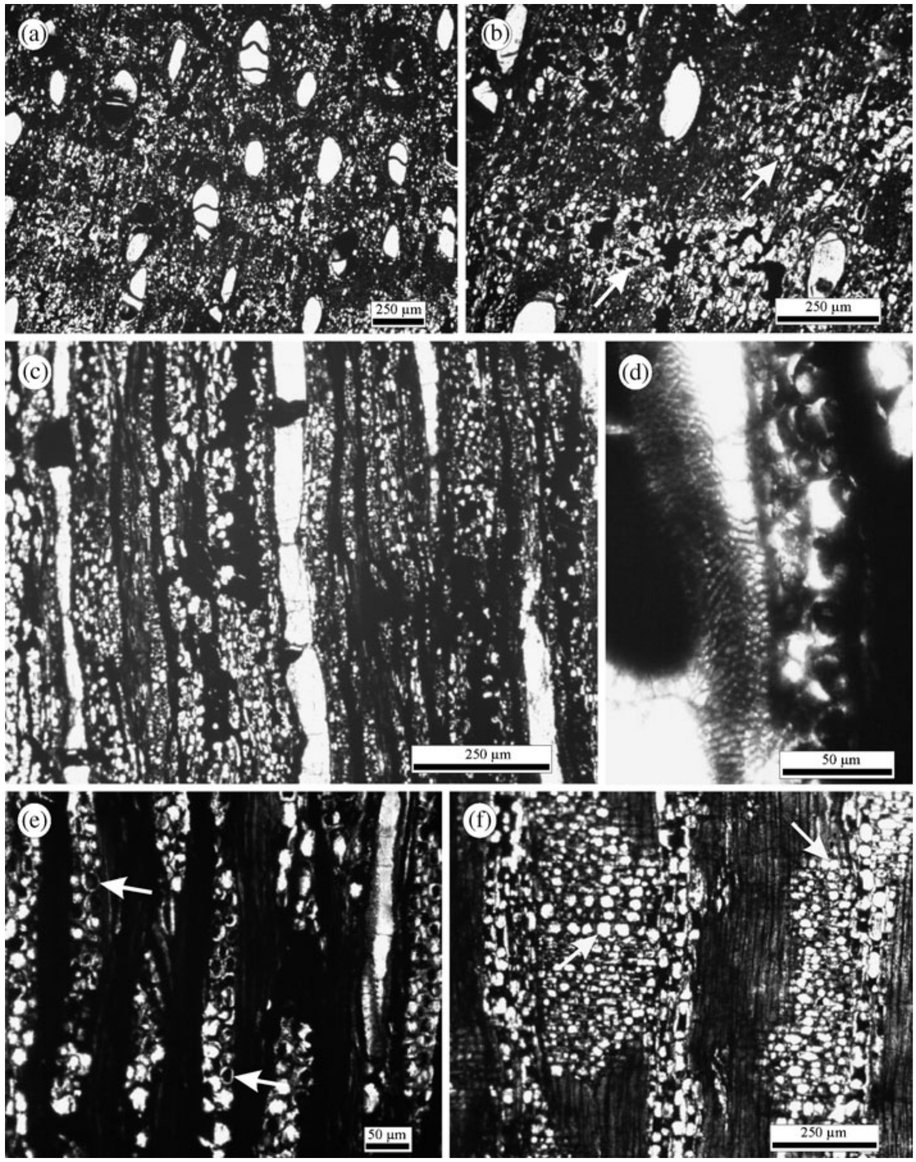

Figure 6. *Cynometroxylon holdenii* (Gupta) Prakash and Bande, **(a)** showing shape, size and distribution of vessels, **(b)** showing parenchyma bands (marked by arrows) alternating with fibre bands, **(c)** showing distribution of xylem rays, **(d)** intervessel pits, **(e)** showing structure of xylem rays (arrows indicating crystals in ray cells), and **(f)** showing weakly heterogeneous ray tissue (arrows indicating square/upright cells).

Locality: Subansiri riverbeds in Dhemaji, Dhemaji District, Assam.
Age: Middle–Late Miocene.

Remarks: The diagnostic features of the fossil wood, such as diffuse porous wood, banded parenchyma, simple perforation plates, vestured intervessel pits, 1–3 seriate homo to heterocellular xylem rays and nonseptate fibres indicate resemblance with *Cynometra* Linn., especially *C. ramiflora* Linn. and *C. polyandra* (Roxb.) Harms. of the Fabaceae (Pearson and Brown 1932; Kribs 1959; Ramesh Rao *et al* 1972; Ilic 1991; Gupta 2007).

Fossil wood resembling *Cynometra* is usually assigned to *Cynometroxylon* (Chowdhury and Ghosh 1946). So far only three of its species are known from various parts of the world. *C. holdenii* (Gupta) (Prakash and Bande 1980) is the most commonly found species during the Neogene in India (Guleria 1992) and most of the fossil species described before 1980 have been merged with it. *C. parainaequifolium* (Prakash 1979a) is known from the Tertiary of Thailand, while *C. tertiarum* (Awasthi and Mehrotra 1997) is described from the Neogene of Tirap District, Arunachal Pradesh. In addition, Mehrotra *et al* (1999) described *Cynometroxylon* sp. cf. *C. holdenii* from the upper Tertiary sediments of Arunachal Pradesh. One of the wood fossils described from the Pleistocene of Zaire by Bande *et al* (1987) has directly been kept under the extant species *Cynometra alexandri* (C. H. Wright). As our fossil is similar to *C. holdenii*, it has been assigned to the same. The rest of the species differ from the present fossil mainly in the structure of xylem rays.

The genus *Cynometra* consists of about 70 species of evergreen trees or shrubs distributed in the tropics of Indo-Malayan region, Philippines, Australia, Pacific Islands, Mexico, Brazil and Africa (Ramesh Rao *et al* 1972; Willis 1973; Mabberley 1997). *C. ramiflora* is a small to medium-sized tree commonly found in the tidal forests of the Andamans and Sunderbans, while *C. polyandra* is a large evergreen tree found in Assam, Meghalaya and Bangladesh (Ramesh Rao *et al* 1972).

Genus: *Hopeoxylon* Navale emend. Awasthi (1977)
Hopeoxylon assamicum Lalitha and Prakash (1980)
(figure 7a–g)

Description: Wood diffuse porous (figure 7a). Growth rings present, delimited by parenchyma bands enclosing the gum canals (figure 7a). Vessels small to large, rarely very small, t.d. 36–140 μm, r.d. 112–280 μm, solitary and in pairs, round to oval, sometimes elongated due to compression, evenly distributed, 12–18 per mm^2 (figure 7a–b), tyloses absent; vessel elements truncate, 56–112 μm in height; perforations simple; intervessel pits bordered, alternate, 5–6 μm in diameter, circular to oval, vestured (figure 7e). Parenchyma both paratracheal and apotracheal; paratracheal vasicentric to aliform-confluent enclosing 2–3 neighbouring vessels (figure 7b); apotracheal in the form of tangential bands enclosing gum canals, bands 1–2 per mm (figure 7a, f); cells about 14–16 μm in diameter and 22–56 μm in height. Xylem rays 1–5 seriate, 8–10 per mm, uniseriates made up of upright cells, 16–28 μm in width and 7–12 cells or 196–280 μm in height; multiseriates made up of procumbent cells with 1–3 marginal rows of upright cells, 28–70 μm in width and 7–40 cells or 196–550 μm in height

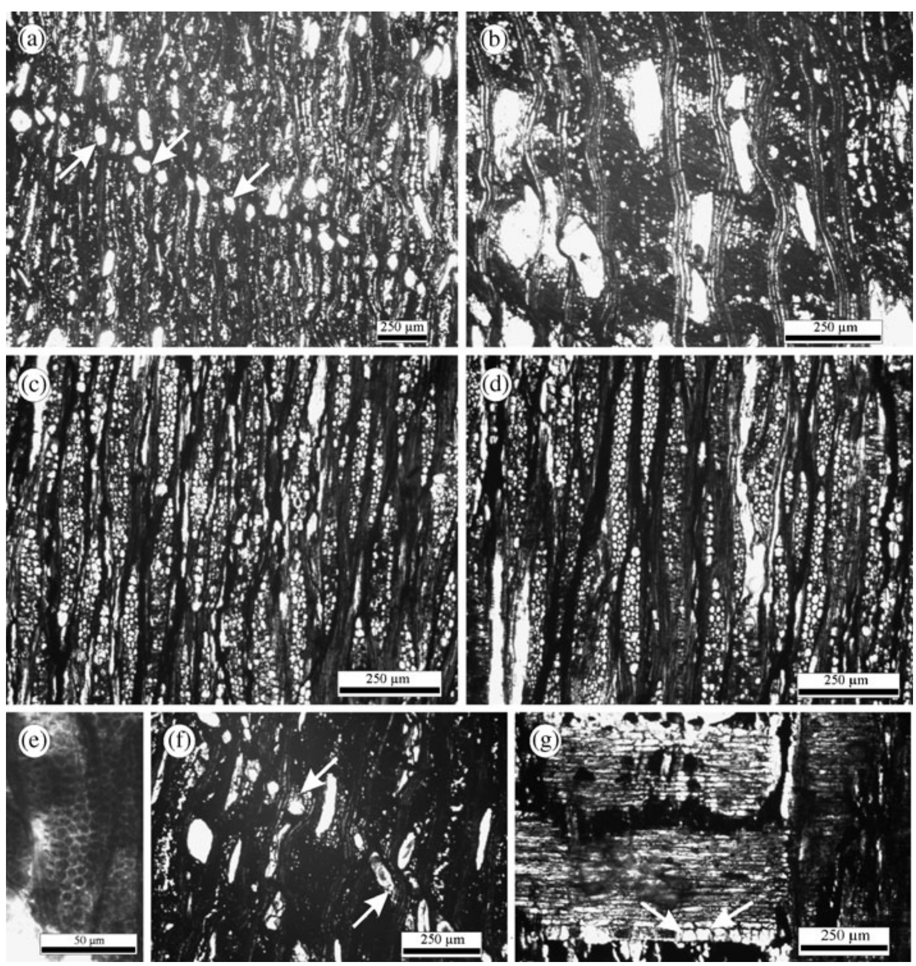

Figure 7. *Hopeoxylon assamicum* Lalitha and Prakash, **(a)** showing shape, size and distribution of vessels and gum canals (marked by arrows), **(b)** showing parenchyma pattern, **(c)** showing distribution of xylem rays, **(d)** showing structure of xylem rays, **(e)** vestured intervessel pits, **(f)** showing a row of gum canals enclosed in parenchyma bands (marked by arrows), and **(g)** showing heterogeneous ray tissue (arrows indicating upright cells).

(figure 7c–d); ray tissue heterogeneous (figure 7g); ray cells crystalliferous; procumbent cells 56–90 μm in radial length and 14–28 μm in tangential height; upright cells 28–42 μm in radial length and 36–42 μm in tangential height (figure 7g). Fibres angular in cross section, moderately thick walled, nonseptate, 22–28 μm in diameter, and 250–330 μm in length (figure 7b, d). Gum canals normal, vertical, arranged in concentric rings, usually smaller than vessels, t.d. 56–112 μm and r.d. 60–112 μm (figure 7a, f).

Figured specimen: Specimen no. BSIP39842.
No. of specimens: 2.
Horizon: Tipam Group.
Locality: Subansiri riverbeds in Dhemaji, Dhemaji District, Assam.
Age: Middle–Late Miocene.

Remarks: The important diagnostic features of the present fossil wood are: presence of growth rings marked by concentric rings of gum canals enclosed in parenchyma bands, small to large vessels, simple perforation plates, vestured intervessel pits, absence of tyloses in the vessels, mostly vasicentric to aliform-confluent parenchyma, 1–5 seriate xylem rays, heterogeneous ray tissue and nonseptate fibres. They indicate affinity with xylotomically inseparable taxa *Copaifera* Linn., *Detarium* Jussieu and *Sindora* Miquel of the family Fabaceae (Metcalfe and Chalk 1950; Normand 1950; Kribs 1959; Lalitha and Prakash 1980; Ilic 1991).

Müller-Stoll and Mädel (1967) instituted the genus *Copaiferoxylon* to include the fossil woods with concentric rows of gum canals resembling *Copaifera, Detarium* and *Sindora*. Lemoigne *et al* (1974) instituted another genus *Sindoroxylon* for describing the fossil wood resembling *Sindora*. Boureau and Louvet (1975) erected one more genus *Detarioxylon* for their fossil wood resembling *Detarium*. Awasthi (1977) assigned the affinities of *Hopeoxylon indicum* (Navale 1963b) to *Sindora* instead of *Hopea* of the family Dipterocarpaceae. Therefore, Lalitha and Prakash (1980) opined that *Hopeoxylon* Navale emend. (Awasthi 1977) should get priority over the other names and had adopted it to designate fossil wood of *Copaifera, Detarium* and *Sindora* instead of *Sindora* only as pointed out by Awasthi (1977). Till date nine species of *Hopeoxylon* are known from various parts of the world. These are: *H. migiurtinum* (Chiarugi) (Lalitha and Prakash 1980) from the Miocene of Somalialand, *H. sindoroides* (Kramer) (Lalitha and Prakash 1980) from the Tertiary of West Borneo, *H. aethiopium* (Lemoigne *et al*) (Lalitha and Prakash 1980) from the Tertiary of Ethiopia, *H. libycum* (Bureau and Louvet) (Lalitha and Prakash 1980) from the Paleogene of Libya, *H. indicum* Navale emend. (Awasthi 1977), *H. arcotense* (Awasthi 1977) and *H. speciosum* (Navale) (Awasthi 1977) from the Cuddalore Sandstone of south India, *H. assamicum* (Lalitha and Prakash 1980) from the Late Miocene of Hailakandi, Assam and *H. eosiamensis* (Prakash 1981) from the Lower Siwalik of Uttar Pradesh. After detailed comparison it has been found that our fossil resembles *H. assamicum* in all the features and therefore, is being described under the same species.

The genus *Copaifera* is found in tropical America and Africa, while *Detarium* is confined to tropical Africa only. *Sindora* comprising about 18–20 species is found in the tropical evergreen forest of southeast Asia, Hainan, western Malaysia, Celebes and Molucca (Ridley 1967; Willis 1973; Mabberley 1997). The distribution pattern of the above three genera indicates that *Sindora* may be the nearest comparable form of the fossil as the rest of the taxa are found in the continents located very far from the present fossiliferous site.

Genus: *Millettioxylon* Awasthi (1967)
Millettioxylon pongamiensis Prakash (1975)
(figure 8a–f)

Description: Wood diffuse porous (figure 8a). Growth rings absent. Vessels small to medium, rarely very small, t.d. 60–145 μm, r.d. 28–140 μm, solitary and in radial multiples of 2–3, rarely in tangential pairs or clusters, round to oval, evenly distributed, 7–15 per mm^2, tyloses absent (figure 8a–b); vessel members truncate, storied, 800–1000 μm in height (figure 8e); perforations simple; intervessel pits bordered, alternate, about 4–6 μm in diameter, circular to oval, vestured (figure 8f). Parenchyma paratracheal banded, bands regular, continuous, alternating with fibre bands, 3–6 cells wide (figure 8a–b); cells 16–42 μm in diameter and 42–112 μm in height (figure 8c–d). Xylem rays 8–10 per mm, mostly biseriate, uniseriates and triseriates rare, storied, made up of procumbent cells only, sometimes showing extensions of 1–6 cells; uniseriate rays about 22 μm in width and 4–5 cells or 18–20 μm in height; multiseriate rays 33–50 μm in width and 7–17 cells or 275–550 μm in height (figure 8c–d); end to end ray fusion rare; ray tissue homogeneous (figure 8e); ray cells crystalliferous, 60–110 μm in radial length and 14–56 μm in tangential height (figure 8e). Fibres angular in cross section, thick to moderately thick walled, nonseptate, 8–28 μm in diameter and about 224–280 μm in length (figure 8b, d). Ripple marks present due to storied nature of xylem rays and vessel elements.

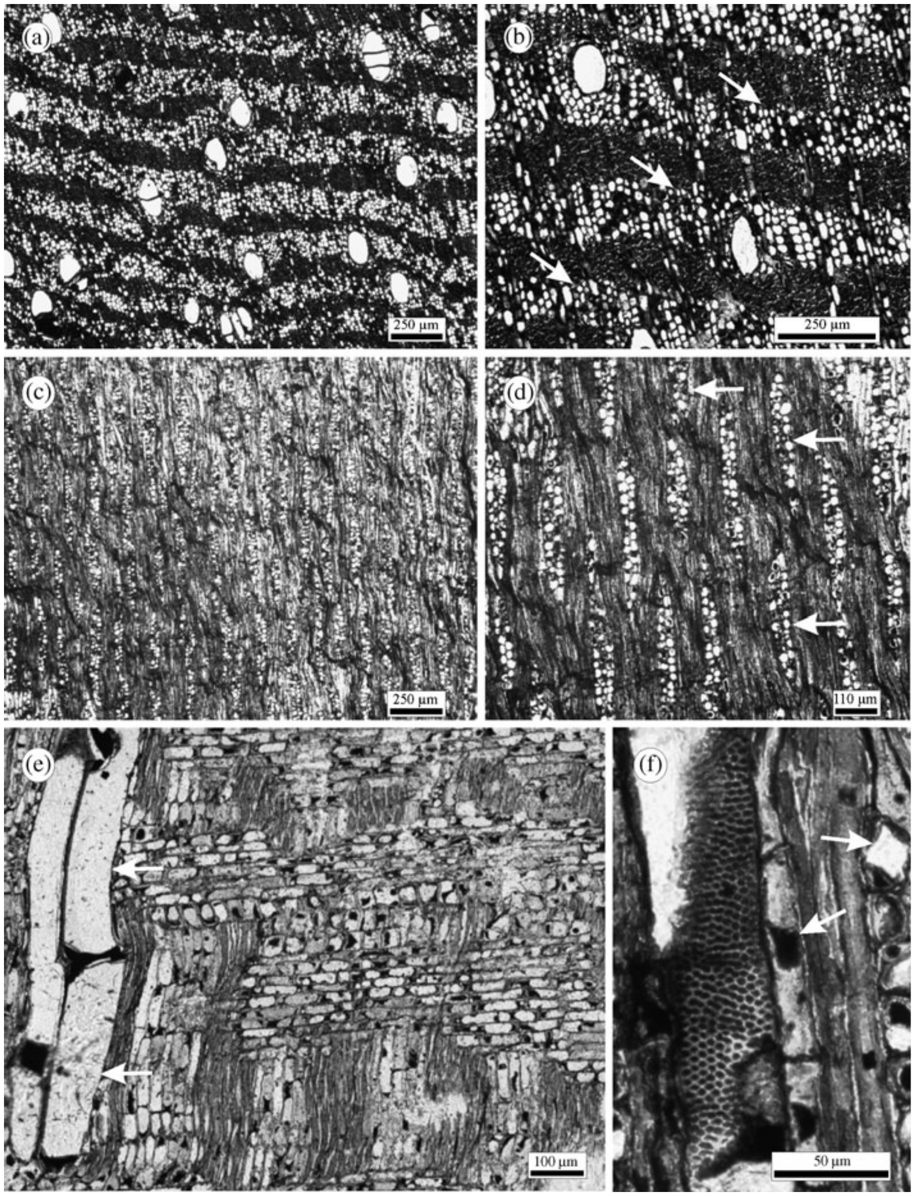

Figure 8. *Millettioxylon pongamiensis* Prakash, **(a)** showing shape, size and distribution of vessels, **(b)** showing parenchyma bands (marked by arrows) alternating with thicker fibre bands, **(c)** showing structure of xylem rays, **(d)** showing storied nature of xylem rays (marked by arrows), **(e)** showing homogeneous ray tissue and storied vessel elements (marked by arrows), and **(f)** vestured intervessel pits and crystals in ray cells (marked by arrows).

Figured specimen: Specimen no. BSIP39843.
No. of specimens: 11.
Horizon: Tipam Group.
Locality: Subansiri riverbeds in Dhemaji, Dhemaji District, Assam.
Age: Middle–Late Miocene.

Remarks: The diagnostic features of the fossil wood, *viz.,* diffuse-porous wood, presence of ripple marks due to storied nature of xylem rays and vessel elements, simple perforation plates, vestured intervessel pits, moderately broad continuous bands of parenchyma alternating with fibre bands, mostly biseriate homocellular xylem rays, non-septate fibres and open vessels indicate affinities with the modern wood of *Millettia* W. and A. and *Pongamia* Vent. of the Fabaceae (Pearson and Brown 1932; Metcalfe and Chalk 1950; Kribs 1959; Ramesh Rao *et al* 1972; Ilic 1991). Prakash (1975) has made a detailed anatomical study of the wood of *Millettia* and *Pongamia*, along with some other similar taxa, such as *Bauhinia* Linn., *Craibia* Harms and Dunn., *Cynometra* Linn., *Dialium* Linn., *Lonchocarpus* Kunth. and *Swartzia* Schreb. and found that their wood can be classified into the following three groups:

- 1st Group: made up of some species of *Millettia* and *Pongamia glabra* Vent.
- 2nd Group: consisting of only *Millettia* spp.

- 3rd Group: includes wood of *Millettia*, *Craibia*, *Dialium* and *Swartzia*.

Our fossil having broad bands, less than 4 seriate homocellular xylem rays and storied elements can be classified under 1st Group having xylotomically indistinguishable *M. prainii* Dunn., *M. pendula* Benth. and *P. glabra* Vent. Though Awasthi (1967) instituted the genus *Millettioxylon* for the fossil wood resembling *Millettia pendula* from the Cuddalore Sandstone Formation of south India, Prakash (1975) on the basis of the above-mentioned facts suggested that fossil wood belonging to the 1st Group should be assigned to *Millettioxylon* Awasthi. The 2nd Group having broader (more than 4 seriate) xylem rays was suggested the name *Eumillettioxylon*, while the 3rd Group characterized by narrower parenchyma bands and xylem rays was designated as *Dialiumoxylon*. Unfortunately, he did not propose any generic diagnosis for *Eumillettioxylon* and *Dialiumoxylon*.

The genus *Millettioxylon* (Awasthi 1967) to which the present fossil belongs, consists of the following six species: *M. indicum* (Awasthi 1967) from the Cuddalore Sandstone Formation of south India, *M. pongamiensis* (Prakash 1975) from the Lower Siwalik of Himachal Pradesh, *M. bengalensis* (Ghosh and Roy 1979) from the Tertiary sediments of Midnapur District of West Bengal, *M. palaeopulchra* (Lakhanpal *et al* 1981) from the Namsang beds of Deomali, Arunachal Pradesh, *M. kalagarhensis* (Trivedi and Mishra) (Guleria 1984a) and *M. embergeri* (Lemoigne 1978) from the Tertiary of Ethiopia. After detailed comparison it has been found that our fossil is similar to *M. pongamiensis* Prakash in all the features and therefore, has been kept under the same species.

Millettia is a genus of about 90 species of trees, shrubs and woody climbers found in the warmer regions of Africa, Asia and Australia. About 30 of its species are reported to occur in the Indian subcontinent, especially in Myanmar. *M. prainii* is a small-sized tree found in the eastern Himalayas in the foot hills of Sikkim extending into the plains of north Bengal, Assam and Meghalaya. *M. pendula* is a medium-sized tree distributed in the drier forests of Myanmar, Pegu Yoma, Shweba, Upper Chindwin and Tenasserim, while *Pongamia glabra* is also a medium-sized tree found throughout the greater part of India and Myanmar, chiefly along streams and rivers, being common in the tidal and beach forests. It is also found in Sri Lanka and Malaysia extending to north Australia and China.

Genus: *Pahudioxylon* Chowdhury *et al* (1960)
Pahudioxylon deomaliense Prakash (1966)
(figure 9a–g)

Description: Wood diffuse porous (figure 9a). Growth rings present, marked by terminal parenchyma (figure 9a). Vessels small to large but mostly medium, t.d. 120–190 μm, r.d. 75–230 μm, solitary as well as in radial multiples of 2–4, round to oval, evenly distributed, 4–6 per mm^2, tyloses occasionally present (figure 9a–b); vessel members truncate, storied, 180–400 μm in height (figure 9f); perforations simple; intervessel pits bordered, alternate, 5–11 μm in diameter, circular to oval (but appearing hexagonal due to crowding), vestured (figure 9d). Parenchyma both paratracheal and apotracheal; paratracheal typically aliform forming 8–14 celled thick sheath around the vessels, occasionally confluent joining similar extensions from adjacent vessels; apotracheal terminal, 2–4 cells or 31–56 μm in thickness (figure 9a–b); cells storied, 17–47 μm in diameter and 35–115 μm in height (figure 9g). Xylem rays 11–14 per mm, 1–4 seriate, mostly 2–3 seriate, homocellular made up of procumbent cells only, showing tendency towards storied arrangement; uniseriate rays 11–12 μm in width and 120–204 μm in height; multiseriate rays 18–54 μm in width and 9–20 cells or 210–440 μm in height (figure 9c, e); ray tissue homogeneous (figure 9f–g); ray cells 31–82 μm in radial length and 12–24 μm in tangential height (figure 9f–g). Fibres angular in cross section, thick walled, nonseptate, crystalliferous, 7–14 μm in diameter and about 500 μm in length (figure 9b, e).

Figured specimen: Specimen no. BSIP39844.
No. of specimens: 1.
Horizon: Tipam Group.
Locality: Dirpai riverbeds in North Lakhimpur, Lakhimpur District, Assam.
Age: Middle–Late Miocene.

Remarks: The characteristic features of the fossil are: diffuse porous wood, occurrence of growth rings delimited by terminal parenchyma, storied vessel elements, typically aliform to aliform-confluent parenchyma, simple perforation plates, vestured intervessel pits, 1–4 seriate homocellular xylem rays having storied tendency and nonseptate fibres. These characters collectively indicate affinity with the xylotomically indistinguishable taxa *Afzelia* Smith and *Intsia* Thouin of the Fabaceae (Pearson and Brown 1932; Metcalfe and Chalk 1950; Kribs 1959; Ramesh Rao *et al* 1972; Ilic 1991).

Chowdhury *et al* (1960) instituted the genus *Pahudioxylon* for the fossil wood showing affinities with that of *Pahudia* Miq. They were unaware of the fact that *Pahudia* had already been merged with *Afzelia* by Leonard (1950). Therefore, Prakash (1966) redefined the organ genus to

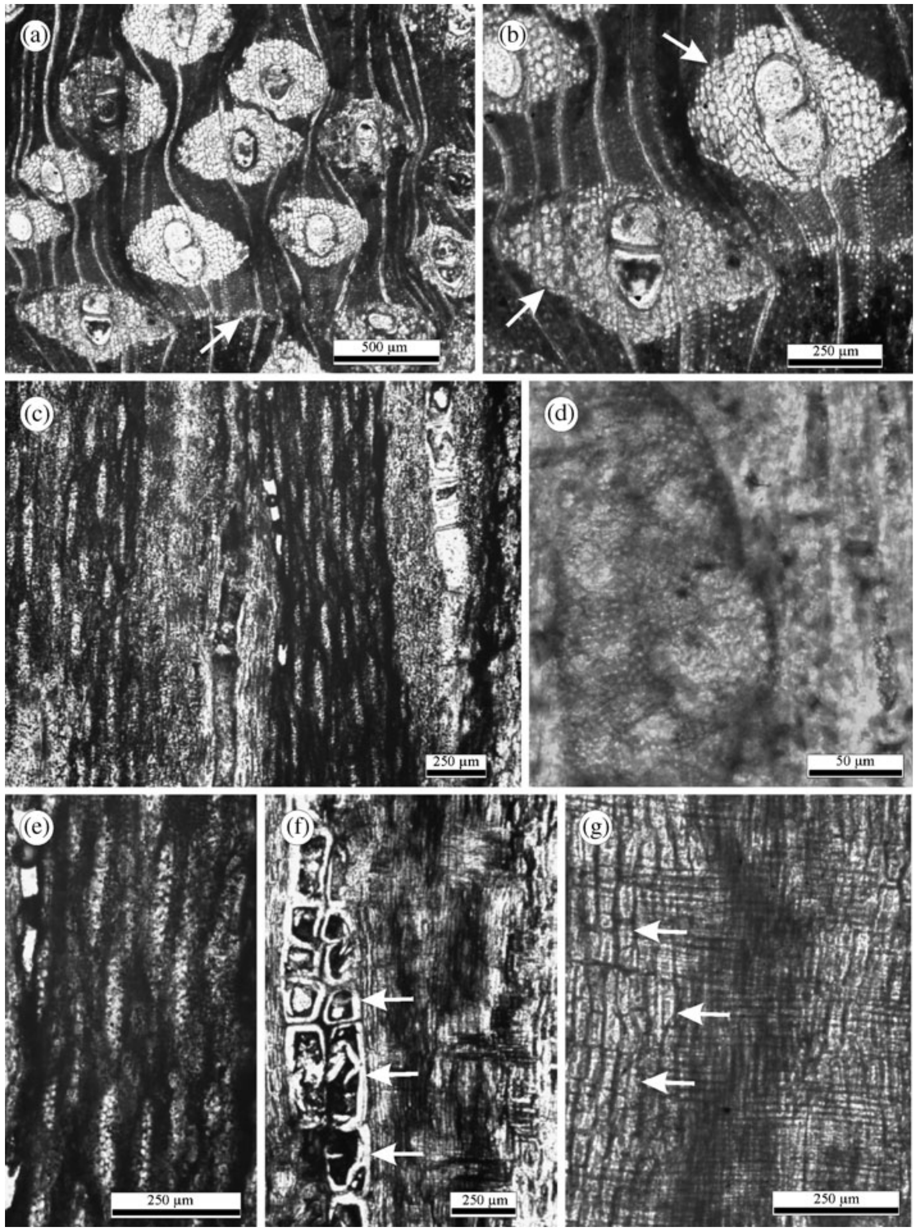

Figure 9. *Pahudioxylon deomaliense* Prakash, **(a)** showing shape, size and distribution of vessels and terminal parenchyma (marked by arrows), **(b)** showing typical aliform parenchyma (marked by arrows), **(c)** showing distribution of xylem rays, **(d)** vestured intervessel pits, **(e)** showing structure of xylem rays, **(f)** showing storied vessel elements (marked by arrows), and **(g)** showing homogeneous ray tissue and storied parenchyma cells (marked by arrows).

include fossil wood of *Afzelia-Intsia* also. So far the following 16 species of it are known from various Tertiary exposures of the world: *P. bankurensis* (Chowdhury *et al* 1960) from West Bengal, *P. sahnii* (Ghosh and Kazmi 1961) from Tripura, *P. arcotense* (Navale 1963a) from Pondicherry, *P. deomaliense* (Prakash 1966) from Arunachal Pradesh, *P. assamicum* (Prakash and Tripathi 1975) from Assam, *P. indicum* (Prakash 1979b) from Himachal Pradesh, *P. bengalensis* (Ghosh and Roy 1982) from West Bengal, *P. garbetaense* (Bera and Banerjee 2001) from West Bengal (all from India), *P. afzelioides* (Boureau) and *P. kiliani* (Louvet) from Indo-China and Algeria respectively (Prakash *et al* 1967), *P. irregulare* and *P. pannonicum* from Antigua and Hungary respectively (Müller-Stoll and Mädel 1967), *P. welkitii* Lemoigne from Ethiopia, *P. paracochinchinense* (Vozenin-Serra 1981) from South Vietnam and *P. furoni* (Koeniguer) (Guleria 1984a) and *P. aethiopcum* (Lemoigne *et al*) (Guleria 1984a) from Republic of Chad and Ethiopia, respectively. Unfortunately, most of these species were established on the basis of minor variations and could be restricted to a few species. Therefore, instead of creating a new species based on minor variations, we have placed our fossil under *P. deomaliense* (Prakash 1966) with which it shares maximum resemblance.

Afzelia is a genus of medium to large-sized trees consisting of 12 species found in tropical Africa and Asia, while *Intsia* has three species found in offshore islands of tropical East Africa, Madagascar and tropical Asia (Willis 1973; Mabberley 1997). In India *Intsia* occurs near mangroves in Sunderbans and Andamans.

4. Discussion

For the reconstruction of palaeoclimate many parameters are in practice, *viz.,* Nearest Living Relative Approach (NLR) (Prakash *et al* 1994; Estrada-Ruiz *et al* 2007; Jeong *et al* 2009; Feng *et al* 2010), Leaf Margin Analysis (LMA) (Wilf 1997; Su *et al* 2010), Climate Leaf Analysis Multivariate Program (CLAMP) (Wolfe 1993; Spicer *et al* 2009) and Coexistence Approach (CoA) (Mosbrugger and Utescher 1997; Böhme *et al* 2007). However, for the analysis of fossil wood the best and reliable method is NLR as it is considered that very little or insignificant change has taken place in wood characters in relation to climate. In the above technique, the plant fossils are considered to be the reliable indicator of the past climate. The modern equivalents of the present fossil assemblage are: *Gluta* (Anacardiaceae), *Bischofia javanica* (Euphorbiaceae), *Bauhinia malabarica*, *Cynometra polyandra*, *C. ramiflora*, *Copaifera-Detarium-Sindora*, *Millettia pendule*, *M. prainii*, *Pongamia glabra* and *Afzelia-Intsia* (Fabaceae). The distribution pattern of these taxa presented in the form of a table (table 2) clearly indicates a tropical climate.

Xylotomical characters have also been used to predict climate by various workers (Wheeler and Baas 1993; Martínez-Cabrera and Cevallos-Ferriz 2008). According to Wheeler and Baas (1991, 1993) diameter and density of vessels can be used to infer presence of tropical or temperate conditions. In wood of little seasonality, vessels may be evenly distributed and of approximately uniform size throughout the wood (diffuse porous condition); while in wood of climates of marked seasonality, vessels may be larger and more numerous in early wood and fewer and smaller in late wood (ring porous condition). As all the fossil wood logs in the present assemblage are diffuse porous in nature and none of them shows ring porosity, they support tropical conditions with little seasonality. The tropical forests of India which have been classified into seven types by Champion and Seth (1968) are: wet evergreen, semi-evergreen, moist deciduous, dry deciduous, littoral and swampy, thorny

Table 2. *Distribution of modern taxa comparable to the fossil flora.*

Fossil taxa	Modern comparable forms	Distribution	Forest types
Anacardiaceae			
Glutoxylon burmense (Holden) Chowdhury	*Gluta*	Madagascar, India, Myanmar, Thailand, Indo-China, China nd throughout Malaysia	Tropical evergreen and littoral and swampy
Euphorbiaceae			
Bischofia palaeojavanica Awasthi	*Bischofia javanica*	Indo-Malayan region ranging from the western peninsula eastward through Myanmar and Thailand to Cochin-China (South Vietnam), the Philippines, Formosa and Polynesia and southward into Malaysia	Tropical moist to dry deciduous
Fabaceae			
Bauhinia miocenica sp. nov.	*Bauhinia malabarica*	Small to moderate-sized tree widely distributed in almost all the states of India	Tropical moist deciduous
Cynometroxylon holdenii (Gupta) Prakash and Bande	*Cynometra ramiflora*, *C. polyandra*	Small to large-sized tree found in Andamans, Sunderbans, Assam, Meghalaya and Bangladesh	Tropical evergreen and littoral and swampy
Hopeoxylon assamicum Lalitha and Prakash	*Sindora*	Southeast Asia, Hainan, western Malaysia, Celebes and Molucca	Tropical evergreen
Millettioxylon pongamiensis Prakash	*Millettia prainii*, *M. pendula* and *P. glabra*	Small to medium-sized tree found in the eastern Himalayas in the foothills of Sikkim extending into the plains of north Bengal, Assam and Meghalaya and Myanmar	Tropical dry deciduous and littoral and swampy
Pahudioxylon deomaliense Prakash	*Afzelia-Intsia*	Medium to large-sized trees found in tropical Africa, Madagascar and Asia, especially in Sunderbans and Andamans	Tropical evergreen and littoral and swampy

deciduous and dry evergreen. As per the table (table 2) *Gluta*, *Bauhinia malabarica*, *Cynometra polyandra*, *C. ramiflora*, *Sindora*, *Millettia prainii*, *Pongamia glabra* and *Afzelia-Intsia* are growing at present in the tropical evergreen to moist deciduous and littoral and swampy forest. *Bischofia javanica* shows its range from moist deciduous to dry deciduous forest, while *Millettia pendule* is found only in dry deciduous forest. As majority of the taxa occur in tropical evergreen to moist deciduous and littoral and swampy forest, it can be inferred from the above facts that a warm and humid climate was prevalent in Upper Assam during the Middle–Late Miocene. The occurrence of *Gluta*, *Afzelia-Intsia* and *Cynometra ramiflora* indicates coastal conditions in the region. It means that the sea was situated much more inland than where it is today. This might have some impact over the vegetation of the region. Lakhanpal (1970) has already suggested that the Bay of Bengal was extending northwards than its present day boundary. According to Wolfe and Upchurch Jr (1987) woody plants growing in periods of drought show grouping of vessels, reduction in vessel diameter, increase in vessel density and development of vasicentric tracheids, while those growing in abundant precipitation have high proportions of large and solitary vessels with simple perforation plates and lack vasicentric tracheids. In the present assemblage vasicentric tracheids are absent and vessels are generally large with simple perforation plates which indicate high precipitation. It has been further observed by Wolfe and Upchurch Jr (1987) that mega thermal woods have high amount of paratracheal parenchyma. As most of the taxa in the present assemblage have this type of parenchyma, this indicates high temperature. The presence of homocellular and storied rays in some of the taxa of the assemblage supports the above view (Woodcock and Ignas 1994). The present fossil assemblage has also been compared with the palynological as well as megafossil data obtained from the nearby areas of Assam (Prakash *et al* 1994; Kumar *et al* 2001; Mehrotra *et al* 2005) and it is found that our interpretations are in line with them.

The coexistance analysis (CoA) developed by Mosbrugger and Utescher (1997) is based on the concept that the climatic requirements of fossil species are similar to those of their NLRs (Mosbrugger 1999). It reconstructs the paleoclimate parameters for a given fossil flora using climatic intervals in which all the NLRs of the fossil flora could coexist. The climatic tolerances of all the fossil wood NLRs of the present assemblage (table 2) are obtained from Champion and Seth (1968) and climatological tables of observatories in India (1931–1960) and the following reconstructed climatic estimates are obtained: MAT (mean annual temperature) 23.1–26°C, CMT (mean temperature of the coldest month) 20–21°C, WMT (mean temperature of the warmest month) 25–27.1°C, MAP (mean annual precipitation) 2160–2625 mm (figure 10a–d) and RH (mean relative humidity) 77.5%. It is observed that maximum NLRs could coexist in the obtained climate ranges though *Sindora* and *B. malabarica* are two outliers which indicate anomalous evolutionary changes. Exclusion of these outliers minimizes the effect of such changes. The data obtained (figure 10) shows that the seasonality was less pronounced at the time of deposition which supports the existence of tropical climate as deduced from the modern comparable forms of the fossil taxa (table 2). The result obtained supports the above view of warm and humid conditions in the region.

The fossil assemblage is conspicuous in having some southeast Asian elements, such as *Gluta*, *Afzelia-Intsia* and *Sindora*. The theory of Plate Tectonics helps in explaining their presence in the flora. According to Smith and Briden (1979), Smith *et al* (1994) and Chatterjee and Scotese (1999) the Indian Plate was moving northwards after its separation from the other Gondwanaland continents during the Cretaceous. At the end of the Eocene it collided with the Asian Plate, but suturing between them was not complete in order to facilitate the migration of taxa. The land connections were established by the end of the Late Oligocene/Early Miocene as Dipterocarpaceae, the typical Malaysian element, was absent in India during the Palaeogene. As most of the southeast Asian elements entered India through its northeast corner (Assam) during the Middle Miocene (Srivastava and Mehrotra 2010), we get *Gluta, Afzelia-Intsia* and *Sindora* in the fossil assemblage. These taxa were growing luxuriantly during the Neogene not only in northeast India but also in eastern, western, southeastern and northern parts of India (Awasthi 1992; Guleria 1992). After the Neogene, they disappeared from the Indian subcontinent due to the decrease in temperature caused by further uplift of the Himalaya due to the sinking of the Indian Plate against the Asian Plate. Being sensitive to the changing environment they failed to survive. *Gluta travancorica* Bedd. is the only living species which occurs in the extreme south of India under the equable climate (Champion and Seth 1968).

In the present assemblage the fabaceous genera are more in comparison to those of the other families. The same has also been observed by Antal and Awasthi (1993) and Prasad *et al* (2004) while describing their fossil assemblage from the Middle–Late Miocene of India and Nepal, respectively. The

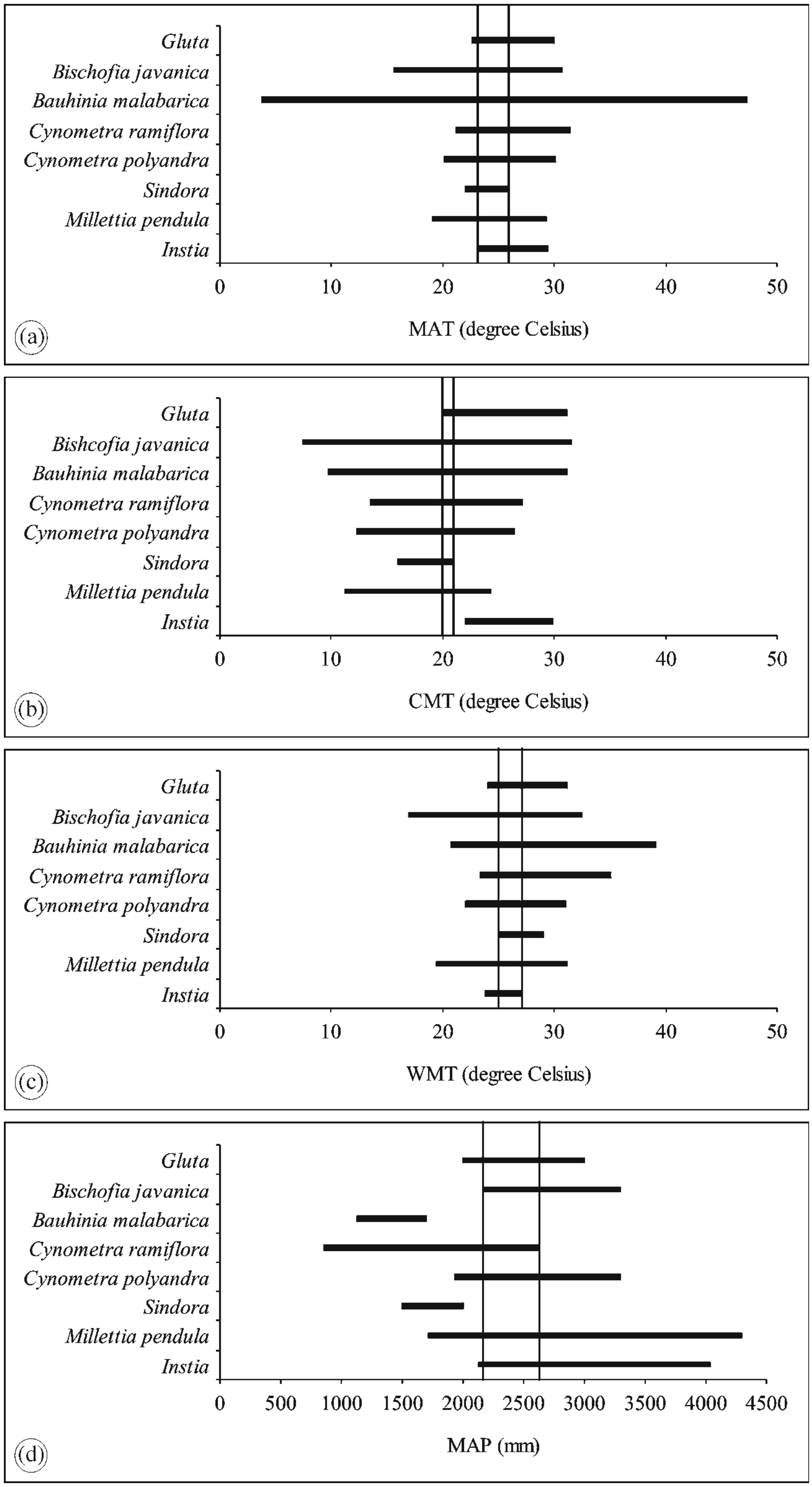

Figure 10. The coexistence interval of the climatic parameters of the megafossils showing, (**a**) MAT, (**b**) CMT, (**c**) WMT, and (**d**) MAP (vertical lines indicating common range of all the modern comparable forms).

following two reasons may be attributed for the same:

- A global warming has been observed at the end of the Oligocene and continued up to the Middle Miocene. This warm phase peaked in the late Middle Miocene climatic optimum (Zachos *et al* 2001). Punyasena *et al* (2008) have suggested that the abundance and richness of the family Fabaceae covary with the temperature.

Therefore, 70% of the taxa in the present assemblage belong to the above family. As during the Middle Miocene the temperature was high, the family flourished a lot.

- During the Middle Miocene a lot of plant migration occurred in India from the neighbouring landmasses (Mehrotra *et al* 2005). As a result many taxa of the Fabaceae growing in southeast Asia migrated and flourished in India under the equable climate.

5. Conclusion

A good number of fossil wood pieces have been collected from two new localities situated in the north Lakhimpur and Dhemaji Districts of Assam. They belong to the Tipam Group considered to be Middle–Late Miocene in age and are of seven types, namely *Glutoxylon burmense*, *Bischofia palaeojavanica*, *Bauhinia miocenica*, *Cynometroxylon holdenii*, *Hopeoxylon assamicum*, *Millettioxylon pongamiensis* and *Pahudioxylon deomaliense* of which *B. miocenica* is a new species. The distribution pattern of their modern equivalents clearly indicates the prevalence of tropical climate in the region during the depositional period. As majority of the taxa occur in tropical evergreen to moist deciduous and littoral and swampy forest, a warm and humid climate may be envisaged in Upper Assam during the Middle–Late Miocene. As most of the taxa possess diffuse porous wood, paratracheal parenchyma, simple perforation plates, large vessels and storied elements, they support the above inference. The presence of some southeast Asian elements in the fossil assemblage provides clear evidence of the complete suturing between Indian and Asian plates in order to facilitate migration of taxa.

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