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Fossil woods from the Middle Siwalik (Upper Miocene) of Tanakpur area in the Himalayan foot hills of Uttarakhand and their palaeoclimatic significance

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ABSTRACT

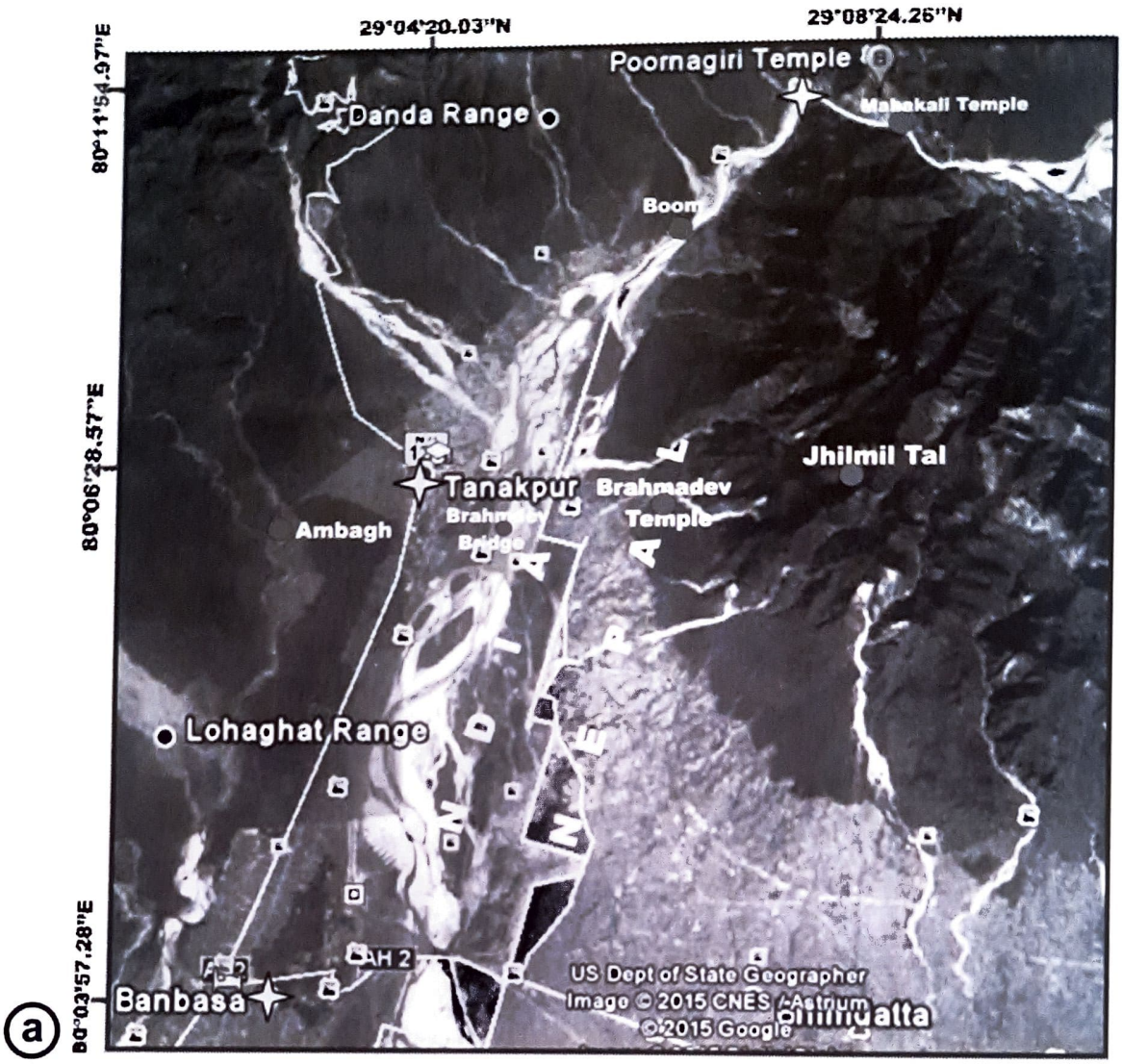
Fossil woods are described for the first time from Upper Miocene sediments of Tanakpur area in the Himalayan foot hills of Champawat District, Uttarakhand, India. Nine species of fossil woods possess affinities with extant *Dipterocarpus indicus* of family Dipterocarpaceae, *Albizia lebbek, A. procera, Baubinia malabarica, B. retusa, Millettia prainii, M. pendula, Pongamia glabra* and *Ormosia robusta* of family Fabaceae, *Bischofia javanica* belonging to family Euphorbiaceae and *Litsea polynthus* of family Lauraceae. The flora indicates that tropical evergreen to moist deciduous plants were flourishing in Tanakpur and nearby area during Upper Miocene, whereas, at present the area is dominated by mixed deciduous plants. The localised extinction of most of the comparable extant species of the fossils indicates that a change in the climate must have taken place since Miocene, most probably due to uplift of Himalaya. The Coexistence Approach (CoA) for palaeoclimate estimation suggests that in the study area tropical climate prevailed during Upper Miocene having Mean Annual Temperature (MAT) 21°-29°C and Mean Annual Precipitation (MAP) 2000 mm – 2900 mm. The presence of diffuse porous condition in all the fossil woods along with medium to large vessels and abundant parenchyma further suggest the prevalence of tropical humid climate during Upper Miocene.

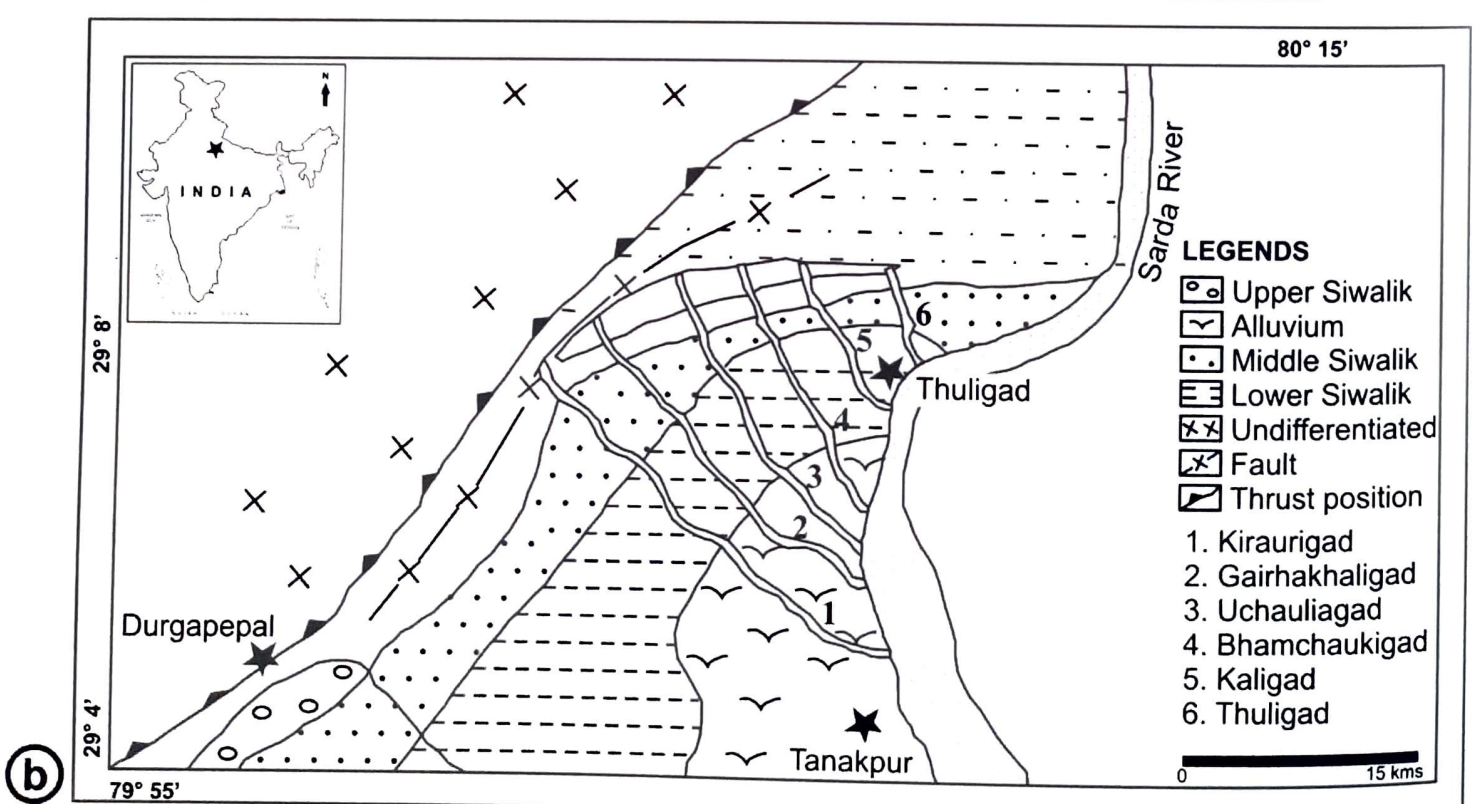
Key-words: Fossil woods, Middle Siwalik, Palaeoclimate, Upper Miocene, Uttarakhand.

INTRODUCTION

The Siwalik deposits are one of the most comprehensively studied sediments in the world. The sediments of Siwalik were deposited continuously by various river systems in the Himalayan foreland since ~20 million years ago (Johnson et.al. 1985). These sediments provide an excellent opportunity to study the plant megafossils those include impressions of carbonized and petrified woods, leaves, fruits and seeds. Lithologically the Siwalik sediments comprise of mudstone, sandstone and coarsely bedded conglomerates. The Siwalik Group has been sub divided into lower, middle, upper Siwalik (Pilgrim, 1913).

The Siwalik sediments in the Tanakpur area (Champawat District, Uttarakhand) are found running in the north east direction and are well exposed all along the Tanakpur –Pithoragad Garh Road and Thuligad-Purnayagiri Road as well as at both the banks of different streams coming down from the Hills (Text-Fig.1a, b).



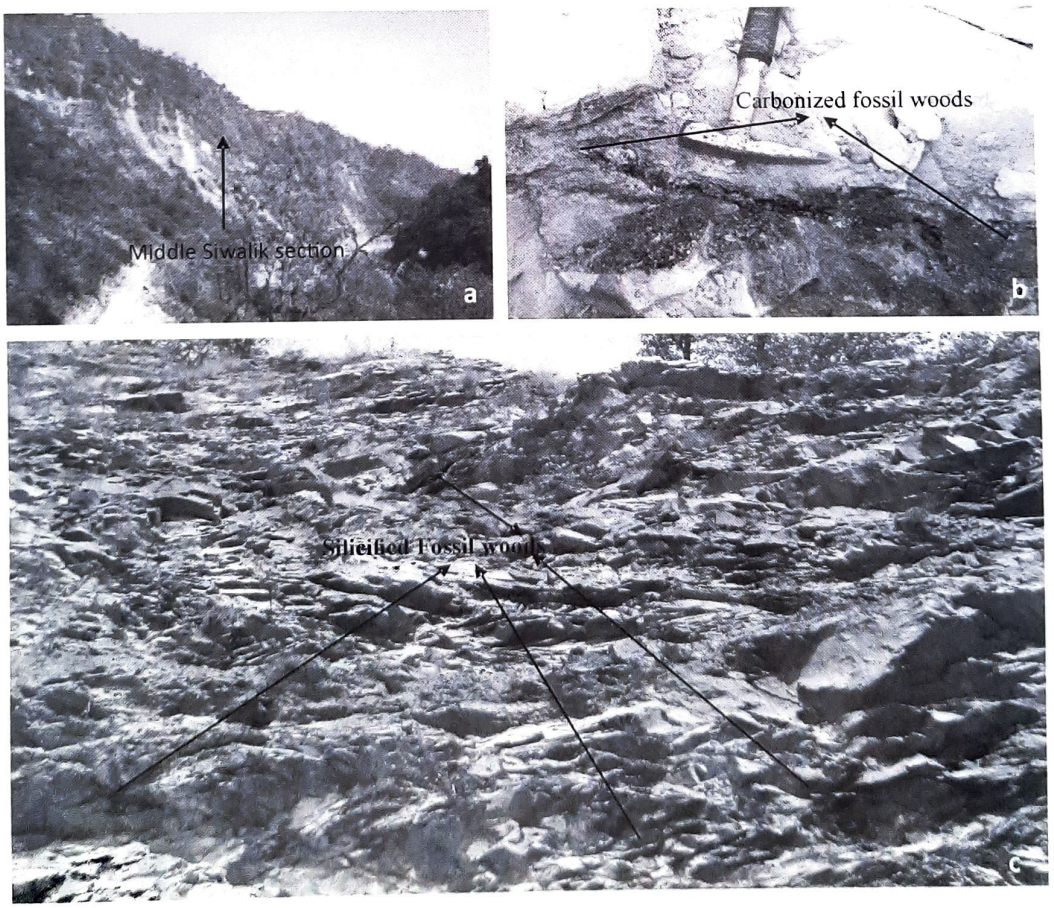


Text-Figure 1a. Google snap showing the location of study area.
Text-Figure 1b. Geological map showing Lower Siwalik sedimentation around the fossil locality

The most important aspect of studying the plant megafossils from Siwalik Foreland Basin is to reconstruct the Siwalik floristic and palaeoclimatic condition during Middle Miocene to Middle Pliocene. Plenty of datasets have been generated but so far very little information on fossil woods are available from the Siwalik sediments of different fossil localities in India and Nepal (Antal et al. 1996, 1999, Awasthi & Prasad 1987, Ghosh & Ghosh 1958, Guleria et al. 2005, Mehrotra et al. 1999, Prakash 1975, 1978, 1979, 1981, Prasad 1990, 1993, 2007, Prasad & Khare 1994, Prasad & Prakash 1988, Prasad & Tripathi 2000, Rawat 1964, Sahni 1931, Trivedi & Ahuja 1978 a,b, 1979, 1980, Trivedi & Panjwani 1986, Trivedi & Misra 1979, 1980, Yadav 1989). In view of meager datasets on fossil woods from the Siwalik sediments, the authors have carried out studies on variety of petrified fossil woods collected for the first time from Middle Siwalik of Tanakpur and nearby areas of Uttarakhand for precise reconstruction of Siwalik floristic and for the palaeoclimatic as well as phytogeographic interpretation. The study on these fossil woods reveals the occurrence of nine fossil taxa comparable to extant taxa viz., *Dipterocarpus indicus* Bedd. (Dipterocarpaceae), *Albizia lebbek* Benth., *A. procera* Benth., *Bauhinia retusa* Ham., *Bauhinia malabarica* Roxb. *Ormosia robusta* Wight, *Millettia prainii* Dun, *M. pendula*, and *Pongamia glabra* Vent., *Bischofia javanica* Bl. (Euphorbiaceae) and *Litsea polyandra* Juss. (Lauraceae). Based on the available data generated from the present study on these fossil woods the palaeoecological perspectives have been discussed.

MATERIAL AND METHODS

More than two hundred specimens of well preserved carbonized and petrified fossil woods were collected from the Middle Siwalik sediments exposed in the Himalayan foot hills of Tanakpur and nearby area in Champawat District of Uttarakhand (Text-Fig. 2).



Text-Figure 2. a. Locality photograph showing Middle Siwalik exposure; **b.** Hard sandstone beds in Middle Siwalik section showing presence of carbonized fossil woods; **c.** Photograph showing thick sandstone beds embedded with silicified fossil woods.

The specimens of petrified fossil woods are fragmentary in nature and black to brown in colour. Thin sections of TS, TLS and RLS were prepared by conventional method. The sections were studied under a high power microscope and identified with the help of published literatures and the reference slides at the Xylarium of BSIP, Lucknow, India. Most of the samples are ill preserved; however, available structural details are suitable for identification. The photographs were taken through digital camera attached to the High power microscope. The terminology used for describing the anatomical characters follows the recommendations of the IAWA Committee 1989. The fossil specimens and slides have been deposited in the Museum of BSIP, Lucknow.

The Climatic parameters, Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP) of the Tanakpur area have been estimated through Coiexistence Approach (CoA) by using the present wood flora. Coiexistence Approach (CoA) is a approach for palaeoclimate estimation (Mosbrugger and Utescher 1997, Utescher et al. 2014) based on the concept that fossil plant taxa of any fossil flora have similar climatic parameter as their Nearest Living Relatives (NLR) i.e., modern counterpart of the fossils. The following four steps are included in this process: 1) For each fossil taxon, the nearest living relatives (NLR) is determined, 2) For each NLR the modern distribution area is compiled, 3) For each distribution area the range of climate parameters (MAT, MAP) is determined separately 4) For each climate parameter analysed, the climatic ranges in which maximum number of NLRs of fossil flora can coexist (coexistence interval) is determined.

SYSTEMATIC DESCRIPTION

Order **MALVALES**

Family **DIPTEROCARPACEAE**

Genus ***DIPTEROCARPOXYLON*** Holden emend. Den Berger 1927

Dipterocarpoxylon siwalicus Prakash 1975

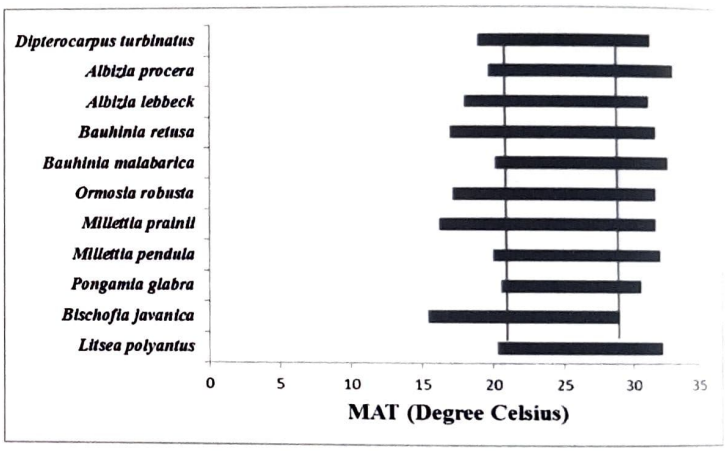
(Pl. 1.1-5)

1927 *Dipterocarpoxylon* Holden emend. Den Berger, p. 495

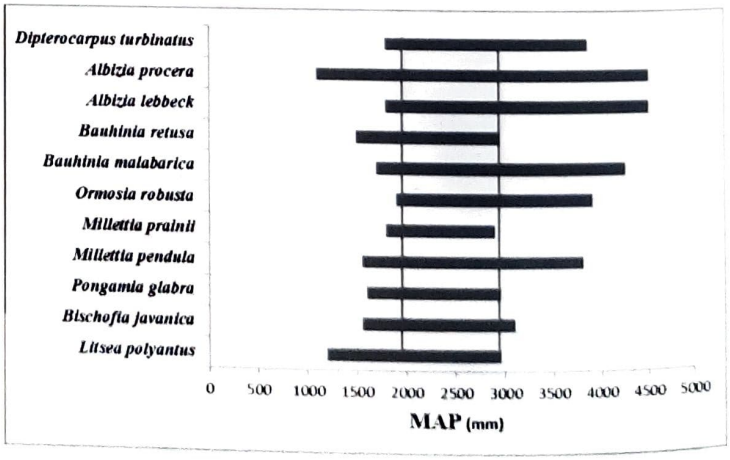
1975 *Dipterocarpoxylon siwalicus* Prakash, p. 193; Pl. 1, figs. 1-3.

2016 *Dipterocarpoxylon siwalicus* Prakash et al., p. 252; Pl. 1, figs. 1-3.

Description: Woods are diffuse-porous, Growth rings are indistinct, vessels are mostly large, t.d. (tangential diameter) 140-240 µm, r.d. (radial diameter) 145-380 µm, solitary, oval to elliptical, 5-9 per sq. mm, tyloses present, vessels 170-590 µm long with truncate to tailed ends, perforations simple, intervessel pits not seen (Pl. 1.1), Vasicentric trachieds are present, paratracheal, slightly bigger than neighboring parenchyma cells in cross section (Pl. 1.1), Parenchyma are mostly apotracheal, diffuse and diffuse aggregate



Text-Figure 3a. Showing the coexistence intervals of climatic parameter, Mean Annual Temperature (MAT) of modern relatives of fossil taxa recorded from Tanakpur area, Uttarakhand (indicate the intervals of coexistence) and vertical line indicating the common range of MAT.



Text-Figure 3b. Showing the coexistence intervals of climatic parameter, Mean Annual Precipitation (MAP) of modern relatives of fossil taxa recorded from Tanakpur area, Uttarakhand (indicate the intervals of coexistence) and vertical line indicating the common range of MAP.

and surrounding the gum canal, paratracheal parenchyma scanty, present around vessels, parenchyma cells also found around gum duct (Pl. 1.1), Xylem rays are 1-5 (6) seriate, 5-10 rays per mm, rays heterocellular, sheath cells generally present on the both flanks of the rays (Pl. 1.3,4). Fibres are libriform, thick walled, non-septate, inter-fibre pits could not be seen, Gum canals are vertical, solitary or in pairs, sometimes in short tangential bands of 2-4, uniformly distributed, small, 50-80 μm in diameter, round to oval in shape (Pl. 1.1)

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16184 (Figured specimen).

Horizon & Age: Middle Siwalik Formation, Upper Miocene.

Locality: Thuligad (29° 9'12.1" N: 80°11'38.5" E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimens: 13

Modern affinities: The presence of vertical gum canals along with vasicentric tracheids, heterogeneous xylem rays and diffuse to diffuse - in - aggregate parenchyma indicates the nearest affinity of fossil wood with the members of the family Dipterocarpaceae. Besides, small scanty solitary gum canals, mostly large solitary vessels and broad, heterogeneous xylem rays with sheath cells on one or both the flanks further suggests its resemblance to modern woods of the genus *Dipterocarpus* Gaertn. f. A comparative study with the thin section of modern wood of *Dipterocarpus* Gaertn.f. shows that the present fossil wood closely resembles the extant taxon *Dipterocarpus indicus* Bedd. (BSIP Wood Slide no. 308) (Syn. *D. turbinatus* Gaertn.f.) in all anatomical features, such as size and distribution pattern of vessel and parenchyma, ray structure and the type and distribution of vertical gum canals.

Fossil record and comparison: A large number of fossil woods belonging to the extant genus *Dipterocarpus* Gaertn.f. are known from the Cenozoic sediments of India and abroad (Tables 1, 2). These taxa having similarity in having the characteristic features viz., shape, size and distribution of vessels and 1-6 seriate xylem rays the present fossil wood shows resemblance to *Dipterocarpoxylon Chowdhurii* Ghosh (1956) from Assam, *D. siwalicus* Prakash (1975) from Siwalik of Nalagad, Himachal Pradesh and from Siwalik sediments of Arjun Khola, western Nepal (Prasad & Gautam 2016), *D. malvii* Ghosh & Ghosh (1959) from Kutch, *D. schenkii* Felix (Schweitzer 1958) from the Tertiary of Java, *D. anisopteroides* (Schweitzer 1958) and *D. javanicum* (Hofman) Schweitzer 1958 from Cenozoic of western Java (Table 2). Except *D. siwalicus* Prakash, the remaining fossil woods differ in possessing larger gum canals and slightly abundant parenchyma. Comparative study suggests that the present fossil wood shows closest affinity with *D. siwalicus* Prakash in shape, size and distribution of vessel and parenchyma nature of xylem rays and gum canals. Therefore, the present fossil wood has been assigned under the same species *D. siwalicus* Prakash.

Present day distribution: *Dipterocarpus* is rather large genus with about 80 species, widely distributed in the Indo-Malayan region. The range of its distribution is from South India and Ceylon in the west to the Philippines in the east. About 13 species grow in the Indian zone (Andamans, Burma, Ceylon, India and Pakistan). The species *Dipterocarpus indicus* Bedd. (Syn. *D. turbinatus* Dyer) which shows close resemblance with the present fossil wood grows in the evergreen forests from north Kanara southwards. It is a common tree in the Tellichery Ghats of the north Malabar Division, as also in Travancore. It also occurs in the Andamans, Assam, Burma, Bangladesh, China and Thailand (Chowdhury & Ghosh 1958).

Order FABALES

Family FABACEAE

Genus *ALBIZINIUM* Prakash 1975

Albizinium Eolebbekianum Prakash 1975

(Pl. 2.1-6)

1975 *Albizinium eolebbekianum* Prakash, p. 197, Pl. 3, figs. 9,11,12.

Description: Woods are diffuse-porous, Growth rings are present, delimited by smaller vessels and terminal parenchyma (Pl. 2.1), Vessels are large to

Table 1. Systematic list of fossil wood flora from Siwalik Group.

Fossil taxa	Locality	Horizon	References
MONOCOTYLEDONS			
Arecaceae	Tawi River, Jammu	U. Siwalik	Sahni 1931
Palmoxylon wadiai	Kalagad, Uttarakhand	L. Siwalik	Prasad 1987
P. jammuense	Tawi River, Jammu	U. Siwalik	Sahni 1931
DICOTYLEDONS			
Anonaceae			
Polyalthioxylon indicum	Kalagad, U.P	L. Siwalik	Prakash 1978
Dipterocarpaceae			
Anisopteroxylon jawalamukhii	Jawalamukhi, H.P.	M. Siwalik	Ghosh & Ghosh 1958
A. kalagarhensis	Kalagad, Uttarakhand	L. Siwalik	Prakash 1978
A. oblongoides	Kalagad, Uttarakhand	L. Siwalik	Yadav 1989
Dipterocarpoxylon siwalicus	Nalagad, H.P.	L. Siwalik	Prakash 1975
D. arcotense	Kalagad, Uttarakhand	L. Siwalik	Prasad 1994b
D. nalagarhense	Nalagad, H.P.	L. Siwalik	Prakash 1975
D. premacrocarpum	Nalagad, H.P.	L. Siwalik	Prakash 1975
D. parabaudii	Kalagad, Uttarakhand	L. Siwalik	Prakash 1978
D. nungarhensis	Kalagad, Uttarakhand	L. Siwalik	Trivedi & Ahuja 1980
D. surangeii	Kalagad, Uttarakhand	L. Siwalik	Prakash 1981
D. kalagarhensis	Kalagad, Uttarakhand	L.Siwalik	Yadav 1989
Dipterocarpoxylon sp.	Mohand, U.P.	M. Siwalik	Rawat 1964
Dipterocarpoxylon sp.	Haridwar, Uttarkhand	M. Siwalik	Prasad & Khare 1994
Dipterocarpoxylon sp.	Oodlabari,W.B.	M. Siwalik	Antal et al. 1999
Shoreoxylon ornatum	Kalagad, Uttarakhand	L. Siwalik	Trivedi & Ahuja 1979
S. siwalicus	Kalagad, Uttarakhand	L. Siwalik	Prasad & Prakash 1988
S. evidens	Arunachal Pradesh	? Miocene	Mehrotra et al. 1999
S. jammuense	Nagrota, J & K.	M. Siwalik	Guleria et al. 2001
Hopenium prenutansoides	Kalagad, Uttarakhand	L. Siwalik	Prasad & Prakash 1988
H. pondicherriense	Kalagad, Uttarakhand	L. Siwalik	Prasad 1994b
H. kalagarhensis	Kalagad, Uttarakhand	L. Siwalik	Prasad & Prakash 1988
	Hamirpur, H.P.	M. Siwalik	Prasad 2010
	Laxmi River, Bhutan	L. Siwalik	Prasad & Tripathi 2000
Vaterioxylon kalagarhensis	Kalagad, U.P.	L. Siwalik	Trivedi & Misra 1980
V. miocenicum	Kalagad, U.P.	L. Siwalik	Trivedi & Misra 1980
Sterculiaceae			
Sterculinium foetidense	Kalagad, U.P.	L. Siwalik	Prasad 1994b
S. kalagarhense	Kalagad, U.P.	L. Siwalik	Prasad 1994b
Sterculia kathgodamense	Kathgodam, U.P.	L. Siwalik	Prasad 1994c
Sterculioxylon kalagarhense	Kalagad, U.P	L. Siwalik	Trivedi & Ahuja 1978a
Burseraceae			
Burseroxylon preserratum	Kalagad, Uttarakhand		Prasad 1994b
Meliaceae			
Aglaia nahanensis	Nalagad, H.P.	L. Siwalik	Yadav 1989
Sapindaceae			
Euphorioxylon deccanense	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
Euphorioxylon indicum	Kalagad, Uttarakhand	L. Siwalik	Prasad 1993
Anacardiaceae			
Dracontomelumoxylon mangiferumoides	Nalagad, H.P.	L. Siwalik	Prakash 1978
Glutoxylon kalagarhensis	Kalagad, Uttarakhand	L. Siwalik	Trivedi & Ahuja 1978b
Glutoxylon burmense	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999

Fabaceae			
Albizinium eolebekkianum	Nalagad, H.P.	L. Siwalik	Prakash1975
A. arunachalensis	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
Bauhinioxylon indicum	Mohand	M. Siwalik	Rawat 1964
Bauhinium palaeomalabarica	Kalagad, Uttarakhand	L. Siwalik	Prakash & Prasad 1984
B. miocenicum	Kalagad, Uttarakhand	L. Siwalik	Trivedi & Panjwani 1984
Cassinium prefistulai	Nalagad, H.P.	L Siwalik	Prakash 1975
	Jammu, J & K	M. Siwalik	Guleria et al. 2001
C. borooahii	Kalagad, Uttarakhand	L. Siwalik	Prakash 1978
	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
Cynometroxylon indicum	Nalagad, H.P.	L. Siwalik	Prakash 1975
Cynometroxylon sp. cf. *C. indicum*	Kalagad, Uttarakhand	L. Siwalik	Prakash1978
Cynometroxylon holdeni	Kalagad, Uttarakhand	L. Siwalik	Trivedi & Ahuja 1978c
	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
Pahudioxylon bankurensis	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
P. indicum	Nalagad, H.P.	L. Siwalik	Prakash 1979
Dialiumoxylon kalagarhense	Kalagad, Uttarakhand	L. Siwalik	Trivedi & Misra 1978
D. palaeoindicum	Kalagad, Uttarakhand	L. Siwalik	Prasad 1993
Hopeoxylon eosiamensis	Kalagad, Uttarakhand	L. Siwalik	Prakash 1981
Hopeoxylon speciosum	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
Millettioxylon pongamiensis	Nalagad, H.P.	L. Siwalik	Prakash 1975
M. indicum	Kalagad, Uttarakhand	L. Siwalik	Prasad 1993
Ormosioxylon bengalensis	Kalagad, Uttarakhand	L. Siwalik	Prasad 1988
Koompassioxylon elegans	Nalagad, H.P.	L. Siwalik	Yadav 1989
Adenantheroxylon pavoninium	Nalagad, H.P	L. Siwalik	Yadav 1989
Acrorpus siwalicus	Nalagad, H.P.	L. Siwalik	Yadav 1989
Kingiodendron prepinnatum	Jammu, J & K	M. Siwalik	Yadav 1989
Combretaceae			
Terminalioxylon palaeomanii	Kalagad, Uttarakhand	L. Siwalik	Prakash 1981
Terminalioxylon belericum	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
T. siwalicus	Kalagad, Uttarakhand	L. Siwalik	Prasad 1988
Lecythidaceae			
Careyoxylon pondicherriense	Nalagad, H.P.	L. Siwalik	Prakash1979b
Lythraceae			
Duabangoxylon indicum	Kalagad, Uttarakhand	L. Siwalik	Awasthi & Prasad 1987
Chrysophylloxylon pondicherriense	Arjun Khola, Nepal	M. Siwalik	Prasad 2006
Ebenaceae			
Ebenoxylon miocenicum	Kalagad, Uttarakhand	L. Siwalik	Prakash 1978
	West Bengal	M. Siwalik	Antal et al. 1996
E. siwalicus	Kalagad, Uttarakhand	L. Siwalik	Prakash 1981
E. palaeocandoleana	Kalagad, Uttarakhand	L. Siwalik	Prasad 1993
E. kalagarhensis	Kalagad, Uttarakhand	L. Siwalik	Prasad1988
Lauraceae			
Laurinoxylon siwalicus		L. Siwalik	Prasad 1990
Euphorbiaceae			
Bischofia palaeojavanica	Siang District, A.P.	M. Siwalik	Mehrotra et al. 1999
Moraceae			
Artocarpoxylon deccanensis	Kalagad, Uttarakhand	L. Siwalik	Prasad 1993
Ficoxylon kalagarhensis	Kalagad, Uttarakhand	L. Siwalik	Prasad 1993
Incertae sedis			
Dryoxylon nahanai	Nalagad, H.P.	L. Siwalik	Prakash 1975

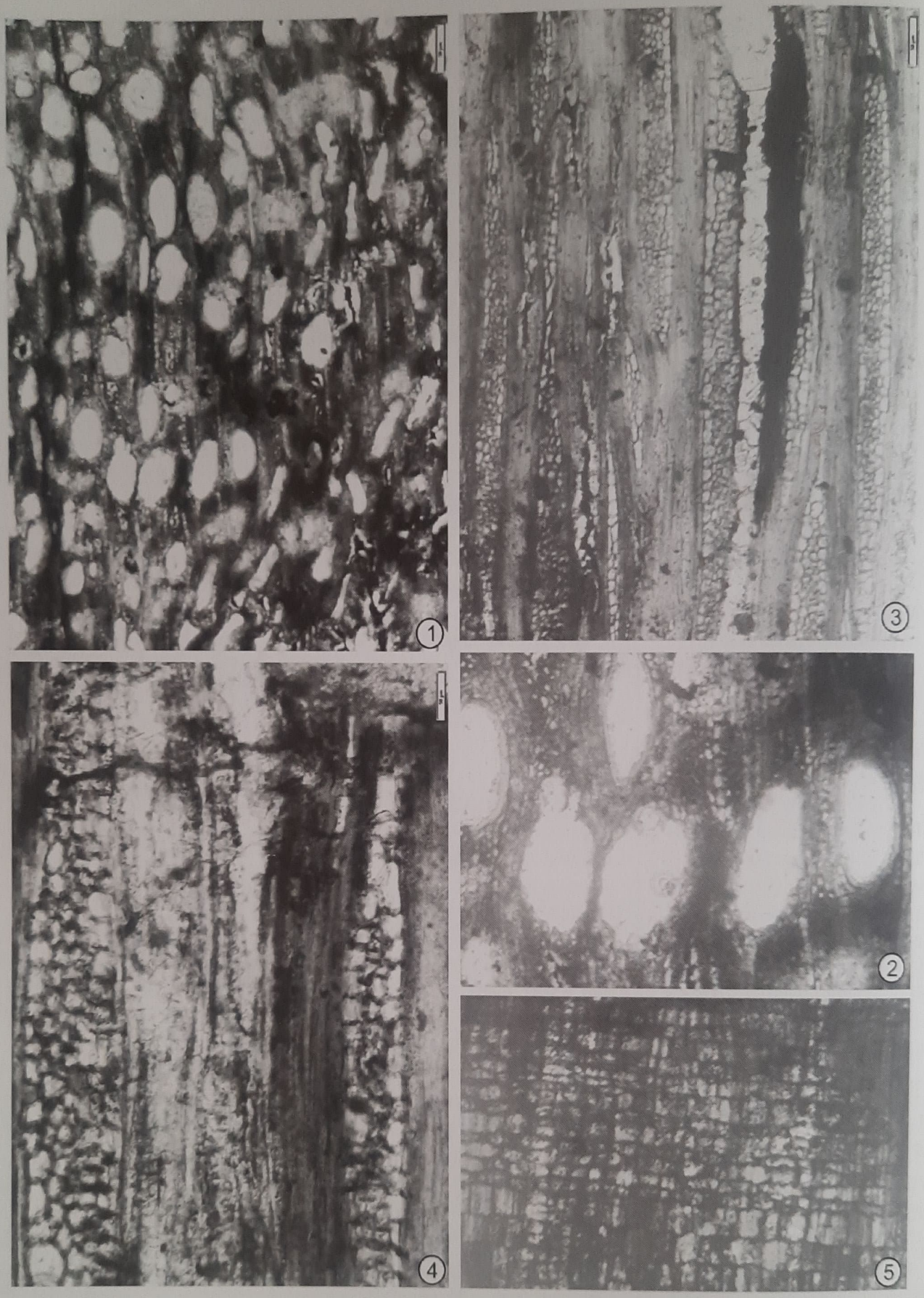


PLATE 1

***Dipterocarpoxylon siwalicus* Prakash**

1. Cross section of the fossil wood showing nature of vessels, parenchyma and gum canals. x 60 (BSIP Museum Slide No. 16184-I).
2. Cross section of the fossil wood magnified to show the details of parenchyma and vessels. x 120 (BSIP Museum Slide No. 16184-1).
3. Tangential longitudinal section of the fossil wood showing nature and arrangement of xylem rays. x 80 (BSIP Museum Slide No. 16184-II).
4. Tangential longitudinal section of the fossil wood magnified to show details of xylem rays with sheath cells at one or both flanks of the rays. x 150 (BSIP Museum Slide No. 16184-II).
5. Radial longitudinal section of the fossil wood showing heterocellular xylem rays. x 120 (BSIP Museum Slide No. 16184-III).

medium-sized, t.d. 135-305µm, r.d. 140-340µm, mostly solitary, sometimes in radial multiples of 2-3 cells, 3-5 per sq mm, mostly empty (Pl. 2.1,2); vessel segments short, 130-360 µm long, usually truncate; perforations simple; inter-vessel pit-pairs vestured, alternate, 6-8mm in diameter with linear-lenticular apertures (Pl. 2.4,6), Parenchyma are paratracheal and apotracheal; pareatracheal parenchyma vasicentric to nearly aliform, occasionally confluent joining adjacent vessels; apotracheal parenchyma terminal and diffuse scattered among the fibres (Pl. 2.2); cells sometimes crystalliferous, Xylem rays are 1-3(4) seriate; ray tissue homogeneous (Pl. 2.3,4,6), Fibres are thin walled, septate (Pl. 2.4).

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16185 (Figured specimen).

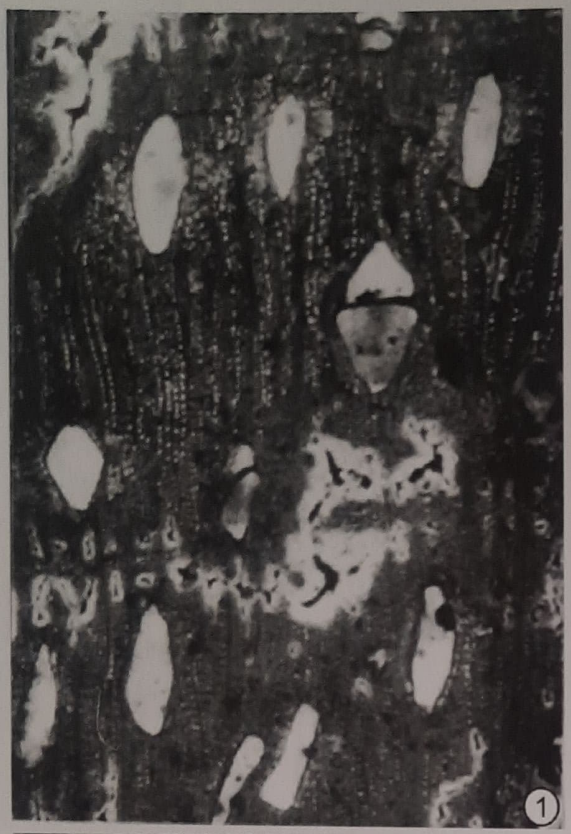
Horizon & Age: Middle Siwalik Formation, Upper Miocene.

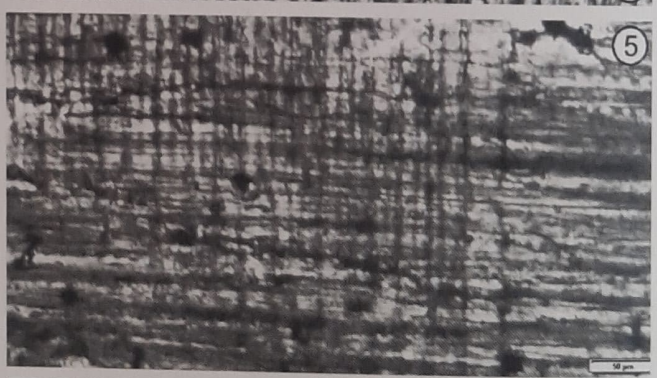
Locality: Sidhbaba nala (29° 4'2.7'' N: 80°8'57.6'' E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimens: 4

Modern affinities: The anatomical characters exhibited by the present fossil woods indicate that they most closely resemble to the modern wood of the leguminous genus *Albizzia* Duraz., although it also shows a superfical resemblance to the mature seconday xylem of *Acacia* (*A. lenticularis)* and *Cassia* (*C. nodosa* and *Afzelia intsia*). However, the fibres are non-septate in *Acacia lenticularis*. Similarly *Cassia nodosa* has larger vessels and the paratracheal parenchyma is aliform with long wings, sometimes joining each other. *Afzelia intsia* also differ from the present fossil wood in having nonseptate fibres and the xylem rays are sometimes arranged in echelon, whereas the fossil wood has septate fibres, nonstoried xylem rays and vasicentric to mostly aliform parenchyma. A critical study of all available woods of the genus *Albizzia* indicates that the nearest affinity of the fossil is with *Albizzia lebbek* Benth. (BSIP Wood Slide no. 145, 230). The study includes the observation of thin sections of *Albizzia lebbek* Benth., *A. amara* Boiv. *A. lucida* Benth., *A. mollis* F. Mull., *A. molucana* Mig., *A. odorattissima* Benth. *A. procefra* Benth, *A. stipulata* Biov., *A.coriaria* Welw., *A. falcata* Backer, *A. toona* Bailey, *A. zygia* Mech., *A. versicolor* Welw. ex. Oliver, *A. sassa* chiov., *A. ferruginea* Benth., and *A. lebbekioides* Benth. and published descriptions of eleven other species. The latter are *A. montana* Benth., *A. tomentella* Mig. (Moll & Janassonius 1914), *A. acle* (Blanco) Merr., *A. marginata* Merr., (Kanehira 1924, Kribs 1959), *A. adianthifolia* (Schum.) W.F. Wingth, *A. grandibracteata* Taub. (Brazier & Franklin 1961), *A. xanthoxylon* C.T. (Osb.) Merr. (Reyes 1938) and *A retusa* Benth. (Schneider 1916). The present fossil wood resembles the modern wood of *Albizzia lebbek* in the size and distributional pattern of the vessels, in the type of perforation plates and inter-vascular pit-pairs, in parenchyma distribution, and the fibre and ray structure.

Fossil record and comparison: Several fossil woods belonging to the family Fabaceae are known (Muller-Stoll & Madel 1967). However, the fossil woods related to *Albizzia* are only limited to few references in the literature. Niktin (1935) first described a fossil wood resembling the modern wood of *Alibizia julibrissin* Duraz. from the Pliocene of eastern Georgia as *Albizioxylon hyrcanicum*. He did not mention the parenchyma pattern and the presence of septate fibres and these features are also not clear from the illustrations given by him. Consequently, Muller- Stoll & Madel (1967) instituted a new name *Ingoxylon* to include the fossils showing the wood structure of the extant genera *Inga, Albizzia, Piptadenia, Pithecellobium, Leucaena* and some species of *Afzelia.* Later on Prakash (1975) described a fossil wood resembling the genus *Albiziz* Duraz, as *Albizinium* from the Siwalik sediments of Himachal Pradesh, India. So far, five species of this genus are known from India and abroad. These are *Albizinium eolebbekianum* from Siwalik (Middle Miocene) of Nalagad, Himachal Pradesh, India (Prakash, 1975); Upper Miocene of Birbhum District, West Bengal (Ghosh & Roy 1981); Dupitila Series (Mio-Pliocene) of Deomali, Arunachal Pradesh, India (Lakhanpal et al. 1981); Kankawati Series (Pliocene) of Mothala, Kachchh, Gujarat (Guleria 1984), *A. pondicherriensis*





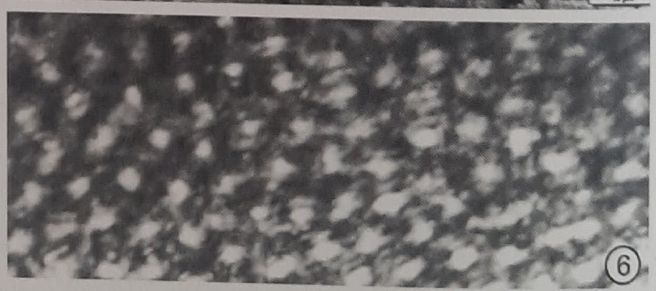


PLATE 2

***Albizinium eolebbkianum* Prakash**

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma and. Xylem rays. x 60 (BSIP Museum Slide No. 16185-I).
2. Cross section of the fossil wood magnified to show the details of fibres, parenchyma and vessels. x 120 (BSIP Museum Slide No. 16185-1).
3. Tangential longitudinal section of the fossil wood showing nature and arrangement of xylem rays. x 60 (BSIP Museum Slide No. 16185-II).
4. Tangential longitudinal section of the fossil wood magnified to show details of xylem rays with storied arrangement of the xylem rays. x 120 (BSIP Museum Slide No. 16184-II).
5. Radial longitudinal section of the fossil wood showing heterocellular xylem rays. x 120 (BSIP Museum Slide No. 16185-III).
6. Inter-vessel pit pairs. X 800 (BSIP Museum Slide No. 16185-II).

Awasthi from Cuddalore Series (Mio-Pliocene) of Pondicherry (Awasthi 1997); Kanawati Series (Pliocene) of Dhaneti, Kachchh, Gujarat (Guleria 1984); Tipam Sandstones (Miocene), Hailakandi, Cachar District, Assam (Prakash et al. 1994); Tipam Group (Miocene) of Tirap District, Arunachal Pradesh (Awasthi & Mehrotra 1997); Bengal Basin Early Pleistocene of Birbhum District, West Bengal (Bera & Banerjee 2001); Warkalli Formation (Miocene) of Kundra Clay Mine, Kerala (Srivastava 2001), *A. arunachalensis* from Siwalik Group (Late Miocene-Pliocene) of Siang District, Arunachal Pradesh (Mehrotra et al. 1999), *A. borjanensis* from Tipam Sandstones (Miocene) of Mon District, Assam (Prakash et al. 2001), *A. palaeolucidum* from Warkalli Formation (Miocene) of Varkala Cliff Section, Kerala (Srivastava 2001). After a detailed comparison of present woods with the above mentioned fossil woods it has been concluded that the fossil wood, *Albizinium eolebbekianum* Prakash described from Siwalik of Himachal Pradesh shows close similarity with the present fossil woods in almost all the anatomical features. As the present fossil wood shows a close resemblance to the fossil wood *Albizinium eolebbekianum* Prakash hence it is assigned to the same specific name.

Present day distribution: *Albizia* Duraz. are large trees or shrubs, widely scattered throughout the tropics and subtropics of Asia, Africa, Australia. *Albizia lebbek* Benth. resembles with the present fossil wood that grows throughout India from the eastwards of the River Indus along the sub-Himalayas to Assam, Burma and Andamans (Pearson & Brown 1932, pp. 454-455).

Genus *ALBIZINIUM* Prakash 1975

Albizinium Arunachalensis Mehrotra et al. 1999 (Pl. 3.1-7)

1999 *Albizinium arunachalensis* Mehrotra et al., p. 240,, Pl. 7, figs. 5-6, Pl. 8, figs.1-2.8,11,12.

Description: Woods are diffuse-porous, Growth rings are present, delimited by a band of dense parenchyma (Pl. 3.5), Vessels are medium to large-sized, t.d. 110-295 μm, r.d. 120-305 μm, solitary as well as in radial multiples of 2-3 cells, 3-6 per sq. mm; tyloses absent (Pl. 3.1,3,5); vessel segments 120-340 mm long, usually truncate; perforations simple; intervessel pit- pairs vestured, alternate , 6-8 μm in diameter with linear-lenticular apertures (Pl. 3.2,4,6), Parenchyma are paratracheal and apotracheal; paratracheal parenchyma vasicentric to nearly aliform, occasionally confluent; apotracheal parenchyma terminal and diffuse scattered among the fibres, cells round to oval 15-75 μm in diameter (Pl. 3.1,3), Xylem rays are 1-4 (2-3) seriate, 7-9 per mm, 8-20 cells in height; ray tissue homogeneous, ray cells 14-28mm in tangentiall height and 16- 140 μm in radial length (Pl. 3.2,4,7), Fibres are thin walled, 8-20 mm in diameter, non-septate (Pl. 3.2,4).

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16186 (Figured specimen).

Horizon & Age: Middle Siwalik Formation, Upper Miocene.

Locality: Sidhbaba nala (29° 4'2.7'' N: 80°8'57.6'' E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimens: 4

Modern affinities: The characteristic feature exhibited by the present fossil woods such as vasicentric to confluent parenchyma, usually 2-3 seriate homocellular xylem rays, simple perforation plates, vestured pits and non-septate fibres indicate their resemblance with the modern wood of the genus *Albizia* Duraz. of family Fabaceae. A critical examination of all the available wood slides of the genus *Albizzia* viz., *Albizzia lebbek* Benth., *A. amara* Boiv., *A. lucida* Benth., *A. mollis* Mull., *A. molucana* Miq., *A. odorattissima* Benth. *A. procefra* Benth, *A. procera* Benth. *A. stipulata* Biov., *A. coriaria* Welw., *A. falcata* Backer, *A. toona* Bailey, *A. zygia* Mech., *A. versicolor* Welw. ex. Oliver, *A. sassa* Chiov., *A. ferruginea* Benth. and *A. lebbekioides* Benth. and published descriptions of some other species suggests that the fossil woods recovered from the present study shows nearest affinity with *Albizia procera* Benth. (BSIP Wood Slide no. 149; Pearson and Brown 1932, Rao & Purkayastha 1972, Kanehira 1924, Kribs 1959).

Fossil record and comparison: Fossil woods showing close affinity with the genus *Albizia* Duraz.

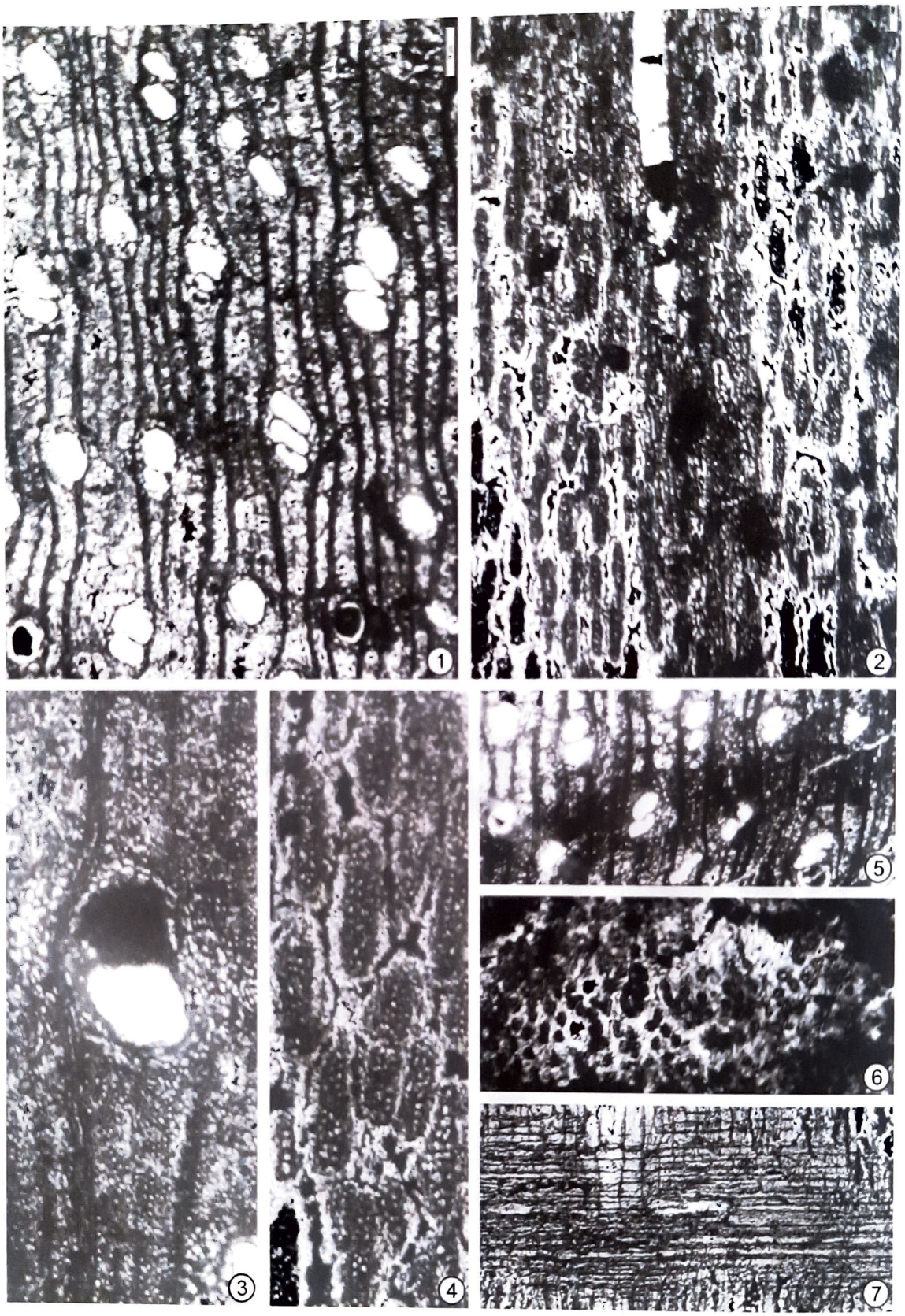


PLATE 3

Albizinium arunachalensis Mehrotra et al.

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma and. Xylem rays. x 60 (BSIP Museum Slide No. 16186-I).
2. Tangential longitudinal section of the fossil wood showing nature and arrangement of xylem rays. x 80 (BSIP Museum Slide No. 16186-II).
3. Cross section of the fossil wood magnified to show the details of fibres, parenchyma and vessels. x 120 (BSIP Museum Slide No. 16186-I).
4. Tangential longitudinal section of the fossil wood magnified to show details of xylem rays with irregularly storied arrangement of the xylem rays. x 120 (BSIP Museum Slide No. 16186-II).
5. Cross section of the fossil wood showing growth ring demarcated by dense fibres. x 40 (BSIP Museum Slide No. 16186-I).
6. Inter-vessel pit pairs. x 400 (BSIP Museum Slide No. 16186-II).
7. Radial longitudinal section of the fossil wood showing heterocellular xylem rays. x 100 (BSIP Museum Slide No. 16186-III).

are described under the form genus *Albizinium* Prakash. So far, five species of this genus have been known from a number of Cenozoic localities in India and abroad. Out of these, *Albizinium arunachalensis* Mehrotra et al. reported from Siwalik Group (Late Miocene-Pliocene) of Siang District, Arunachal Pradesh shows close similarity with the present fossils in being possessing comparatively smaller rays and non-septate fibres. Thus it is assignable to *Albizinium arunachalensis*.

Present day distribution: *Albizia procea* Benth., with which the present fossil wood closely resembles are large straight tree grows in Assam, Bihar, Orissa, central India, Andamans and Myanmar. It is more common in swampy places or moist ravines (Pearson & Brown 1932).

Genus *BAUHINIUM* Prakash & Prasad 1984

Bauhinium paleomalabricum Prakash & Prasad 1984

(Pl. 4.1-6)

1984 *Bauhinium paleomalabricum* Prakash & Prasad, p. 140. Pl. 1, figs. 1, 3; Pl. 2, figs. 5-8

Description: Woods are diffuse-porous, *Growth rings* are not seen, *Vessels are* small to large, t.d. 90-200 µm, r.d. 100-250 µm, round to oval, solitary and also in radial groups of 2-3, sometimes filled with black contents, 8-12 per sq mm (Pl. 4.1,2); vessels 160-490 µm long with truncate ends, irregularly storied; perforations simple; inter-vessel pit pairs vestured , alternate, usually oval (Pl. 4.2,4,6), Parenchyma are paratracheal confluent, forming somewhat sinuate continuous concentric bands alternate with broader bands of fibres; paratracheal parenchyma vasicentric, relatively scanty forming 1-2 seriate interrupted sheath; parenchyma cells arranged in radial rows, thin walled, 10-22 µm in diameter, parenchyma strands irregularly storied and 410-1290 µm in dimension (Pl. 4.1,2,4), Xylem rays are 1-2 seriate, mostly uniseriate 16-50 µm in width 4-25 cells or 130-650 µm in length, nearly storied; ray tissue heterogeneous, rays composed of procumbent cells in the middle part and 1-2 rows of marginal upright cells at the ends, ray cells thin walled, sometimes filled with gummy infiltrations; procumbent cells 12-18 µm in vertical height and 20-50 µm in radial length; upright cells with vertical height 20-30 µm and radial length 14-20 µm (Pl. 4.3,4,5), Fibres are libriform to non-libriform, moderately thick walled, non-septate, polygonal in cross section (Pl. 4.4).

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16187 (Figured specimen).

Horizon & Age: Middle Siwalik Formation, Upper Miocene.

Locality: Kaligad (29° 7'25.4" N: 80° 9'37.9" E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimens: 2

Modern affinities: The characteristic features of the present fossil woods are small to large with round to oval shape, banded parenchyma are 1-2 (1) seriate, heterocellular, storied rays showing ripple marks and non-septate fibres. These anatomical features are found common in those of extant *Bauhinia* Linn. of the family Fabaceae. The thin slides of available species of this genus viz., *Bauhinia anguina* Roxb., *B. malabarica* Roxb., *B. purpurea* LInn., *B. recemosa* Linn., *B. retusa* Ham., *B. reticulata* D.C., *B. vahlii* W. & A. were studied in detail along with published descriptions and figures of some more species (Kribs 1959, Pearson & Brown 1932, Rao & Purkayastha 1972, Ilic 1991, Gupta 2007) in order to find out the living counter part of the present fossil wood. The above study revealed that *B. malabarica* (BSIP wood slide no.3426) shows close similarity in almost all the structural details with that of the present fossil wood.

Fossil record and Comparison: The fossil wood showing affinities with the modern wood of *Bauhinia* was reported from the Siwalik beds of Mohand District Saharanpur, U.P. (Rawat 1965) under the generic name *Bauhinioxylon*. No description and illustration of this fossil wood was provided by Rawat (1965), hence the genus in not valid according to the International Code of Botanical Nomenclature. In view of this, a new name *Bauhinium* was proposed by Prakash & Prasad (1984) for the fossil woods of *Bauhinia*. The fossil woods so far described under the form genus, *Bauhinium/ Bauhinia* are: *B. palaeomlabaricum* from the Siwalik sediments of Kalagad, Uttar Pradesh (now in

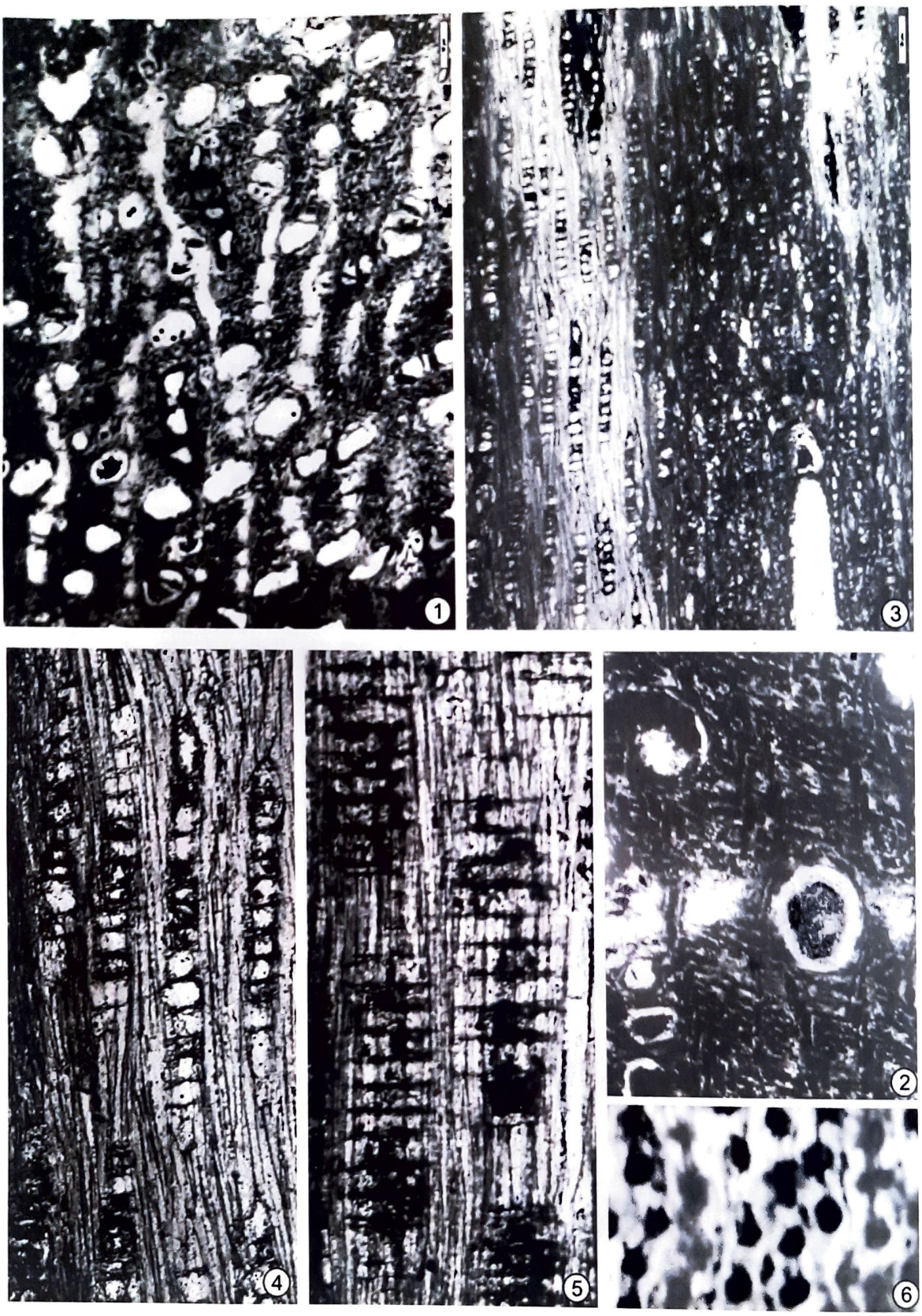


PLATE 4

***Bauhinium palaeomalabaricum* Prakash & Prasad**

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma and. xylem rays. x 60 (BSIP Museum Slide No. 16187-I).
2. Cross section of the fossil wood magnified to show the alternate arrangement of fibre, and parenchyma band. x 120 (BSIP Museum Slide No. 16187-1).
3. Tangential longitudinal section of the fossil wood showing storied arrangement of xylem rays. x 80 (BSIP Museum Slide No. 16187-II).
4. Tangential longitudinal section of the fossil wood magnified to show details of xylem rays fibre and parenchyma strands. x 150 (BSIP Museum Slide No. 16187-II).
5. Radial longitudinal section of the fossil wood showing weakly heterocellular xylem rays. x 150 (BSIP Museum Slide No. 16187-III).
6. Inter-vessel pit pairs. x 800 (BSIP Museum Slide No. 16187-II).

Uttarakhand; Prasad & Prakash 1984) and Oodlabari area of Darjeeling District, West Bengal (Antal et al. 1996), *B. miocenicum* from the Siwalik of Kalagad, Uttarakhand (Trivedi & Panjwani 1986), *B. tuipangensis* from Lower Miocene of Tuipang area, Mizoram (Agarwal et al. 2006), *Bauhinia deomalica* from the Namsang beds of Deomali, Arunachal Pradesh (Awasthi & Prakash 1987), Neyveli Lignite of South India (Agarwal 1991) and Tippam Group of Udaipur, South Tripura District, Tripura (Mehrotra et al. 2006), *Bauhinia tertiara* from Tippam Sandstones of Nagaland (Awasthi & Mehrotra 1990) from the Neogene of Tripura (Sen & Bera, 2005), *B. miocenica* from Tippam group of Dhemaje District, Assam (Mehrotra et al. 2011). The present fossil woods have been compared with all the above known fossil woods species and found that one of the known species, *Bauhinium palaeomalabaricum* Prasad & Prakash shows similarity in almost all the anatomical features and hence assigned to the same species.

Present day distribution: Genus *Baubinia* Linn. consists of about 300 species that are widely scattered throughout the tropics of the world. About 30 species are found in India and Myanmar. *B. malabarica* Roxb. with which the fossil wood resembles closely is a small to medium-sized tree, distributed in moist deciduous forests of sub-Himalayan tract and outer Himalayas stretching from the east of River Ravi to Assam. It is also distributed in the central provinces, Gujarat, Bihar, Orissa and west coast of southern India. It is also common in Peguyoma and South Myanmar (Pearson & Brown 1932, Rao & Purkayastha 1972, Mabberley 1997).

Genus *BAUHINIUM* Prakash & Prasad 1984

Bauhinium miocenicum Trivedi & Panjwani 1986

(Pl. 5.1-5)

Description: *Woods* are diffuse-porous, Growth rings are not seen, Vessels are medium to rarely large, t.d. 130-210 µm, r.d. 140-230 µm, circular to oval, solitary and also in radial groups of 2-3, filled with resinous substance, 6-9 per sq mm (Pl. 5.1); vessel members 180-300 µm long with truncate or tailed ends; vessel segments nearly storied; perforations simple; inter-vessel pit pairs bordered, alternate, orbicular (Pl. 5.2,5), Parenchyma are paratracheal and parenchyma vasicentric, relatively scanty forming 1-2 seriate interrupted sheath; paratracheal parenchyma forming bands up to 6 cells wide which alternate with the fibrous bands of mostly equal width; parenchyma cells arranged in radial rows (Pl. 5.1), Xylem rays are 1-3 seriate, mostly biseriate; ray tissue heterogeneous, rays composed of procumbent cells in the middle part and 1-3 rows of marginal upright cells at the ends, 6-18 cells or 250-430 µm high, 10-12 per mm, ray cells filled with gummy infiltrations; upright cells with vertical height 20-30 µm, radial length 15-20 µm; procumbent cells 15-18 µm in vertical height and 26-45 µm in radial length; rays nearly storied forming ripple marks (Pl. 5.2,3,4), Fibres are libriform, nonseptate not arranged in radial rows, in the form of regular tangential bands alternating the parenchyma bands of almost equal width (Pl. 5.1).

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16188 (Figured specimen).

Horizon & Age: Middle Siwalik Formation, Upper Miocene.

Locality: Bomchowkigad (29° 6'4.2'' N: 80°8'36.1'' E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimens: 3

Modern affinities: The anatomical features exhibited by the present fossil woods such as banded parenchyma, 1-3 (2) seriate, heterocellular, irregularly storied xylem rays non-septate fibres are shared by the fossil wood with those of extant *Bauhinia* Linn. of the family Fabaceae. In order to identify up to the species level a critical survey of wood slides of all the available species of the genus *Bauhinia* Linn. as well as their published descriptions and figures (Gamble, 1902; Pearson & Brown, 1932; Ramesh Rao & Purkayastha, 1972) has been carried out. The above survey revealed that *B. retusa* Ham, (BSIP Wood Slide no. 258) shows close agreement in almost all the structural details with that of the present fossil wood.

Fossil record and comparison: The fossil woods showing affinities with the modern wood of *Bauhinia* was reported under six form species. In view of the

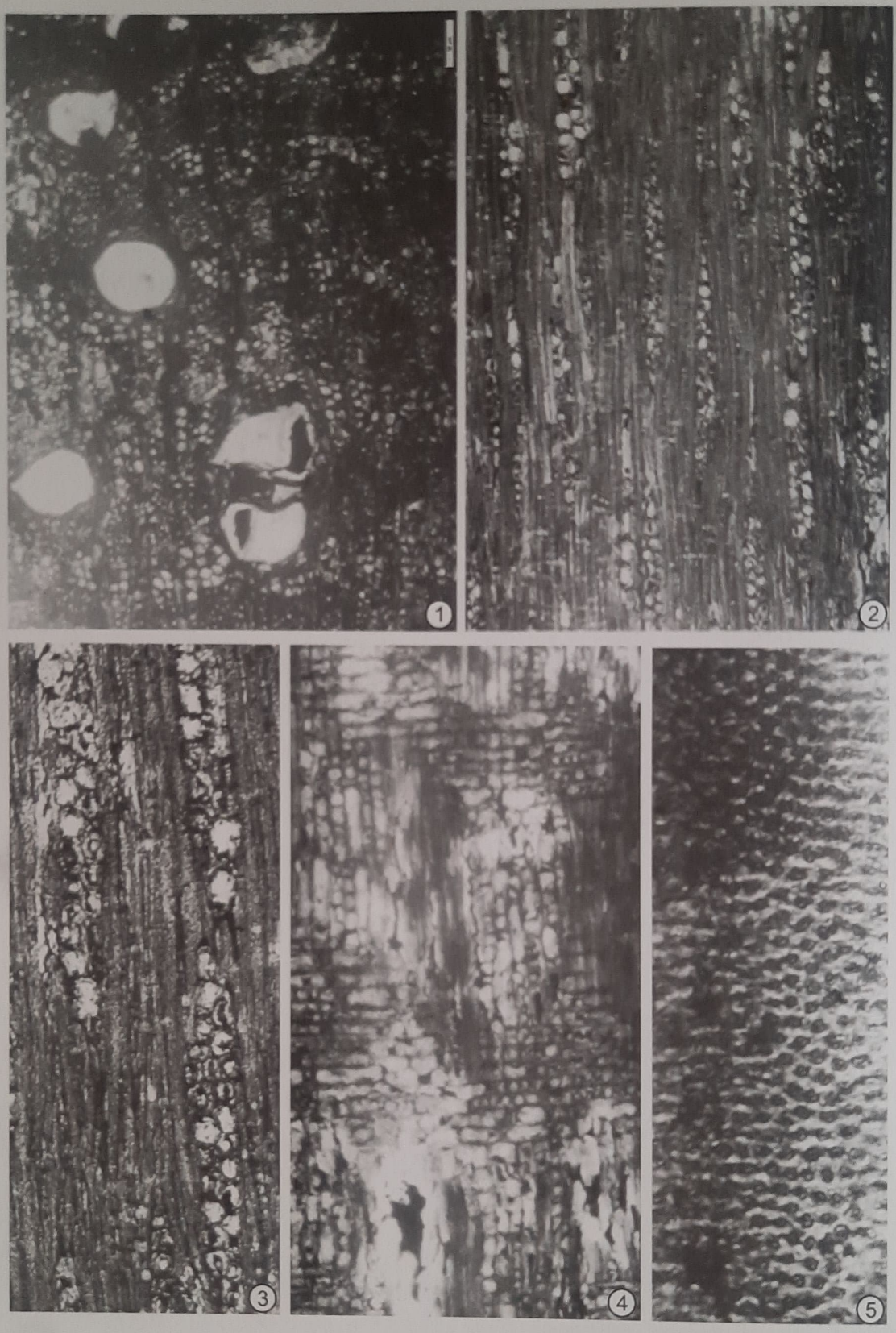


PLATE 5

***Bauhinium miocenicum* Trivedi & Panjwani**

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma, fibres and. xylem rays. x 60 (BSIP Museum Slide No. 16188-I).
2. Tangential longitudinal section of the fossil wood showing irregularly storied arrangement of xylem rays. x 80 (BSIP Museum Slide No. 16188-II).
3. Tangential longitudinal section of the fossil wood magnified to show details of xylem rays fibre and parenchyma strands. x 150 (BSIP Museum Slide No. 16188-II).
4. Radial longitudinal section of the fossil wood showing weakly heterocellular xylem rays. x 80 (BSIP Museum Slide No. 16188-III).
5. Inter-vessel pit pairs. x 500 (BSIP Museum Slide No. 16188-II).

closest resemblance of the present fossil wood with one of the reported species, *Bauhinium miocenicum* Trivedi & Panjwani, the Tanakpur fossil woods have been reported under the same species. It can be differentiated from the earlier described species, *Bauhinium palaeo malabaricum* in having medium sized vessels (132-176 μm), somewhat narrow parenchyma bands (2-6 seriate) and 1-3 (mostly 2) seriate xylem rays in contrast to small to large vessels (t.d. 900-200 μm, thicker parenchyma bands and 1-2 (usually 1) seriate rays present in *B. malabaricum.*

Present day distribution: The modern comparable species *B. retusa* Ham. with which the fossil wood resembles closely is small to medium-sized tree, distributed in the sub-Himalayan tract and outer Himalayas from River Bias to Nepal ascending up to 1300 m. It is also found in the Chotanagpur plateau, slopes of Eastern Ghats, parts of Madhya Pradesh and Mysore but rather scarce (Rao & Purkayastha 1972).

Genus *MILLETTIOXYLON* Awasthi 1967

Millettioxylon indicum Awasthi

(Pl. 6. 1-5)

1967 *Millettioxylon indicum* Awasthi, p. 180, figs.1-3

Description: Woods are diffuse-porous, Growth rings are indistinct, Vessels are small to medium, rarely large sized t.d. 70-140 μm, r.d. 85-210 μm circular to oval, sometimes compressed and filled with dark contents, thick-walled (Pl. 6.1,2), vessel members storied, short, 225-390 μm long, usually with truncate ends; perforations simple; inter vessel pits alternate, vestured, about 4-6 um in diameter (Pl. 6.3,5), Parenchyma are regular concentric bands alternating with fibre bands of more or less same width, bands slightly undulating, sometime bifurcating and joining adjacent bands, 4-7 bands/mm, 4-8 cells wide parenchyma strands storied, thin-walled, 20-30 um in diameter, round to oval in cross section (Pl. 5.1,2), Xylem rays are fine 1-3 (mostly 2), rarely 3 seriate , 8-26 μm wide 4-25 cells or 80-400 μm in length , storied ray tissues homogeneous to weakly heterogeneous consisting of procumbent cells or rarely with a single margin rows of square or upright cells at one or both ends (Pl. 6.3,4), Fibres are forming concentric bands, alternating with parenchyma bands, circular to angular, 8-10 um in diameter, non-septate, thick walled (Pl. 6.1,2). Ripple marks are present due to storied arrangement of parenchyma stands, xylem rays and vessel members (Pl. 6.3).

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16189 (Figured specimen).

Horizon & Age: Middle Siwalik Formation, Upper Miocene.

Locality: Kaligad (29° 7'25.4" N: 80° 9'37.9" E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimen: 1

Modern affinities: Small to rarely large vessels, medium sized vestured pits, regular concentric bands of parenchyma occasionally undulated and bifurcated with storied strands, 1-3 (mostly 2) seriate homogenous to weakly heterogeneous and storied xylem rays, the presence of ripple marks due to storied arrangement of xylem rays, parenchyma strands and vessel segments are found common in the secondary xylem of *Millettia* Wight & Arnott. and *Pongamia* Vent. of the family Fabaceae. Examination of all the thin sections of the available species of *Millettia* Wight and *Pongamia* Vent. woods at Xylarium of Birbal Sahni Institute of Palaeosciences, Lucknow and consultation of published literature on wood anatomy of the genus *Millettia* suggests that the fossil wood shows closest affinity with the wood of *M. prainii* Dunn, *M. pendula* Bentham and *Pongamia glabra* Vent. (Pearson & Brown 1932, Metcafe & Chalk 1950, Kribs 1959, Rao et al. 1972, Ilic 1991).

Fossil record and comparison: The fossil woods resembling the genera *Millettia* Wight and *Pongamia* Vent. are reported under following form species. First of all, *Millettixylon indicum* has been reported from the Cuddalore Series of South India (Awasthi 1967, 1975), the Upper Cenozoic of Thailand (Prakash 1979), the Kankawati Series Kachchh (Guleria 1984) the Siwalik beds of Kalagad, Pauri Garhwal District, Uttarakhand *M. pongamiensis* from the Lower Siwalik sediments of Nalagad, Himachal Pradesh (Prakash 1975), from the Cenozoic of West Bengal (Bande and

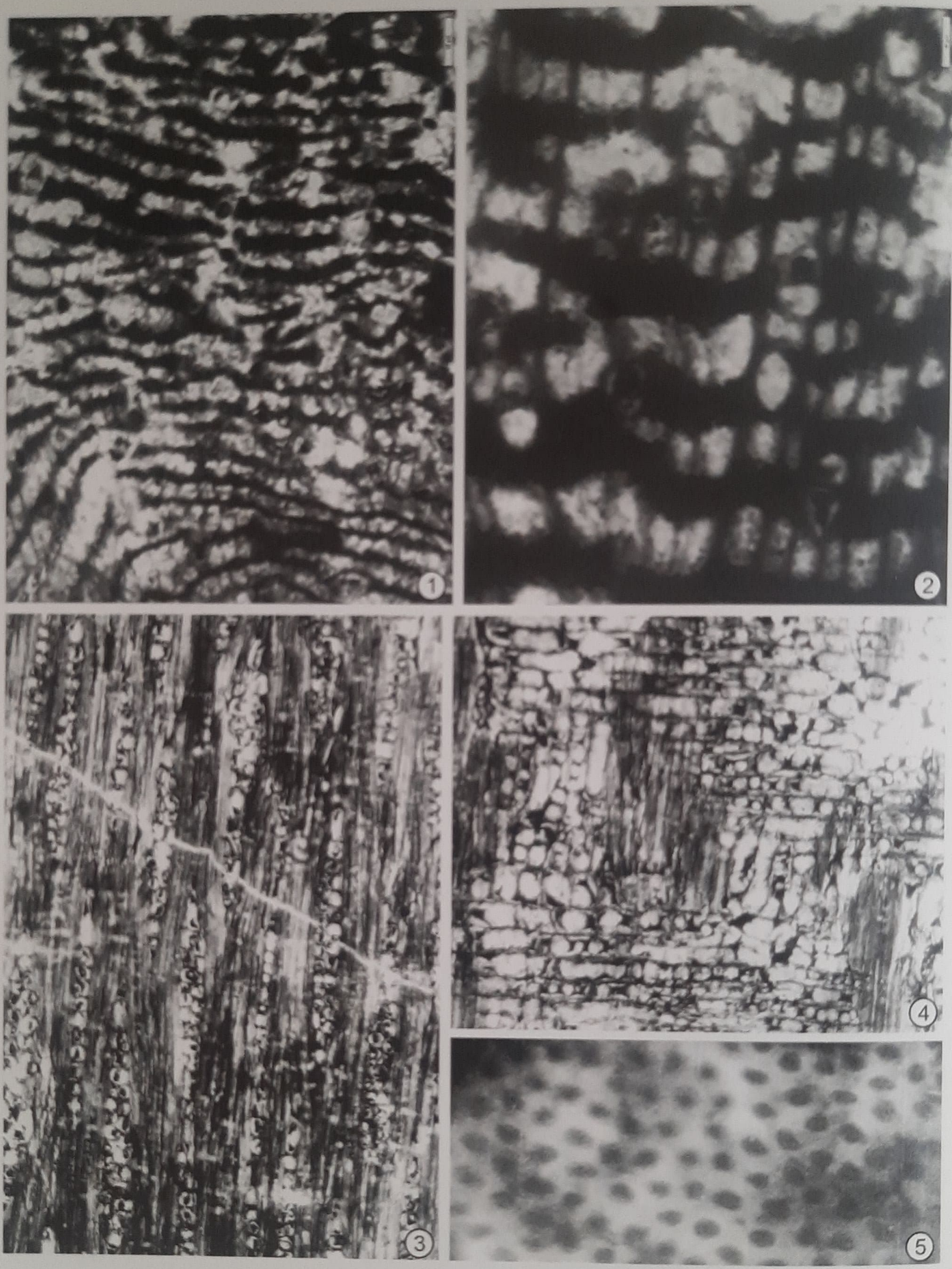


PLATE 6

***Millettioxylon indicum* Awasthi**

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma, fibres and xylem rays. x 30 (BSIP Museum Slide No. 16189-I).
2. Cross section of the fossil wood magnified to show the alternate arrangement of fibre and parenchyma band. x 90 (BSIP Museum Slide No. 16189-1).
3. Tangential longitudinal section of the fossil wood showing irregularly storied arrangement of xylem rays. x 90 (BSIP Museum Slide No. 16189-II).
4. Radial longitudinal section of the fossil wood showing weakly heterocellular xylem rays. x 90 (BSIP Museum Slide No. 16189-III).
5. Inter-vessel pit pairs. x 600 (BSIP Museum Slide No. 16189-II).

Prakash 1980b, Ghosh & Roy 1981) and from Tippam Group of Lakhimpur District, Assam (Mehrotra et al. 2011); *M embergeri* from the Miocene of Ethopia (Lemogine 1978); *M. bengalensis* from Midnapur District, West Bengal (Ghosh & Roy 1979b) and *M. kalagarhense* from Mio-Pliocene beds of Kalagad (Trivedi & Misra 1978, Guleria 1984); *M. palaeopulchera* from Namsang beds of Deomali, Arunachal Pradesh (Lakhanpal et al. 1981). A comparative study of the above described fossil woods revealed that the fossil woods of the present study area shows close similarity with *Millettixylon indicum* Awasthi in almost all anatomical features and hence it is assigned under the same species.

Present day distribution: The genus *Millettia* Wight consists of about 80 species distributed in the tropical regions of Africa, Asia and Australia. More than 30 species are found in the Indian subcontinent. Of the three comparable modern taxa, *Millettia Prainii* is a small tree and grows in Sikkim, West Bengal and Assam along the right bank of the River Monos and Tura-Dalu Road in the Garo Hills. *M. pendula* medium sized tree occurring in the drier forest of Myanmar, Pengu Yama, Tenasserim and Upper Chindwin; and *Pongamia glabra* is also a medium to large sized tree distributed in the central and eastern Himalayas, Ceylon, north Australia, Polynesia and the Seychelles (Brandis 1971, Gamle 1972, Mabberley 1997).

Genus *ORMOSIOXYLON* Bande and Prakash 1980

Ormosioxylon bengalensis Bande and Prakash 1980

(Pl. 7.1-5)

1980 *Ormosioxylon bengalensis* Bande and Prakash, p. 152, Pl. 3, figs. 12-16

1988 *Ormosioxylon bengalensis* Bande and Prakash, Prasad, p. 135, Pl. 1, figs. 1-4

1989 *Ormosioxylon bengalensis* Bande and Prakash, Yadav, p. 60, Pl. 3, figs. 1,3

Description: Woods are diffuse-porous, Growth rings are indistinct, Vessels are mostly medium to rarely large, solitary as well as in radial multiples of 2-6 (mostly 2-4), 4-8 per sq mm, mostly empty, t.d. 105-230 μm, r.d. 140-305 μm (Pl. 7.1,2); vessel members 165-580 μm long; intervessel pits vestured, alternate, 6-10 μm in diameter, circular to oval in shape with linear to lenticular apertures (Pl. 7.3,5), Parenchyma are paratracheal, aliform to predominantly aliform confluent, joining a few adjacent vessels, slightly thick-walled, cells 8-10 μm in diameter and parenchyma strands 150-350 μm in length (Pl. 7.2,3), Xylem rays are 1-4 (mostly 3) seriate, 16-80 μm in width and 10-32 cells or 160-590 μm in height; ray tissue weakly heterogeneous with rays composed of mostly procumbent cells and rarely with 1-2 rows of upright cells at one or both the ends (Pl. 7.3); upright cells 18-36 μm in vertical height and 10-25 μm in radial length; procumbent cells 18-80 μm in radial length and 15-24 μm in vertical height (Pl. 7.4), Fibres are polygonal in cross-section, non-septate, semi-libriform, 8-20 μm in diameter and 360-680 μm in length (Pl. 7.3), Ripple marks are indistinct.

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16190 (Figured specimen).

Horizon & Age: Middle Siwalik Formation, Upper Miocene.

Locality: Kaligad (29° 7'25.4" N: 80° 9'37.9" E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimens: 5

Modern affinities: The most diagnostic features of the present fossil woods are medium to large vessels having 2-6 vessels in multiples with simple perforations and vestured intervessel pit-pairs, aliform to aliform-confluent parenchyma, 1-4seriate (mostly 3 seriate), weakly heterogeneous, poorly storied xylem rays and non-septate fibres. These features are found common in the modern woods of the genus *Ormosia* Jack. of the family Fabaceae. The thin sections slides of *Ormosia robusta* Wight, *O. fordiana* Olive. and *O. watsonii* Fischer have been examined and concluded that the wood of *O. robusta* Wight (BSIP wood slide no. 1542) belongs nearest to the presently studied fossils.

Fossil record and comparison: The fossil wood having affinity with the modern woods of the genus *Ormosia* Jack. has been described by Bande and Prakash (1980) under the form genus *Ormosioxylon*.

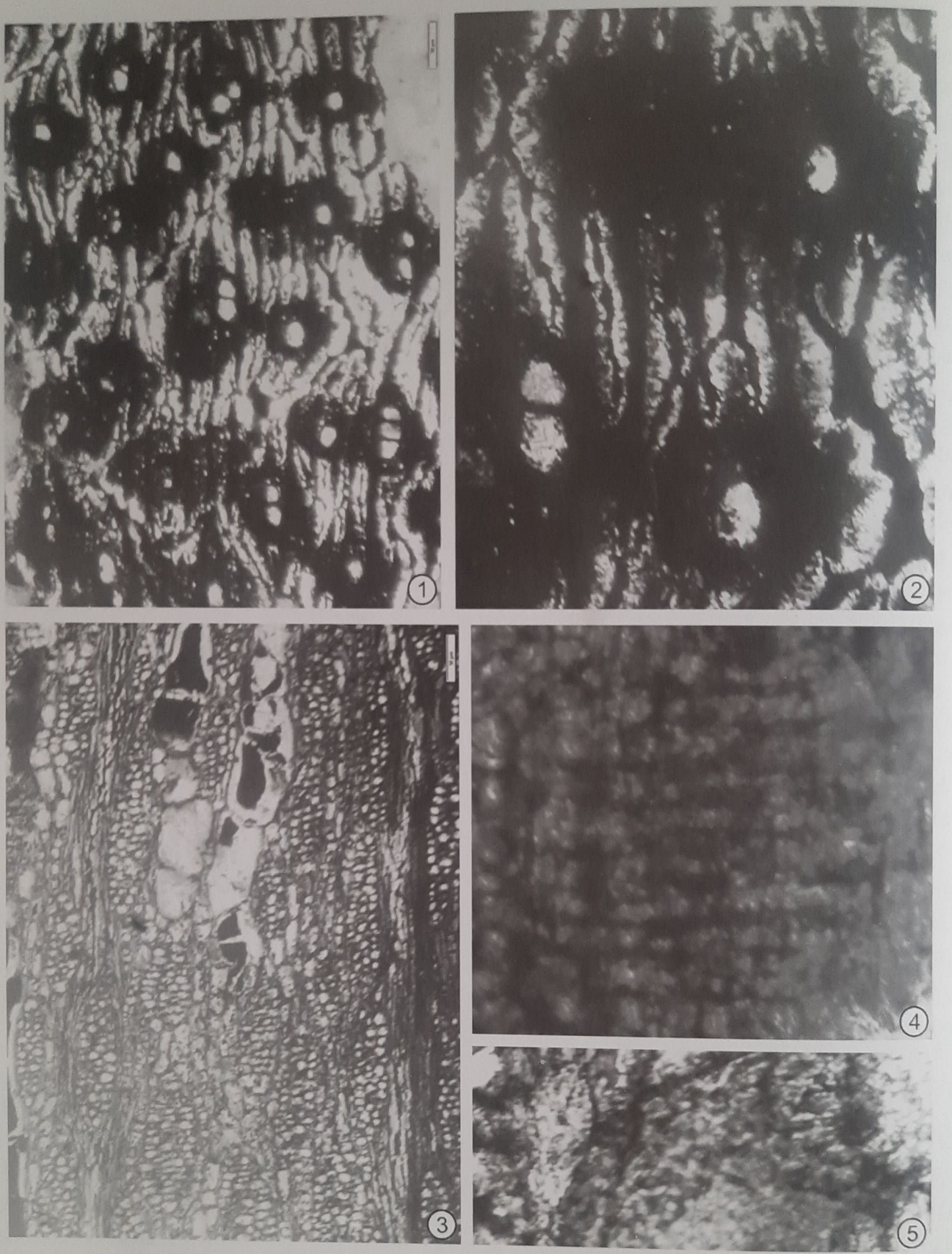


PLATE 7

***Ormosioxylon bengalensis* Bande & Prakash**

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma, fibres and xylem rays. x 30 (BSIP Museum Slide No. 16190-I).
2. Cross section of the fossil wood magnified to show the details of fibre and parenchyma. x 90 (BSIP Museum Slide No. 16190-1).
3. Tangential longitudinal section of the fossil wood showing irregularly storied arrangement of xylem rays. x 90 (BSIP Museum Slide No. 16190-II).
4. Radial longitudinal section of the fossil wood showing weakly heterocellular xylem rays. x 90 (BSIP Museum Slide No. 16190-III).
5. Inter-vessel pit pairs. x 500 (BSIP Museum Slide No. 16190-II).

They described a fossil wood showing close resemblance with *Ormosia robusta* Wight and *O. watsonii* Fischer as *Ormosioxylon bengalensis* from the Tertiary of West Bengal. Later on same species was reported from the Siwalik sediments of Kalagad, Pauri Garhwal District, Uttarakhand. The present Siwalik woods possess similar anatomical characters as exhibited by *Ormosioxylon bengalensis* Bande & Prakash. Hence it is placed under the same species.

Present day distribution: Genus *Ormosia* Jack. comprises of about 100 species distributed in tropical Asia and America amongst which 8 species are found in India and Myanmar. *Ormosia robusta* Wight with which the fossil wood shows closest resemblance is a large tree distributed in evergreen forest of Arunachal Pradesh, Sibsagar and Cachar districts of Assam, Sylhet and Chittagong in Bangladesh and Myanmar (Mabberley 1997, Rao & Purkayastha 1972).

Family EUPHORBIACEAE

Genus *BISCHOFIA* Blume

Bischofia palaeojavanica (Awasthi) Guerlia et al. 2001

(Pl. 8.1-5)

2001 *Bischofia palaeojavanica* (Awasthi) Guerlia *et al.*, p. 242, p.5 figs. 1-5

Description: Woods are diffuse-porous, Growth rings are not visible, Vessels are small to large mostly medium sized, t.d. 50-230 µm and r.d. 75-280 µm solitary and in radial multiples of 2-3; mostly filled with tyloses, 5-7 vessel per mm (Pl. 8.1,2), vessels segments 230-565 µm in length with truncate to oblique end walls, peforations simple, inter-vessel pits alternate, bordered, usually orbicular with lenticular aperture, 8-12 µm in diameter (Pl. 8.3,4,5), Parenchyma are scanty paratracheal, few cells around the vessels, parenchyma cell 20-30 µm in diameter and 90-150 µm long, apotracheal parenchyma present, diffuse to aggregate (Pl. 8.1,2), Rays are 1-6, mostly 3 seriate, 4-8 per mm, rarely uniseriate, 4-9 cells or 140-490 µm long, consists wholly of upright cells; multiseriate rays heterocellular, 2-6 cells or 65-190 µm in width and 8-28 cells or 230-1150 µm in length; rays made up of procumbent cells in the centre with extension of 1-7 upright cells at one or both the ends, end to end ray fusion rare (Pl. 8.3); procumbent cells with tangential height and 90-110 µm in radial length; upright cells 95-150 µm in tangential height and 40-68 µm in radial length; prismatic crystals present in upright cells (Pl. 8.4), Fibres are aligned in radial rows; mostly oval to flattered and polygonal, libriform and thick walled, 40-50 µm in diameter in cross section, septate, inter-fibre pits present (Pl. 8.3).

Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16191 (Figured specimen).

Horizon & Age: Middle Siwalik Formation, Upper Miocene.

Locality: Kaligad (29° 7'25.4" N: 80° 9'37.9" E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimen: 1

Modern affinities: The diagnostic characters of the presently studied fossil wood such as solitary or multiples of 2-3, medium to large vessels filled with abundant tyloses, simple perforations; scanty paratracheal, septate parenchyma; 1-6 (mostly 3) seriate xylem rays undoubtedly indicates that the fossil belongs to the *Glochidion* group of sub-family Phyllanthoideae (Metcalfe & Chalk 1950, Pearson & Brown 1932) of the family Euphorbiaceae. Among the genera of *Glochindion* group, the fossil wood shows nearest affinity with the wood of the modern genus *Bischofia* Bl. Out of the two species viz., *B. javanica* Bl. and *B. polycarpa* Airy-Shaw, *B. javanica* Bl. (BSIP wood slide no. 599) is most closely comparable to the presently described taxon.

Fossil record and comparison: Ramanujam (1960) instituted the genus *Bischofioxylon* for the fossil wood showing affinity with the genus *Bischofia* Bl. and reported under form species, *Bischofioxylong miocenicum* from Pondicheery, South India. Later on Madel (1962) opined that the fossil wood reported by Ramanujam (1960) did not belong to *Bischofia,* and transferred it to the genus *Bridelioxylon* Ramanujam (1956). Bande (1974) instituted another form genus *Bischofinium* for the fossil woods having affinity with

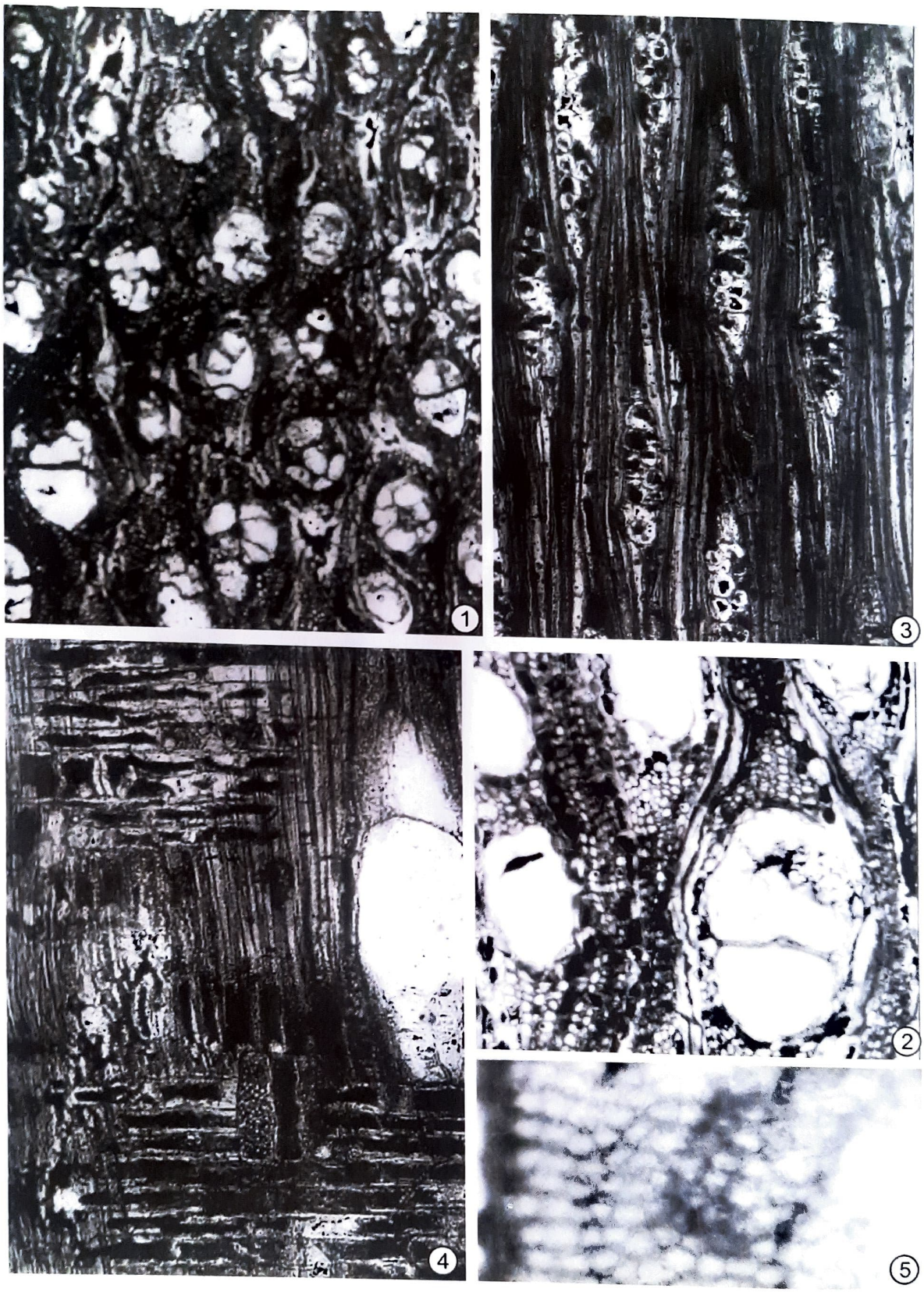


PLATE 8

***Bischofia palaeojavanica* Awasthi**

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma, fibres and. xylem rays. x 60 (BSIP Museum Slide No. 16191-I).
2. Cross section of the fossil wood magnified to show the details of fibres, parenchyma and vessels. x 150 (BSIP Museum Slide No. 16191-1).
3. Tangential longitudinal section of the fossil wood showing nature and arrangement of xylem rays. x 90 (BSIP Museum Slide No. 16191-II).
4. Radial longitudinal section of the fossil wood showing heterocellular xylem rays. x 120 (BSIP Museum Slide No. 16191-III).
5. Intervessel pit pairs. x 500 (BSIP Museum Slide No. 16191-II).

Bischofia Bl. and described a form species *Bischofinium deccanii* from the Deccan Intertrappean, India. Awasthi (1989) critically examined the type slides of both *Bischofioxylon micenicum* Ramnujam and *Bischofinium deccanii* Bande and suggested that the former belongs neither to *Bischofia* nor to *Bridelia* and the latter also differs from *Bischofia* and thus described the fossil wood under the genus *Bischofia* Bl. viz., *B. palaeojavanica* which shows close similarity with the modern wood of *Bischofia javanica* Bl. (Awasthi 1989). So far, six fossil woods have been described under *B. palaeojavanica* Awasthi from the Neyveli lignite deposit of Tamil Nadu (Agarwal 1994); Late Miocene sediments of Mon District, Nagaland (Awasthi & Mehrotra 1990), Middle Miocene deposits of Thiruvananthapuram, Kerala (Srivastava & Awasthi 1996), Deccan Intertrappean sediments of Kachchh, Gujarat (Guleria & Srivastava 2001), Mohargarh Formation of Ramnagar, Jammu & Kashmir (Guleria et al. 2001) and from Middle-Late Miocene sediments of Lakhimpur District Assam (Mehrotra et al. 2011) There are three more records of fossil woods resembling the genus *Bischofia,* viz., *Bischofia javanica* Bl. and *B. polycarpa* Airy-Shaw, described from the Late Cenozoic rocks of Wuhan, China (Qi et al. 1987, Yang Jia-Ju et al. 1998) and from the early Miocene of northern Taiwan (Li et al. 2003). After a detailed comparative study of the above known fossil woods it has been concluded that the present fossil shows closest resemblance to *Bischofia palaeojavanica* Awasthi described from Mohargad Formation, Jammu & Kashmir and hence it is assigned to the same species.

Present day distribution: The genus *Bischofia* consists of two species, *B. javanica* Bl. and *B. polycarpa* Airy-Shaw. *B. javanica* Bl. with which fossil wood shows affinity is a large deciduous tree and is mainly confined to Indo-Malaysian region (Santapau & Henry 1973, Pearson & Brown 1932).

Family LAURACEAE

Genus *LAURINOXYLON* Felix 1883

Laurinoxylon siwalicus Prasad 1990

(Pl. 9.1-5)

1990 *Laurinoxylon siwalicus* Prasad, p. 191, Pl. 1, figs. 1-5.

Description: Woods are diffuse-porous, Growth rings are indistinct, Vessels are small to large, t.d. 80-220 µm, r.d. 110-360 µm, solitary as well as in radial multiples of 2-4, 8-12 µm per sq. mm, round to oval in shape, tyloses present, sometimes filled with black deposits (Pl. 9.1,2); vessel segments 140-570 µm in length with usually truncate ends; perforations simple; inter-vessel pit-pairs bordered, 8-10 µm in diameter, alternate, circular to oval in shape with lenticular apertures (Pl. 9.3,4), Parenchyma are not easily recognizable, scanty paratracheal, few cells associated with vessels, not forming complete sheath, moderately thick walled, 20-30 µm in diameter and 290-600 µm in length, Xylem ray are 1-4 (mostly 3) seriate, 6-15 cells or 230-860 mm in height; ray tissue heterogeneous, rays homo to heterocellular, rays consisting of usually single marginal row of upright cells at one or both the ends and procumbent cells in the median portion (Pl. 9.3,4). Fibres are moderately thick-walled, septate, about 30 µm in diameter (Pl. 9.2,3), Oil cells are round to oval in shape, 55-70 µm in diameter, abundant, scattered among fibres (Pl. 9.2) and also occur at one or both the ends of xylem rays Pl. 9.3).

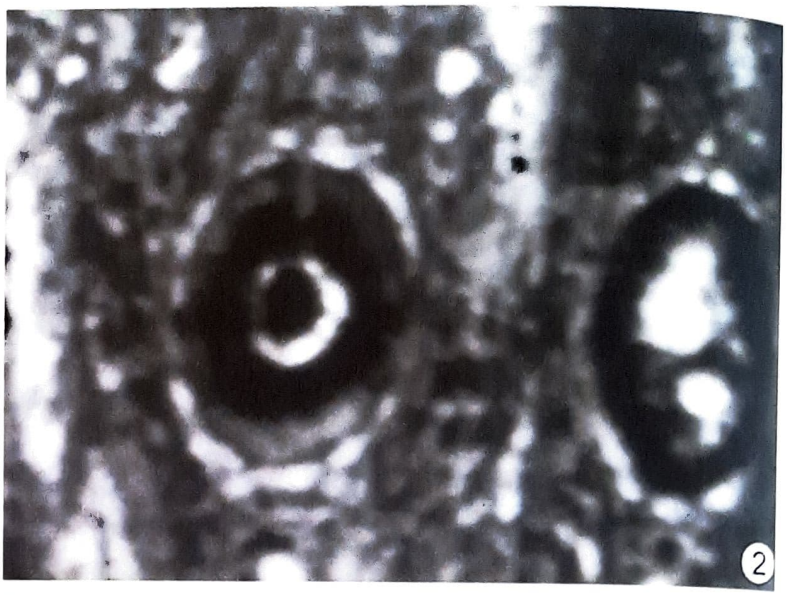
Repository: Birbal Sahni Institute of Palaeosciences, Lucknow Museum No. 16192 (Figured specimen).

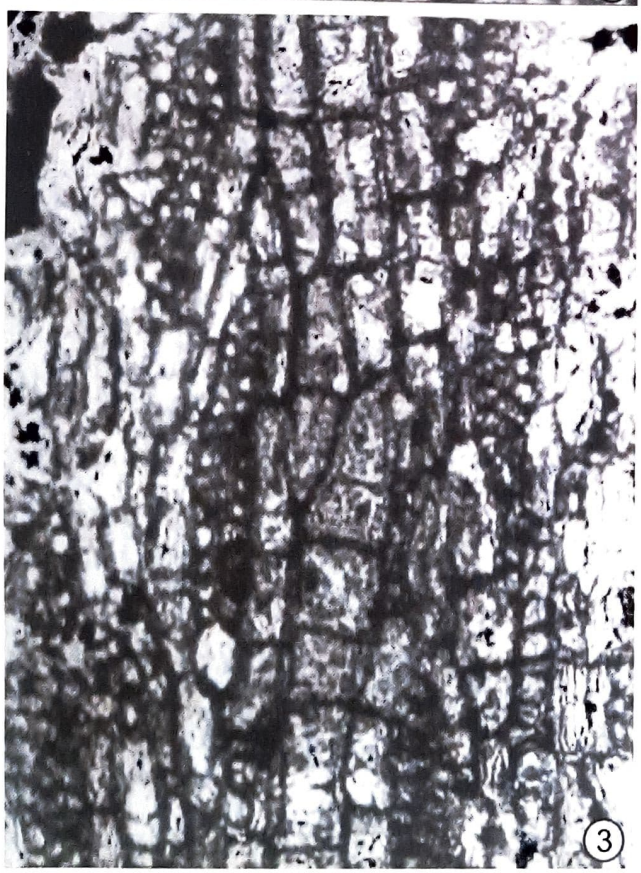
***Horizon & Age*:** Middle Siwalik Formation, Upper Miocene.

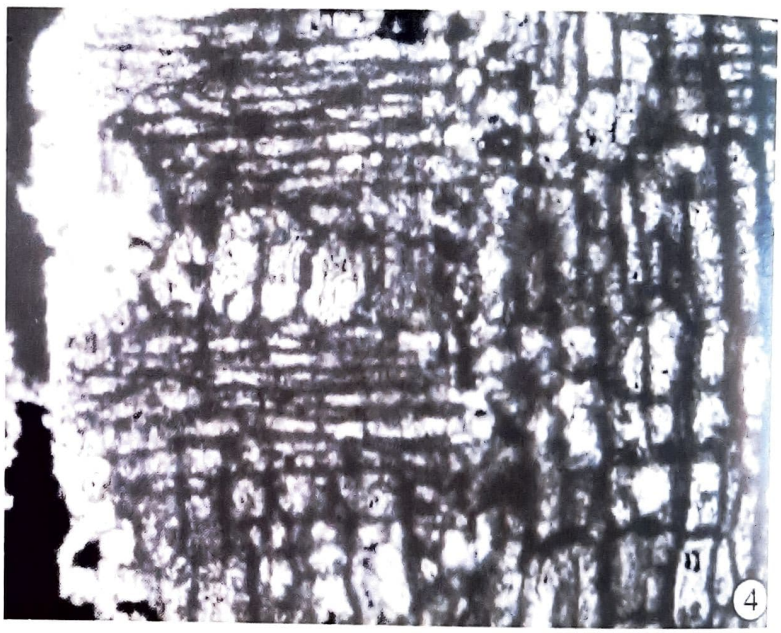
Locality: Thuligad (29° 8'18.7" N: 80° 10'41.1" E), Tanakpur area, Champawat District, Uttarakhand, India.

Number of specimens: 6

Modern affinities: The most important feature of the present fossil woods such as presence of oil cells scattered among fibres and also in xylem rays and other important anatomical features like 1-4 seriate, heterogeneous xylem rays and septate fibres indicate the affinities of the present fossil wood with the family Lauraceae. After a critical examination of a number of lauraceous woods it has been concluded that the woods of family Lauraceae are homogeneous in nature and it is difficult to differentiate its various genera and species on the basis of wood anatomy. The present Siwalik wood is, therefore, placed under the genus







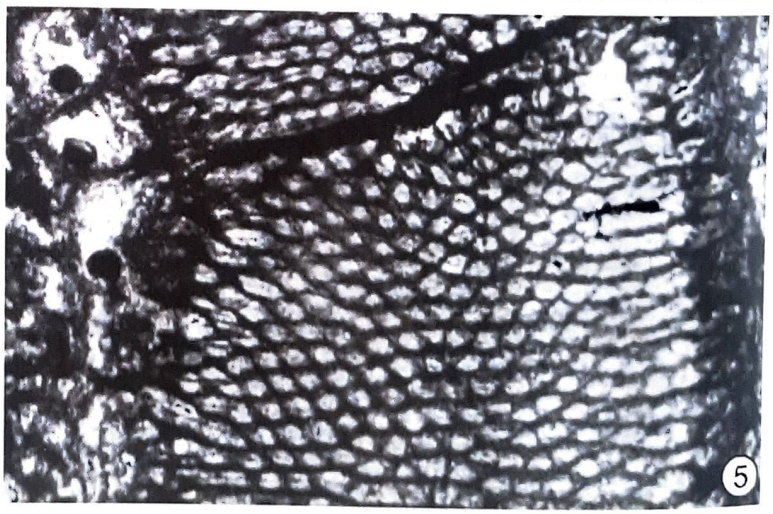


PLATE 9

***Laurinoxylon siwalicus* Prasad**

1. Cross section of the fossil wood showing nature and distribution of vessels, parenchyma, fibres and. xylem rays. x 40 (BSIP Museum Slide No. 16192-I).
2. Cross section of the fossil wood magnified to show the details of fibres, parenchyma and vessels. x 90 (BSIP Museum Slide No. 16192-I).
3. Tangential longitudinal section of the fossil wood showing nature and arrangement of xylem rays and presence of oil cells at one or both the ends. x 90 (BSIP Museum Slide No. 16192-II).
4. Radial longitudinal section of the fossil wood showing heterocellular xylem rays. x 120 (BSIP Museum Slide No. 16192-III).
5. Inter-vessel pit pairs. x 500 (BSIP Museum Slide No. 16192-II).

Laurinoxylon Felix instituted to include fossil woods of Lauraceae. Further, this fossil wood has been compared with all the available genera and species of the family Lauraceae and found that the modern woods of *Litsea polyanthus* Juss. (BSIP wood slide no. 812) shows closest affinity with the present fossil wood in almost all the anatomical features.

Fossil record and comparison: So far ten fossil woods have been assigned to the form genus *Laurinoxylon* from the Cenozoic sediments of India. These are *L. tertiarum* from Tippam sandstone of Hailakandi, Assam (Prakash & Tripathi 1974), *L. deccanensis* from Deccan Intertrappean sediments of Mandla District, Madhya Pradesh (Bande & Prakash 1980a), *L. namsangensis* and *L. deomaliensis* from Namsang beds of Deomali, Arunachal Pradesh (Lakhanpal et al. 1981), *L. varkakalaensis* from the Varkala beds, South India (Awasthi & Ahuja 1982), *L. siwalicus* from Middle Miocene of Kalagad, Pauri Garhwal, Uttarakhand (Prasad 1990), *Laurinoxylon* sp. cf. *namsangensis* Lakhanpal et al. from the Miocene of Birbhum District, West Bengal (Bande & Srivastava 1989), *Laurinoxylon* sp. from Palaeocene-Eocene of Baratang Islands, Andaman-Nicobar Islands (Awasthi & Jafar 1990), *L. dilcheri* from Tippam Group of Mamit District, Mizoram (Tiwari & Mehrotra 2000) and *L. naginimariense* from Tippam Group of Mon District, Nagaland (Awasthi & Mehrotra 1990). A detailed study of above fossil woods revealed that *L. siwalicus* Prasad described from Middle Miocene of Kalagad, Uttarakhand shows close similarity with the present fossil wood in their anatomical features except the vessel frequency. In view of this, the presently studied fossil has been assigned to the same species.

Present day distribution: Lauraceae comprises about 32 genera comprising of 2,000-2,500 species of trees and shrubs distributed widely throughout the warmer parts of the world but mostly abundant in tropical and subtropical regions, also extending its presence into Malayan Archipelago and tropical South America (Purkayastha 1982, Pearson & Brown 1932). *Litsea polyanthus* Juss. with which the presently studied fossil wood resembles is a moist deciduous tree growing in Punjab and Salt Range all along the foothills of Himalaya ascending to 3000 ft. eastwards to Assam and southwards to the Satpura Range. It is also commonly found in Tennaserrim, Penang, Java and China.

DISCUSSION AND CONCLUSION

The fossil localities at Tanakpur and nearby areas are known to yield diversified plant fossils (Prasad 2017a,b). However, during an extensive field excursion a variety of fossil woods were also collected from the Tanakpur area. It is interesting to note that the fossil leaves found abundantly in the fossiliferous shale beds of Lower Siwalik section are either in impression or compression form. However, the fossil woods were found imbedded in the sandstone beds of Middle Siwalik section (Fig. 2c). Systematic study on the several well preserved fossil woods revealed the presence of nine form taxa viz., *Dipterocarpoxylon siwalicus* Prakash, *Albizinium eolebbekianum* Prakash, *Albizinium arunachalensis* Mehrotra et al., *Bauhinium palaeomalabaricum* Prakash & Prasad, *Bauhinium miocenicum* Trivedi & Panjwani, *Millettioxylon indicum* Awasthi, *Ormosioxylon bengalensis* Bande & Prakash, *Bischofia palaeojavanica* Awasthi, *Laurinoxylon siwalicus* Prasad belonging to four families viz., Dipterocarpaceae, Fabaceae, Euphorbiaceae and Lauraceae. The present day distribution of comparable extant taxa (Table 2) show that they occur in the tropical evergreen and moist deciduous forests of northeast and south India, Bangladesh, Myanmar and Malaya suggesting that Tanakpur area was warm and humid during the Miocene period as compared to the relatively dry climate present today. All the referable species (except *Bauhinia retusa* Ham.) represented in the present wood flora are not extant in Tanakpur and nearby area. This local extinction of comparable species within the region is an indication of a climatic variability since the Miocene due to which the evergreen and moist deciduous forest was gradually replaced by the present day mixed to dry deciduous forest.

The fossil woods from Tanakpur are mainly represented by two phytogeographically important families viz., Dipterocarpaceae and Fabaceae. The flora is dominated by family Fabaceae consisting of six

Table 2. Present day distribution and forest types of modern equivalent taxa of the fossils recovered from Siwalik of Tanakpur area, Uttarakhand.

Fossil taxa	Modern equivalents	Forest types	Distribution
Dipterocarpoxylon siwalicus Prakash	*Dipterocarpus indicus* Bedd. (Syn. *D. turbinatus*	Evergreen	North Kanara to southwards, Tillchary Ghats, North Malabar, Travancore, Andaman, Assam, Myanmar, Bangladesh, China and Thailand
Albizinium eolebbekianum Prakash	*Albizi lebbek* Benth.	Evergreen to Moist deciduous	East side of River Indus to Assam, Andaman and Myanmar,
Albizinium arunachalensis Mehrotra *et al.*	*Albizia procera* Benth.	Evergreen	Assam, South India, Andaman and Myanmar
Bauhinium palaeomalabaricum Prakash & Prasad	*Bauhinia malabarica* Roxb.	Moist deciduous	Ravi eastward to Assam, Western Coast, South and central India and Myanmar
Bauhinium miocenicum Trivedi & Panjwani	*Bauhinia retusa* Ham.	Mixed deciduous	Sub-Himalayan tract, Eastern Ghats, Madhya Pradesh and South India
Millettioxylon indicum Awasthi	*Millettia prainii* Dunn. *M. pendula* Benth *Pongamia glabra* Vent.	Evergreen to Moist deciduous	Sikkim, West Bengal, Assam, Garo Hills, central and eastern Himalayas, Myanmar, Peguyoma, Tennaserrim, North Australia and Seychellis
Ormosioxylon bengalensis Bande & Prakash	*Ormosia robusta* Wight	Evergreen	Arunachal Pradesh, Sibsagar and Cachar districts of Assam, Chittagong (Bangladesh) and Myanmar
Bischofia palaeojavanica Awasthi	*Bischofia jananica* Blume	Evergreen to moist deciduous	Indo-Malayan region, Sub-Himalayan tract, Assam, South India and Andaman
Laurinoxylon siwalicus Prasad	*Litsea polyanthus* Juss.	Evergreen to moist deciduous	Himalayan foothills, Assam, Tennaserim, Penang, Java and China

species, whereas, the family Dipterocarpaceae is represented by only one species *Dipterocarpoxylon siwalicus* Prakash was the most common species during the Miocene period in Tanakpur area since more than 40 percent wood sample collected from the area are belonging to this species. It is worth mentioning that the genus *Dipterocarpus* is widely distributed throughout India, Nepal and Bhutan (Prasad 2008, Prasad et al. 2017a,b) during Miocene. On increasing aridity and seasonality after Late Miocene and Pliocene the climatic conditions became unsuitable for the growth of dipterocarps (Morely 2000) and therefore, it started gradual disappearance along with other moist loving species from most part of India (except south and northeast India). The present and past distribution of dipterocarpaceous taxa indicates that the whole family is pantropical and mostly belongs to tropical Asian region. On the basis of fossil records of the genus *Dipterocarpus* as well as its other family members like: *Shorea, Hopea, Anisoptera, Isoptera* and *Dryobalanops* from the Cenozoic sediments of India and abroad, it can be summarised that the family Dipterocarpaceae originated during the early Middle Oligocene (Merril 1923, Muller 1970) in western Malaysia and then diversified eastward to Philippines and northward to India through Myanmar when the land connection between Malaya Myanmar and eastern India was established.

The family Fabaceae dominated the present flora by representing six species belonging to four genera viz., *Albizia, Bauhinia, Millettia* and *Ormosia* which are mainly distributed in the evergreen to moist deciduous forests of tropical region of Indian subcontinent. This family is originated in the tropical region along the Tethys seaway during Palaeogene period (Shrine 2005). The fossil records suggests that the genera of Fabaceae are most common in the Neogene (Mio-Pliocene) sediments (Guleria 1992, Prasad 2008) but they have not been authentically reported from the Palaeogene sediments of Indian subcontinent. For this they have taken later entry in Indian subcontinents at the end of Oligocene or early Miocene after establishment of land connection with the southeast Asian region (Smith & Briden 1979, Smith

Table 3. Showing xylotomical characters of fossil woods recovered from the Upper Miocene of Tanakpur area, Uttarakhand.

Name of the Taxa	Wood	Growth rings	Vessels	Parenchyma	Vasicentric tracheids	Rays	Fibres	Gum cannal
Dipterocarpoxyl on siwalicus Prakash	Diffuse porous	Indistinct	Mostly large, t.d. 140-240 µm, r.d. 145-380 µm, solitary, 5-9 per sq. mm, tyloses present, vessels 170-590 µm long with truncate to tailed ends, perforations simple, inter-vessel pits not seen	Abundant, apotracheal, diffuse and diffuse aggregate and surrounding the gum canal, paratracheal parenchyma scanty, present around vessels,	Present	1-5 (6) seriate, 5-10 rays per mm, rays heterocellular, sheath cells generally present on the both flanks of the rays	Thin walled, non-septate	Vertical, solitary or in pairs, sometimes in short tangential bands of 2-4, small, 50-80 µm in diameter.
Albizinium eolebbekianum Prakash,	Diffuse porous	Present, delimited by smaller vessels and terminal parenchy ma	Large to medium-sized, t.d. 135-305 µm, r.d. 140-340 µm, 3-5 per sq. mm, mostly empty; vessel segments short, 130-360 µm long, perforations simple; inter-vessel pit- pairs vestured	Abudant, paratracheal parenchyma vasicentric to nearly aliform, occasionally confluent joining adjacent vessels	Absent	1-4 (2-3) seriate, 7-9 per mm, 8-20 cells in height; ray tissue homogeneous.	Thin walled, septate	Absent
Albizinium arunachalensis Mehrotra, Awasthi and Dutta,	Diffuse porous	Present, delimited by a band of dense parenchy ma	Medium to large-sized, t.d. 110-295µm, r.d. 120-305 µm, , 3-6 per sq. mm; tyloses absent, vessel segments, 120-340 µm long, usually truncate; perforations simple; inter-vessel pit-pairs vestured	Abuntant, paratracheal parenchyma vasicentric to nearly aliform, occasionally confluent	Absent	1-4 (2-3) seriate, 7-9 per mm, 8-20 cells in height; ray tissue homogeneous.	Thin walled, 8-20 µm in diameter, non-septate	Absent
Bauhinium paleomalabricu m Prakash & Prasad	Diffuse porous	Not seen	Small to large, t.d. 90-200 µm ,r.d. 100-250µm, filled with black contents, 8-12 per sq mm vessel members 160-490 µm long with truncate ends, irregularly storied; perforations simple; intervessel pit pairs vestured	Abundant, paratracheal confluent, forming somewhat sinuate continuous concentric bands alternate with broader bands of fibres; cell 10-22 µm in diameter, parenchyma strands irregularly storied and 410-1290 µm	Absent	1-2 seriate, mostly uniseriate 16-50 µm in width 4-25 cells or 130-650 µm in length, nearly storied; ray tissue heterogeneous,	Moderately thickwalled, non-septate	Absent
Bauhinium miocenicum Trivedi & Panjwani	Diffuse porous	Not seen	Medium to rarely large, t. d. 130-210 µm, r.d. 140-230 µm, , 6-9 per sq mm; vessel members 180-300 µm long with truncate or tailed ends; vessel segments nearly storied; perforations simple; intervessel pit pairs bordered	Abundant, paratracheal parenchyma vasicentric, relatively scanty forming 1-2 seriate interrupted sheath; paratracheal parenchyma forming bands up to 6 cells wide which alternate with the fibrous bands of mostly equal width;	Absent	1-3 seriate, mostly biseriate; ray tissue heterogeneous, rays nearly storied forming ripple marks	Libriform, non-septate	Absent
Millettioxylon indicum Awasthi	Diffuse porous	Indistinct	Small to medium, rarely large sized t.d. 70-140 µm, r.d. 85-210 µm vessel members storied, short, 225-390 µm long, usually with truncate ends; perforations simple; inter vessel pits vestured	Abundant, in regular concentric bands alternating with fibre bands of more or less same width	Absent	1-3 (mostly 2), rarely 3 seriate , 8-26 µm wide 4-25 cells or 80-400 µm in length , storied ray tissues homogeneous to weakly heterogeneous	Thick walled, non septate	Absent

Ormosioxylon bengalensis Bande and Prakash	Diffuse porous	Indistinct	Mostly medium to rarely large, solitary as well as in radial multiples of 2-6 (mostly 2-4), 4-8 per sq mm, mostly empty, t.d. 105-230 µm, r.d. 140-305 µm (Pl. 7.1,2); vessel members 165-580µm long; inter-vessel pits vestured,	Abundant, paratracheal, aliform to predominantly confluent, joining a few adjacent vessels	Absent	1-4 (mostly 3) seriate, 16-80 µm in width and 10-32 cells or 160-590 µm in height; ray tissue weakly heterogeneous	Thick walled, non-septate	Absent
Bischofia palaeojavanica Awasthi	Diffuse porous	Not seen	Mmall to large mostly medium sized, t.d. 50-230 µm and r.d. 75-280 µm solitary and in radial multiples of 2-3; mostly filled with tyloses, 5-7 vessel per mm; vessels segments 230-565 µm in length with truncate to oblique end walls, perorations simple inter-vessel pits alternate	Scanty, paratracheal, few cells around the vessels, parenchyma cell 20-30 µm in diameter and 90-150 µm long, apotracheal parenchyma present, diffuse to aggregate	Absent	1-6, mostly 3 seriate, 4-8 per mm, uniseriate rare, 4-9 cells or 140-490 um long; multiseriate rays heterocellular, 2-6 cells or 65-190 µm in width and 8-28 cells or 230-1150 µm in length	Thick walled, 40-50 µm in diameter in cross section, septate,	Absent
Laurinoxylon siwalicus Prasad	Diffuse porous	Indistinct	mall to large, t.d. 80-220, r.d. 110-360, 8-12µm per sq mm, tyloses present, vessel segments 140-570 µm in length with usually truncate ends; perforations simple; intervessel pit- pairs bordered	Scanty, not easily recognizable, paratracheal, few cells associated with vessels, not forming complete sheath,.	Absent	1-4 (mostly 3) seriate, 6-15 cells or 230-860 µm in height; ray tissue heterogeneous	Moderately thick- walled, septate, oil cells round to oval in shape, 55-70 in diameter, abundant,	Absent

et al. 1994). It is evidenced by a report of the fabaceous fossil wood, *Bauhinium tuipangensis* (Agarwal et al. 2006) from the Lower Miocene sediments of Mizoram, northeast India. Later on they became diversified westward in the Himalayan foot hills and then southward to western and southern India where they growing in higher density during Neogene (Guleria 1992, Prasad 2008).

In Tanakpur wood flora all the fossil plant taxa have their individual Nearest Living Relatives (NLR) and for each NLR the different distribution areas are compiled and then the range of climatic parameters (MAT, MAP) for the distribution area obtained from different sources like, published literatures (Champion & Seth 1968), climatological table of observation in India (1931-1960) and through internet (https//weather and climate.com/ average monthly rain fall-temperature-sunshine-in Malaysia/ Philippines; www.en.climate-data.org; www.sdwebx.worldbank.org; www.eatherspark.org etc.). The whole process has led us to sumarise that the MAT and MAP values for the Tanakpur wood flora are about 21°-29° C and 2000 mm - 2900 mm respectively (Figs. 3a,b).

Thus, Coexistence Approach (CoA) suggests that the Tanakpur area in the Himalayan foot hills of Uttarakhand enjoyed a tropical climate with the values of MAT 21°- 29° C and MAP 2000 mm – 2900 mm) along with plenty of rainfall during the Upper Miocene.

The xylotomical characters of the fossil woods recovered from Tanakpur area have also been analysed (Table 3) in order to infer the climatic condition during the Miocene. Bass (1973) opined that environmental factors influence the structure of secondary xylem due to which a quantitative changes in the anatomical characters are taken due to variation in the climate. According to Dickison (2000) the quantitative changes of fibres and vessels related to environmental condition as they provide security and efficiency in the transport

of water and other soluble material, narrow and numerous vessel elements with simple perforation plate evolved in dry condition with low humidity. However, the solitary and more common vessel elements with greater lamina are evolved in wet and humid conditions. In the fossil woods so far described here the quantitative changes in vessel element, its diameter, and length and the amount of parenchyma and fibres are very little. In all of them the vessels are mostly solitary and evenly distributed having optimum size and greater lumina (Table 3). Thus, it may be sumarised that there was wet and humid condition with no marked variation in the climate during the Miocene. Further, according to Carlquist (2001) the plants that inhabit environments with defined seasonality and species that undergo period of stress (drought condition) have the sparseness of axial parenchyma i.e., storage system. Most of the species (except *Laurinoxylon siwalicus* Prasad) present in the present assemblage possess abundant axial parenchyma suggesting the undefined seasonality in environments and no drought condition in their inhabit environments. The other anatomical features that result from seasonal variation are diameter and density/ frequency of the vessels (Carlquist 1997) and can be used to infer the presence of tropical or temperate condition (Wheeler and Bass 1993). According to him the vessels of any wood occurring in the climate of little seasonality may be evenly distributed (diffuse-porous) and of almost uniform size while the vessels in the woods of climate having marked seasonality may be larger with higher frequency in early wood and smaller with lower frequency in late wood (ring-porous). As all the fossil woods described in the present wood flora are diffuse porous in nature (Table 3) and thus it infer tropical condition with little seasonality during the Miocene.

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