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Fossil woods from Upper Tertiary sediments of Jammu region (Jammu & Kashmir) North-West India and their significance

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ABSTRACT

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Petrified dicotyledonous woods are reported for the first time from the Middle Siwalik sediments of Jammu region (Jammu & Kashmir) in the northwestern part of India. The fossil woods resembling modern woods of *Dipterocarpus* Gaertn.f. (Dipterocarpaceae), *Bischofia* Blume (Euphorbiaceae), *Cassia* Linn. and *Kingiodendron* (Roxb.) Harms (Leguminosae) have been described in detail. Based on the distribution of comparable extant genera and species, prevalence of humid climate and existence of a mixed lowland tropical forest, comprising moist deciduous to evergreen elements, in the area have been deduced. Evidently *Bischofia*, *Dipterocarpus* and *Kingiodendron* existed in the Jammu region during the Late Tertiary time and subsequently shrunk in their distribution due to climatic change. They no longer grow in the area as they require more humid conditions. The occurrence of *Dipterocarpus* is particularly noteworthy as it extends the limit of Dipterocarpaceae in the geological past as far west as Jammu region in the north-west India. The arboreal C_3 forms show that the landscape was well forested.

Key-words—Fossil woods, Xylotomy, Middle Siwalik, Middle Pliocene, Palaeoclimate, Phytogeography, Jammu & Kashmir (India).

उत्तर-पश्चिमी भारत के जम्मू मण्डल (जम्मू तथा कश्मीर) के उपरि टर्शियरी अवसादों से प्राप्त अश्मित काष्ठ एवं उनकी प्रासंगिकता

जसवन्त सिंह गुलेरिया, एस.एस. गुप्ता एवं रश्मि श्रीवास्तव

सारांश

भारत के उत्तर-पश्चिमी भाग के जम्मू मण्डल (जम्मू तथा कश्मीर) के मध्य शिवालिक अवसादों से प्रथम बार अश्मित द्विबीजपत्री काष्ठ अंकित की गयी है। यह अश्मित काष्ठ आधुनिक काष्ठों *डिप्टेरोकार्पस* गार्टेन. एफ. (डिप्टेरोकार्पेसी), *बिस्कोफ़िया* ब्लूम (यूफ़ोर्बिएसी), *कैशिया* लिन. तथा *किंगियोडेण्ड्रॉन* (रॉक्स बी.) हार्म्स के सदृश है। इसका विस्तृत विवेचन प्रस्तुत शोध पत्र में किया गया है। तुलनीय विद्यमान वंशों एवं प्रजातियों के वितरण के आधार पर क्षेत्र में आर्द्र जलवायु की प्रमुखता तथा नम पर्णपाती से लेकर सदाहरित तत्वों से युक्त एक सम्मिश्र निम्नभूमि ऊष्णकटिबन्धीय वनों की उपस्थिति प्रस्तावित की जाती है। अन्तिम टर्शियरी कल्प के दौरान जम्मू मण्डल में *बिस्कोफ़िया, डिप्टेरोकार्पस* तथा *किंगियोडेण्ड्रॉन*

के होने के प्रमाण मिले हैं, जो जलवायुविक परिवर्तनों के कारण घटते चले गए। आज ये इस क्षेत्र में बिल्कुल भी नहीं पाए जाते हैं, क्योंकि इन्हें वर्तमान की तुलना में अधिक आर्द्र स्थितियों की आवश्यकता होती है। *डिप्टेरोकार्पस* की उपस्थिति यहाँ विशेष रूप से महत्वपूर्ण है, क्योंकि ये भू-गर्भीय अतीत में उत्तर-पश्चिमी भारत में पश्चिमी छोर के जम्मू मण्डल तक डिप्टेरोकार्पेसी का विस्तार दर्शाता है। C_3 वृक्षीय रूपों से प्रदर्शित होता है कि यह क्षेत्र वनों से भली-भांति आच्छादित था।

संकेत शब्द—अश्मित काष्ठ, दारु शारीर, मध्य शिवालिक, मध्य प्लायोसीन, पुराजलवायु, पादप भौगोलिकी, जम्मू तथा कश्मीर (भारत).

INTRODUCTION

THE Siwalik Group in the Jammu and Kashmir State of India comprises a thick and uninterrupted sequence of molassic sediments. The basin of deposition apparently consisted of a series of lakes, swamps and flood plains. The sediments of the area have lately been studied by a number of workers (For earlier references see Bhat *et al.*, 1999; Agarwal *et al.*,1993; Tandon, 1991; Dutta *et al.*, 1975; Gupta, 1997b, 2000; Gupta & Prasad, 2001; Gupta & Shali, 1989, 1990). Gupta and Verma (1988) classified the Siwalik Group of Mansar-Uttarbaini Section, Jammu District, into five formations viz., Mansar (Lower Siwalik), Dewal and Mohargarh (Middle Siwalik) and Uttarbaini and Dughor (Upper Siwalik). They further sub-divided the Uttarbaini Formation into the Labli and the Marikhui members. Gupta (1991, 1997a, 2000) recently proposed the suitability of this classification for the entire Siwalik Group of Jammu and further sub-divided the Mansar Formation into the Dodenal and the Ramnagar members (Fig. 1).

The fossil woods reported in the present paper were recovered from the sediments of Mohargarh Formation. The formation exposed in the fossiliferous areas is characterized by thick-bedded, friable, micaceous sandstone with relatively thinner beds of clay and siltstone. The sandstones are buff, grey and yellowish grey, medium to coarse grained, often pebbly and exhibit channel deposition and torrential current bedding. The sandstone bands at places contain conglomerate lenses and occasionally contain lenses of coal and ferruginous matter. The sandstone/conglomerate make up nearly 90 percent of the entire formation.

Group	Sub-group	Formation	Member	Age
	Terraces (T1 -T3)			Holocene
	---------- Unconformity ----------			
S		Dughor (76 m)		
	Upper Siwalik		Marikhui	Lower Pleistocene
I			(1524 m)	
		Uttarbaini (2524 m)		
W			Labli (1000 m)	Upper Pliocene
	---------- Conformable to Para conformable ----------			
A		Mohargarh		
	Middle Siwalik	(915 m)		Middle Pliocene
	---------- Disconformity (0.82 MY) ----------			
L		Dewal (1753 m)		Lower Pliocene
	Lower Siwalik		Ramnagar	Upper Miocene
I			(1498 m)	
		Mansar (1977 m)		
K			Dodenal (479 m)	Middle Miocene
MURREE				Lower Miocene to Upper Eocene

Fig. 1—Stratigraphic sequence of the Siwalik Group in Jammu region.

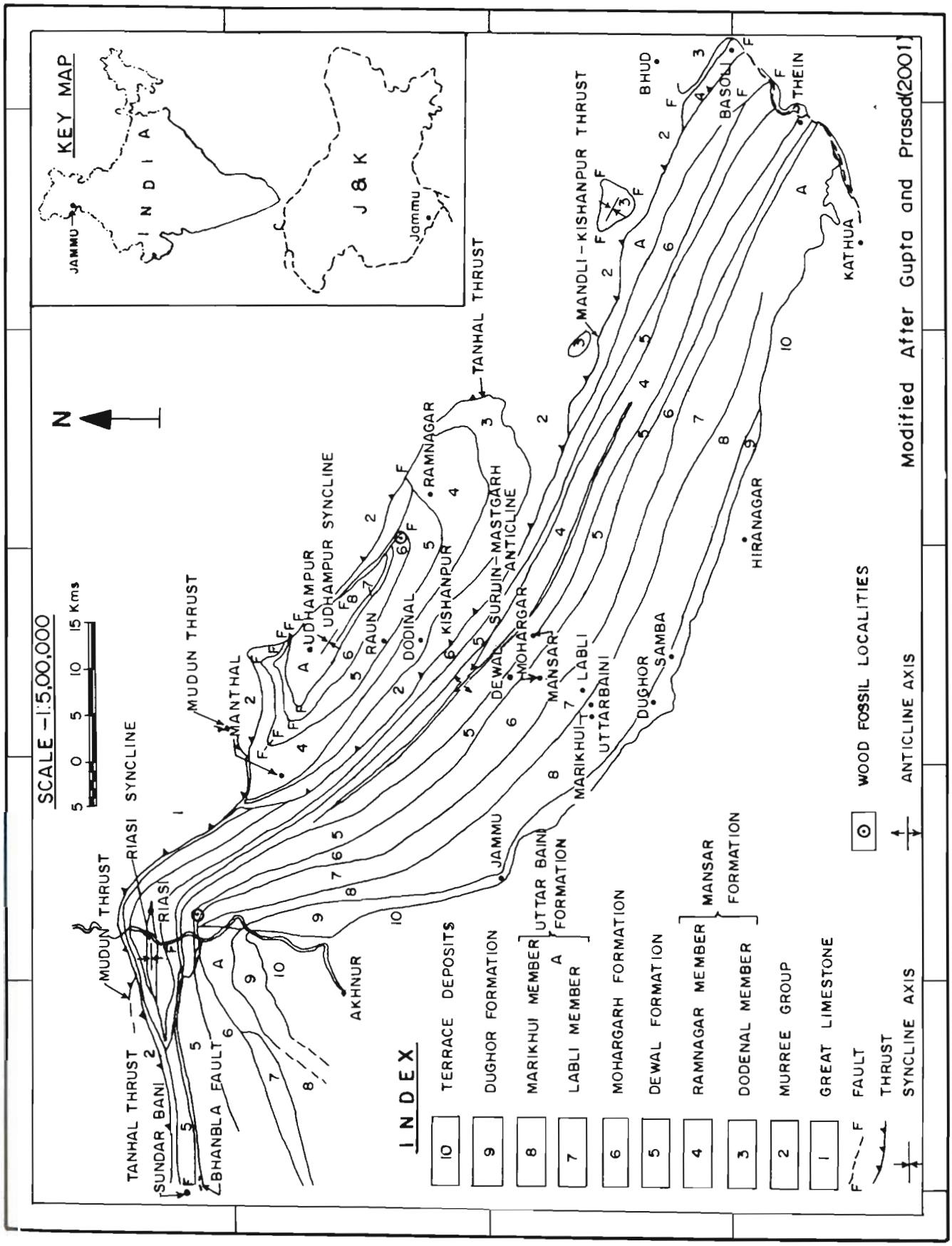

Fig. 2—Geological map of Siwalik Group of Jammu area, J & K, showing fossil wood locations.

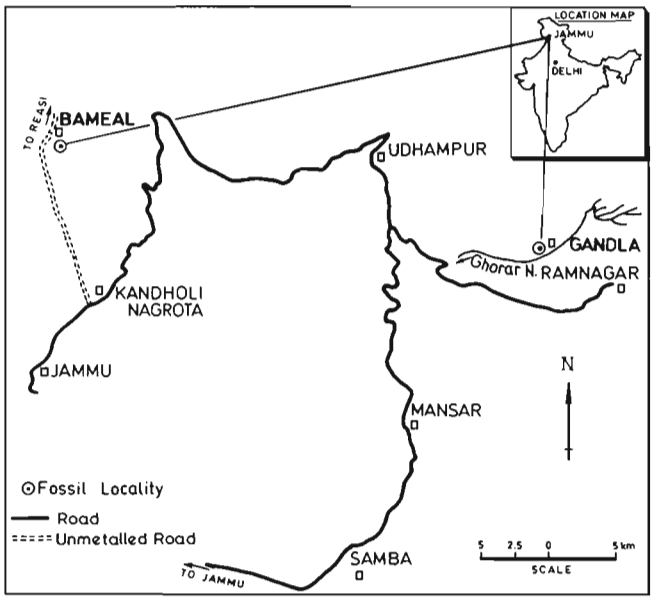

Fig. 3—Map showing fossil wood sites in part of Jammu and Udhampur districts, J & K.

The channel facies sandstone is medium to coarse grained, characterized by large scale trough and planar cross-stratification. Each sandstone unit in a multistoried sandstone body is separated by erosional surfaces which are generally planar but showing scours at places. The latter are generally filled with mud-balls, mud-pellets, calcrete pallets showing tough cross-stratification. The clays occur in thin and widely separated bands and hardly constitute 5 to 10 percent of the Mohargarh Formation. These are generally dark grey, buff, brown and yellowish. Presence of mud-balls along the erosional surfaces suggest the periodic occurrence of strong currents causing reworking of older flood plains. A significant change in sedimentation marked by thick, coarse sediments of Mohargarh Formation suggests an increased fluvial activity and rapid rate of sedimentation along continental fresh water basins. The fossils woods are occasionally found embedded in the sandstone as incomplete logs (Gupta, 2000, p. 58). They are more often encountered in the form of carbonised woody tissues.

There are only a few records of Tertiary plant fossils from the Jammu region. Sahni (1964) reported two species of grass-like leaf impressions of unknown affinities, viz., *Poacites sivalicus* (Sahni, 1964, pp. 8-9, pl. 1, fig. 3) from the Lower Siwalik of Sudnatti Tehsil, Poonch and *P. rajaoriensis* (Sahni, 1964, p. 9, pl. 1, fig. 3) from the Murree sediments of Rajaori, near Poonch and another monocot (plicated parallel veined) leaf impression from the sediments of Murree Series (Miocene) near Rajaori (Sahni, 1964, p. 12, pl. 1, fig. 8). In addition, he described two palm woods, namely, *Palmoxylon wadiai* (Sahni, 1964, pp. 24, 29-30, pl. 1, fig. 12, pl. 2, figs 13-17) and *P. jammuense* (Sahni, 1964, pp. 30-31, pl. 11, figs 75-77) from the alluvial boulder conglomerate deposit (? Pliocene) at the Tawi River, Jammu. *Artocarpus murreecus* is the first fossil dicot leaf reported from this region by Sharma and Gupta (1972) from Thanamandi in Rajaori District, Jammu and Kashmir. Besides, Kumar *et al.* (1979) and Suneja *et al.* (1981a) reported the occurrence of Charophytic gyrogonites represented by *Tectochara meriani meriani, T. meriani huangi* and *Tectochara* spp. in the Lower Siwalik beds (Chinji Formation) of Ramnagar. Suneja *et al.* (1981b) further reported two species of *Chara*, viz., *C. rantzieni* and *C. rantzieni sivalensis* from the Upper Pliocene-Lower Pleistocene sediments of the Tawi Valley, north of Jammu. Lately Bhatia *et al.* (2001) have reported the occurrence of two more charophytic taxa *Hornichara* and *Lychnothamnus* and an angiospermic seed *Boraginocarpus* from the Upper Siwalik sediments of Nagrota Formation. According to Bhatia (1999) the above noted *Tectochara* spp. have been merged under the genus *Nitellopsis* and the *Chara rantzieni sivalensis* under *C. globularis globularis*. Spore-pollen assemblages encountered in the Jammu region have been listed by Mathur (1984). From the above resumé it is clear that no dicotyledonous wood has been reported from this region. Thus, in this paper fossil dicotyledonous woods are being described for the first time from the Jammu region.

MATERIAL AND METHODS

The material for the present study was collected by one of us (S.S.G.) from exposures of the Mohargarh Formation (=Dhokpathan Formation) of Middle Pliocene age (Gupta, 2000). The fossil woods were recovered from two localities, viz., Bameal (32°56'25": 74°52'35") and Gandla (32°50'10": 75°16'00"). The former is situated about 35 km northwest of Jammu near Nagrota in Jammu District; the latter about 25 km southeast of Udhampur town near Ramnagar in Udhampur District of Jammu and Kashmir (Figs 2, 3). The area in general is presently covered by tropical dry mixed deciduous and subtropical pine forests comprising almost pure crop of *Pinus roxburghii* at higher ridges and steep rocky slopes. The angiospermic genera commonly met in the area are : *Acacia, Adhatoda, Aegle, Bauhinia, Butea, Capparis, Cassia, Dalbergia, Dodonea, Ficus, Flacourtia, Lannea, Mallotus, Ougenia, Zizyphus,* etc. (Sharma & Kachroo, 1981). The fossils come from two horizons of the Mohargarh Formation which constitutes 915 m thick sandstone-clay sequence in Bameal Section and 427 m sandstone-conglomerate litho-unit in Gandla Section (Fig. 4). The fossil wood bearing horizons are located 682 m and 194 m above the top of Dewal Formation. In both the localities fossil woods were found embedded in rocks *in situ* and had to be dug out. Occasionally heavy logs were found, which were difficult to carry. From such logs small pieces were removed with the help of a hammer. The fossils comprise only secondary xylem. Preservation of the material is satisfactory to good, though sometimes tissues are highly

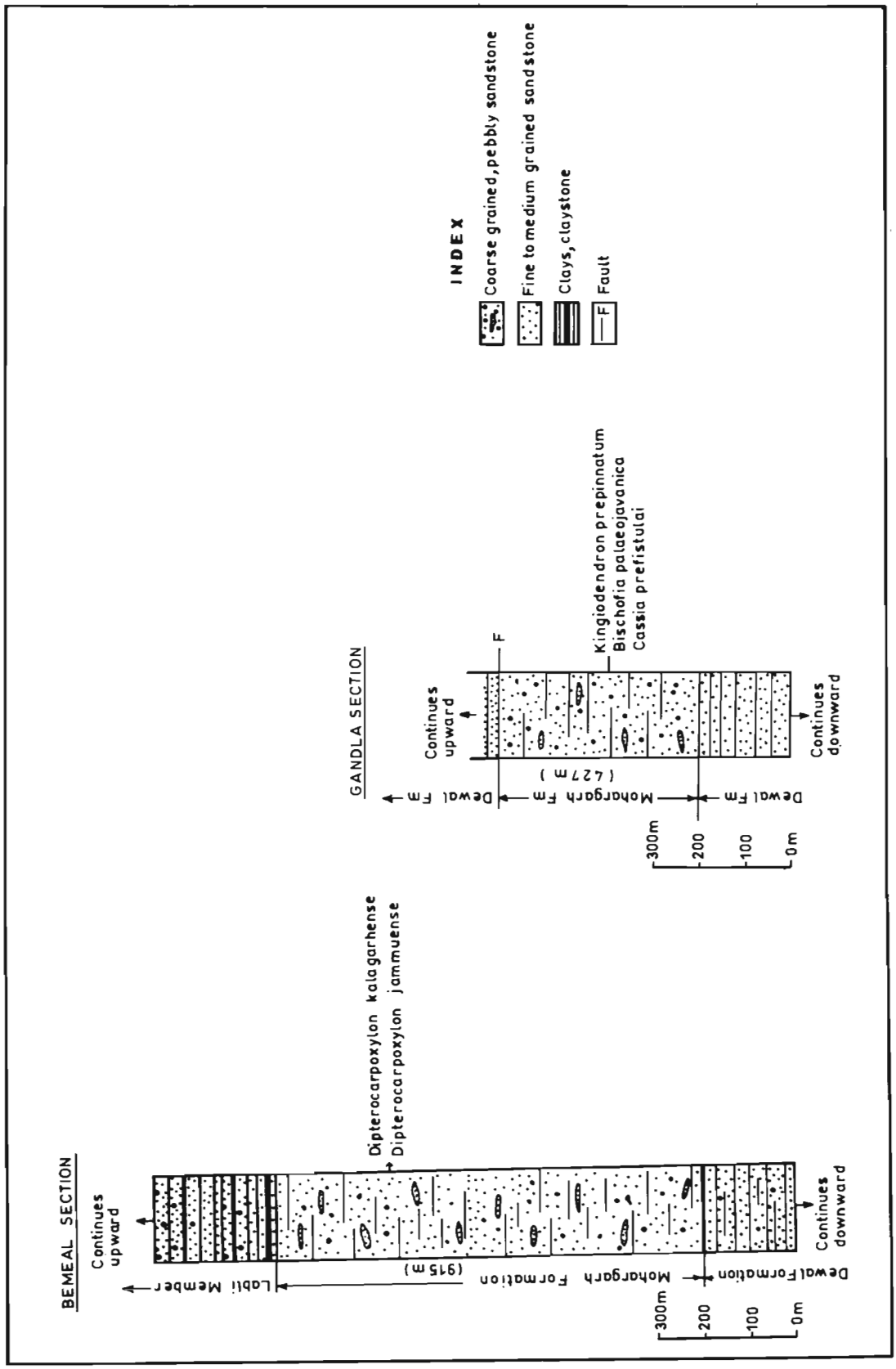

Fig. 4—Litho-columns of Mohargarh Formation showing stratigraphic positions of fossil wood bearing horizons.

degraded. For xylotomical studies the woods were cut into thin slices and transverse, tangential-longitudinal and radial-longitudinal sections were prepared by the usual method of grinding and polishing. The specimens and slides are deposited at the repository of Birbal Sahni Institute of Palaeobotany, Lucknow, India.

SYSTEMATICS

Family—DIPTEROCARPACEAE

Genus—DIPTEROCARPOXYLON Holden emend. Den Berger, 1927

DIPTEROCARPOXYLON JAMMUENSE sp. nov.

(Pl. 1.1-5)

Material—The species is based on a single fairly well preserved specimen 76 cm long and 15.5 cm wide.

Description—Wood diffuse-porous (Pl. 1.1). *Growth rings* not seen. *Vessels* small to large (mostly medium sized), tangential diameter 80-260 µm, radial diameter 100-360 µm; evenly distributed, 3-9 vessels per sq mm; almost solitary (Pl. 1.1); circular to oval, with flattened contact walls when in multiples; tyloses often present; vessel members 140-600 µm long with truncate or oblique end walls; perforations simple; inter-vessel pits not observed. *Vasicentric tracheids* present, intermingled with parenchymatous cells forming thin sheath around vessels, frequently pitted (Pl. 1.4). *Parenchyma* both apotracheal and paratracheal; paratracheal vasicentric, forming uni to biseriate layer with tracheids around vessels; apotracheal scanty, only a few diffuse cells seen, also forming sheath encircling gum canals (Pl. 1.1); cells 48-60 µm in diameter and 28-90 µm in length. *Rays* 1-6 (mostly 3-5) seriate, 5-9 rays per mm; heterocellular (Pl. 1.2, 5); uniseriate rays 2-11 cells or 180-750 µm long, made up of upright cells only or both upright and procumbent cells; multiseriate rays made up of procumbent cells in the centre with uniseriate extensions of 2-12 upright cells at both the ends, sheath cells present on the flanks of multiseriate rays (Pl. 1.3); up to 480 µm wide and 5-45 cells or 200-1,260 µm long; procumbent cells 20-32 µm in tangential height and 40-80 µm in radial length; upright cells 28-48 µm in tangential height and 16-24 µm in radial length; vessel - ray pits simple, many per cell (Pl. 1.5). *Fibres* aligned in radial rows, polygonal in cross section, semilibriform, nonseptate; 36-48 µm in diameter, frequently pitted (Pl. 1.4). *Gum canals* vertical, normal, solitary or in tangential groups of 2-4 (5), smaller than vessels, enclosed by parenchymatous sheath, tangential diameter 65-80 µm, radial diameter 35-65 µm (Pl. 1.1).

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Geological Survey of India, Jammu.

Holotype—BSIP Museum No. 38305.

Locality—Bameal near Nagrota, Jammu & Kashmir.

Horizon—Mohargarh Formation, Middle Siwalik.

Age—Middle Pliocene.

Etymology—Specific name is after the Jammu area from where the fossil wood was collected.

Affinities—The important characters of the fossil are : almost solitary vessels with tyloses, vasicentric tracheids, scattered gum canals, solitary or in groups of 2-4 (5), paratracheal parenchyma vasicentric, apotracheal parenchyma scanty, only as few diffuse cells and around gum canals, 1-6 (mostly 3-5) seriate, distinctly heterocellular rays. The combination of all these characters indicate that the fossil belongs to genus *Dipterocarpus* Gaertn. f. of the family Dipterocarpaceae. Thin sections of a large number of extant woods of *Dipterocarpus* available at the Birbal Sahni Institute of Palaeobotany, Lucknow and Forest Research Institute, Dehradun were examined and published descriptions and figures of many other species were also consulted for comparison (Moll & Janssonius, 1906; Kanehira, 1924a, b; Lecomte, 1926; Pearson & Brown, 1932; Reyes, 1938; Desch, 1957; Chowdhury & Ghosh, 1958; Kribs, 1959; Hayashi *et al.*, 1973; Miles, 1978; Ilic, 1991). From the survey of wood slides and literature it was found that the fossil shows close resemblance with the wood structure of *Dipterocarpus indicus* Bedd. (BSIP wood slide no. 308) and *D. lowii* Hook. f. (BSIP wood slide no. 2106) as diffuse in aggregate parenchyma is almost absent in these two species. The former, however, differs in having greater frequency of gum canals which are arranged more or less regularly in short or long tangential rows. *Dipterocarpus lowii* shows nearest resemblance with the present fossil in all its characters including frequency and distribution of gum canals.

Comparison and Discussion—A number of fossil wood species referable to the genus *Dipterocarpus* have been described under the artificial genus *Dipterocarpoxylon* Holden emend Den Berger (1927). About 17 species are known from the Upper Tertiary sediments of Indian subcontinent which includes India, Pakistan, Nepal, Bhutan, Bangladesh, Srilanka and Myanmar (Awasthi, 1996; Awasthi & Mehrotra, 1997;

PLATE 1 →

Dipterocarpoxylon jammuense sp. nov.

1. Cross section showing shape, size and distribution of vessels, parenchyma and gum canals. x 40. Slide no. BSIP 38305-I.
2. Radial longitudinal section showing heterocellular ray tissue. x 200. Slide no. BSIP 38305-III.
3. Tangential longitudinal section showing uniseriate and multiseriate xylem rays. x 40. Slide no. BSIP 38305-II.
4. Radial longitudinal section showing vasicentric tracheids and fibre tracheids. x 200. Slide no. BSIP 38305-III.
5. Radial longitudinal section showing vessel-ray pits. x 400. Slide no. BSIP 38305-III.

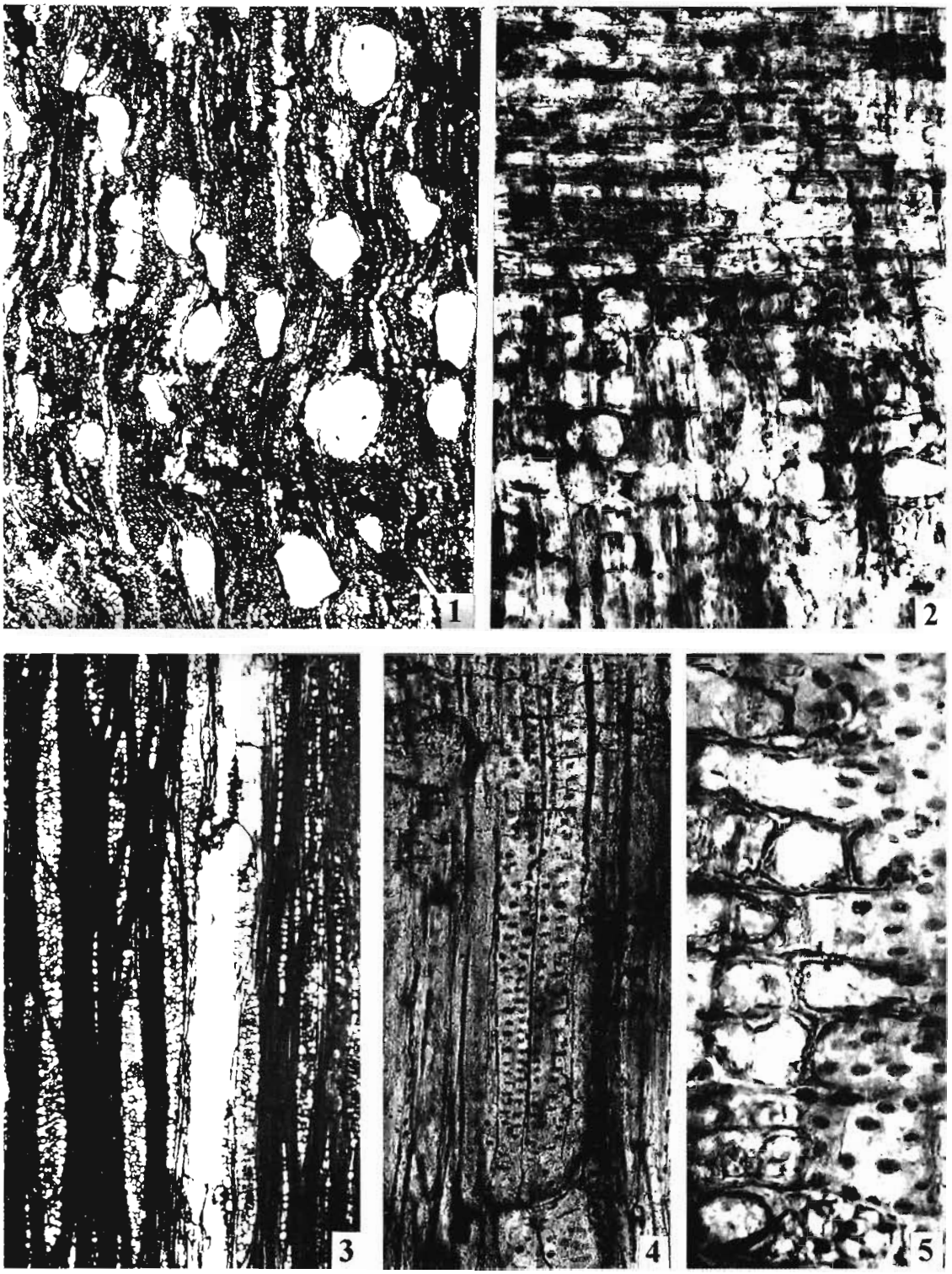

PLATE 1

Guleria, 1996; Prakash *et al.*, 1994; Prasad & Tripathi, 2000; Tiwari & Mehrotra, 2000; Bera & Banerjee, 2001; Srivastava, 2001; references of earlier literature can be seen in these publications). In addition, two fossil woods have been assigned to the natural genus *Dipterocarpus* Gaertn. These have been reported from the Middle Siwalik sediments of Hardwar in Uttar Pradesh and Darjeeling District of West Bengal (Prasad & Khare, 1994; Antal *et al.*, 1999) and compared with the extant wood of *Dipterocarpus speciosus* and *D. gracilis*, respectively. Out of the above referred fossil woods, the present fossil shows apparent similarity in gross structure as well as in the near absence of diffuse-in-aggregate parenchyma with *Dipterocarpoxylon pondicherriense* Awasthi, reported from the Upper Tertiary sediments of Pondicherry and Kachchh in Gujarat (Awasthi, 1974; Guleria, 1983). However, in *D. pondicherriense* frequency of gum canals is high and they are more or less regularly arranged in short or long tangential rows. On the contrary frequency of gum canals is low in the present fossil and are mostly scattered, rarely forming groups and hence, can easily be differentiated from *D. pondicherriense*. Since the present specimen differs from the known species of *Dipterocarpoxylon*, a new specific name *Dipterocarpoxylon jammuense* sp. nov., is assigned to it.

The genus *Dipterocarpus* Gaertn.f. includes about 69 species which are mainly confined to Indo-Malaysian region with maximum development in Borneo, Malaysian Peninsula and Sumatra (Mabberley, 1997, p. 235). The genus ranges in its distribution from India in the west to Philippines in the East. In India, it is found in Assam, the Andamans and the Western Ghats (Chowdhury & Ghosh, 1958; Santapau & Henry, 1973). *Dipterocarpus lowii* Hook.f. with which the fossil shows nearest resemblance is found in the Malaysian region.

DIPTEROCARPOXYLON KALAGARHENSIS Yadav 1989

(Pl. 2.1-5)

Material—The description is based on a well preserved secondary wood, 46 cm long and 18 cm wide.

Description—Wood diffuse-porous (Pl. 2.1-2). *Growth rings* not seen. *Vessels* small to large, tangential diameter 125-315 µm, radial diameter 150-435 µm; almost solitary (Pl. 2.1-2), rarely in radial multiples of two, circular to oval when solitary, flattened at the place of contact when in multiples; tyloses present; 3-7 vessels per sq mm; vessel elements 170-450 µm long with truncate or oblique end walls; perforations simple; inter-vessel pits could not be observed. *Vasicentric tracheids* present, intermingled with parenchymatous cells; forming thin sheath around vessels; frequently pitted (Pl. 2.5). *Parenchyma* abundant, both paratracheal and apotracheal (Pl. 2.1, 2); paratracheal vasicentric, intermingled with vasicentric tracheids forming 1-2 seriate sheath around the vessels; apotracheal abundant, diffuse to diffuse-in-aggregate forming uniseriate broken lines among fibres, fairly conspicuous forming 4-6 celled bands around vertical gum canals (Pl. 2.1, 2); each cell 32-40 µm in diameter and 100-128 µm in length. *Rays* 1-6 seriate, heterocellular, made up of both upright and procumbent cells; 4-7 rays per mm; uniseriate rays 1-16 cells or 145-165 µm long (Pl. 2.3), either made up of upright cells or both upright and procumbent cells; multiseriate 2-6 cells or 40-148 µm wide and 6-35 cells or 240-1,360 µm long; made up of procumbent cells in the centre and extensions of 1-10 upright cells at one or both the ends, sheath cells present on the flanks of multiseriate rays (Pl. 2.3), procumbent cells 20-28 µm in tangential height and 32-60 µm in radial length; upright cells 48-80 µm in tangential height and 24-32 µm in radial length. *Fibres* aligned in radial rows. *Gum Canals* vertical, normal, scattered, solitary or in pairs and sometimes forming tangential groups of 4-6, smaller than the vessels, enclosed by 6-8 seriate apotracheal parenchyma bands (Pl. 2.1); tangential diameter 48-80 µm, radial diameter 80-128 µm.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Geological Survey of India, Jammu.

Specimen No—BSIP 38306.

Locality—Bameal near Nagrota, Jammu & Kashmir.

Horizon—Mohargarh Formation, Middle Siwalik.

Age—Middle Pliocene.

Affinities—From the survey of modern wood slides and literature it was found that the fossil shows nearest resemblance with the wood structure of *Dipterocarpus obtusifolius* Teysm. ex Miq. (BSIP wood slide no. 249). Among the fossil species of *Dipterocarpoxylon* already known from the Indian subcontinent, the present fossil cannot be differentiated from *D. kalagarhensis* Yadav, reported from the Lower Siwalik sediments of Kalagarh, Pauri Garhwal District, Uttaranchal (Yadav, 1989). Therefore, it is placed under the same species.

PLATE 2 →

Dipterocarpoxylon kalagarhensis Yadav 1989

1. Cross section showing shape, size and distribution of vessels, parenchyma and gum canals. x 40. Slide no. BSIP 38306-I.
2. Another cross section showing specially diffuse-in-aggregate parenchyma. x 40. Slide no. BSIP 38306-I.
3. Tangential longitudinal section showing uniseriate and multiseriate xylem rays, multiseriate rays with sheath cells. x 40. Slide no. BSIP 38306-II.
4. Radial longitudinal section showing heterocellular ray tissue. x 100. Slide no. BSIP 38306-III.
5. Radial longitudinal section showing vasicentric tracheids. x 400. Slide no. BSIP 38306-III.

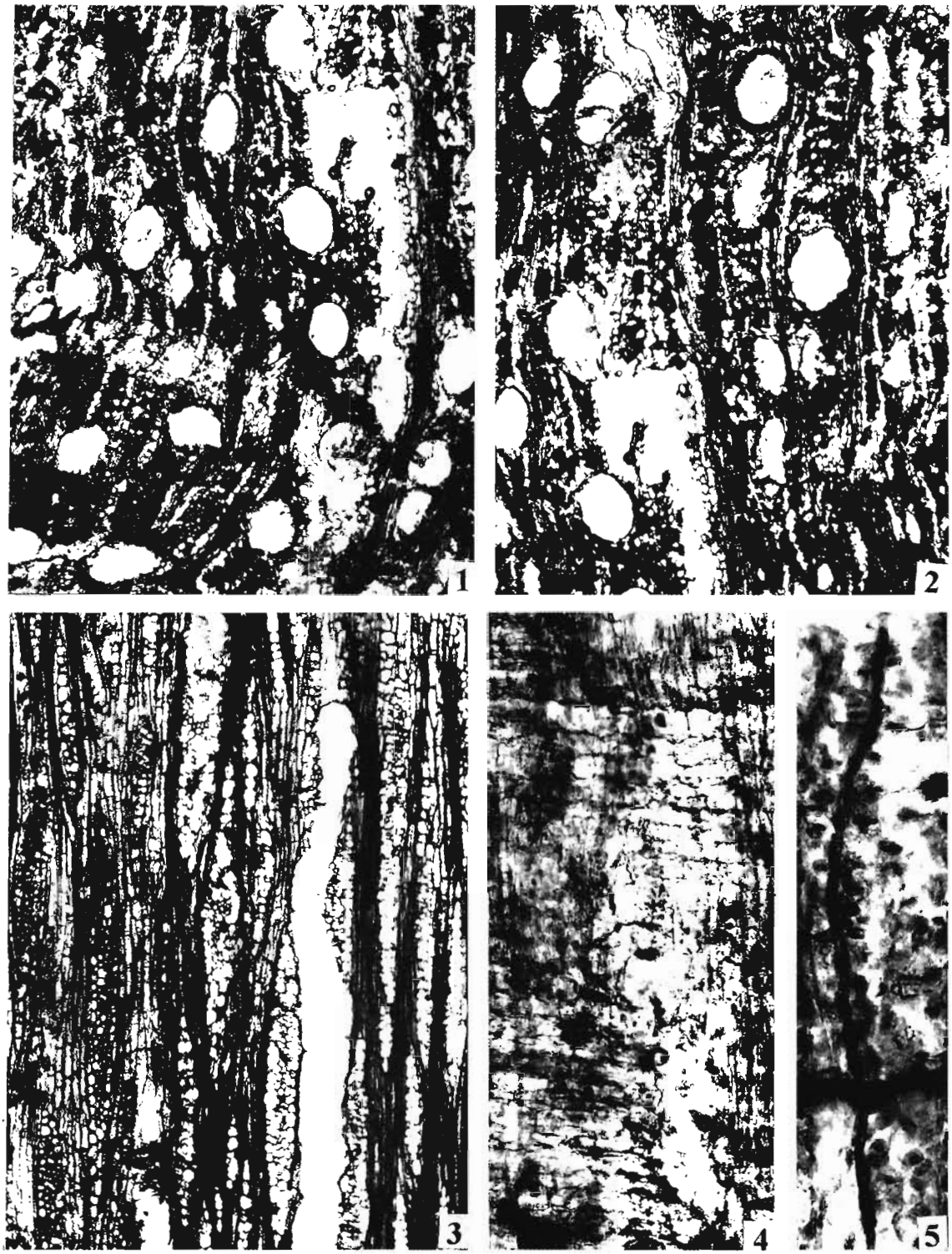

PLATE 2

The species has lately been reported from Neogene sediments of Midnapur District, West Bengal (Bera & Banerjee, 2001).

Dipterocarpus obtusifolius Teysm. ex Miq. with which the fossil shows close resemblance, is a medium to large sized tree and grows gregariously in the lower hill forests of Myanmar up to 900 m above sea level and is found further east in Thailand and Malaysian Peninsula (Chowdhury & Ghosh, 1958 p. 117).

Family—LEGUMINOSAE

Subfamily—CAESALPINIODEAE

Genus—CASSINIUM Prakash 1975

CASSINIUM PREFISTULAI Prakash 1975

(Pl. 3.1-5)

1974 *Peltophoroxylon parenchymatosum* Kramer p. 124, pl. 28, figs 107, 108, 110-112, 114, 115; pl. 29, fig. 116; text-fig. 14 a-d.

1975 *Cassinium prefistulai* Prakash p. 199, pl. 4, figs 14, 16, 17.

Awasthi and Srivastava, 1992, p. 151, pl. 4, figs 1-2.

1975 *Cassinium variegatum* (Ramanujam) Prakash *Peltophoroxylon variegatum* (Ramanujam) Muller-Stoll & Madel 1967.

Ramanujam, 1960: p. 120, pl. 32, figs 37-41; text fig.26.

1975 *Cassinium cassioides* (Prakash & Awasthi) Prakash Prakash and Awasthi 1970: p. 36, pl. 3, figs 15, 16; pl. 4, figs 18, 20, 21.

Prakash, Vaidyanathan and Tripathi 1994: p.129. pl. 4, figs 30-32; text fig. 8.

1979 *Cassinium arcotense* Awasthi p. 159, pl. 2, figs 8, 9, pl. 3, fig. 10.

1981 *Cassinium ballavpurense* Ghosh and Roy p. 285, figs 1-7.

Material—The species is represented by a single specimen with satisfactory preservation, measuring 23 cm in length and 15.5 cm in width.

Description—Wood diffuse-porous (Pl. 3.1). *Growth rings* present, delimited by more or less continuous line of apotracheal parenchyma. *Vessels* small to large, tangential diameter 70-325 µm, radial diameter 65-350 µm; evenly distributed, 4-7 vessels per sq mm; usually solitary or in radial multiples of 2-6 (mostly 2-3); circular to oval when solitary and flattened at the place of contact when in radial multiples (Pl. 3.1); tyloses absent, some filled with dark contents; vessel elements 325-500 µm long with oblique to transverse end walls; perforations simple; intervessel pits alternate, hexagonal, vestured with lenticular aperture (Pl. 3.4), 8-10 µm in diameter. *Parenchyma* paratracheal, vasicentric, aliform to aliform-confluent joining adjacent vessels (Pl. 3.1, 2); each cell 35-50 µm in diameter and 60-135 µm long; crystalliferous strands present. *Rays* 1-3 (mostly 3) seriate (Pl. 3.3); 6-12 rays per mm; non-storied; homocellular to weakly heterocellular (Pl. 3.4), mostly consisting of procumbent cells, sometimes end cells enlarged and crystalliferous; uniseriate rare; 8-20 cells or 170-550 µm long; procumbent cells 24-36 µm in tangential height and 48-72 µm in radial length. *Fibres* aligned in radial rows, polygonal in cross section (Pl. 3.1), semilibriform, 24-30 µm in diameter; nonseptate; interfibre pits not seen.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Geological Survey of India, Jammu.

Specimen No—BSIP 38307.

Locality—Gandla near Ramnagar, Jammu & Kashmir.

Horizon—Mohargarh Formation, Middle Siwalik.

Age—Middle Pliocene.

Affinities—All the above characters indicate that the fossil wood belongs to the family Leguminosae. On comparing the fossil with a large number of leguminous genera, it was found that on the basis of parenchyma distribution (Ramesh Rao *et al.*, 1972) coupled with other characters, it shows resemblance with the extant wood of the genus *Cassia* Linn (s.l.). A large number of thin sections of woods of *Cassia* species viz., *C. aubrevillei* Pellegr., *C. auriculata* Linn., *C. fistula* Linn., *C. grandis* Linn., *C. javanica* Linn., *C. marginata* Roxb., *C. nodosa* Ham. ex Roxb., *C. siamea* Linn. were examined. In addition, published descriptions and photographs of *C. aubrevillei* (Normand, 1950, p. 125, pl. 36), *C. bartonii* Bailey, *C. fistula* (Ilic, 1991, figs 2061, 2062), *C. fastuosa* Willd. (Kribs, 1959, p. 70, fig. 173), *C. javanica*, *C. timoriensis* DC and *C. siamea* (Moll & Janssonius, 1914, pp. 97-108, fig. 156; Kanehira, 1924a, p. 26) were also consulted for comparison with the fossil. It was found that amongst these the fossil shows best resemblance with the woods of *C. fistula*. In both, the fossil wood and the woods of modern *C. fistula,* vessels are small to large, mostly solitary sometimes in multiples with simple perforation plates, intervessel pits vestured; parenchyma terminal apotracheal and aliform to mostly confluent; xylem rays 1-3 (mostly 3 seriate), homocellular to weakly heterocellular; rays and parenchyma cells sometimes crystalliferous, fibres non-septate and thick walled.

PLATE 3 →

Cassinium prefistulai Prakash 1975

1. & 2. Cross sections showing shape, size and distribution of vessels and parenchyma pattern. x 40. Slide no. BSIP 38307-I.
3. Tangential longitudinal section showing 1-3 seriate xylem rays. x 100. Slide no. BSIP 38307-II.
4. Vestured intervessel pits. x 400. Slide no. BSIP 38307-II.
5. Radial longitudinal section showing weakly heterocellular rays. x 100. Slide no. BSIP 38307-III.

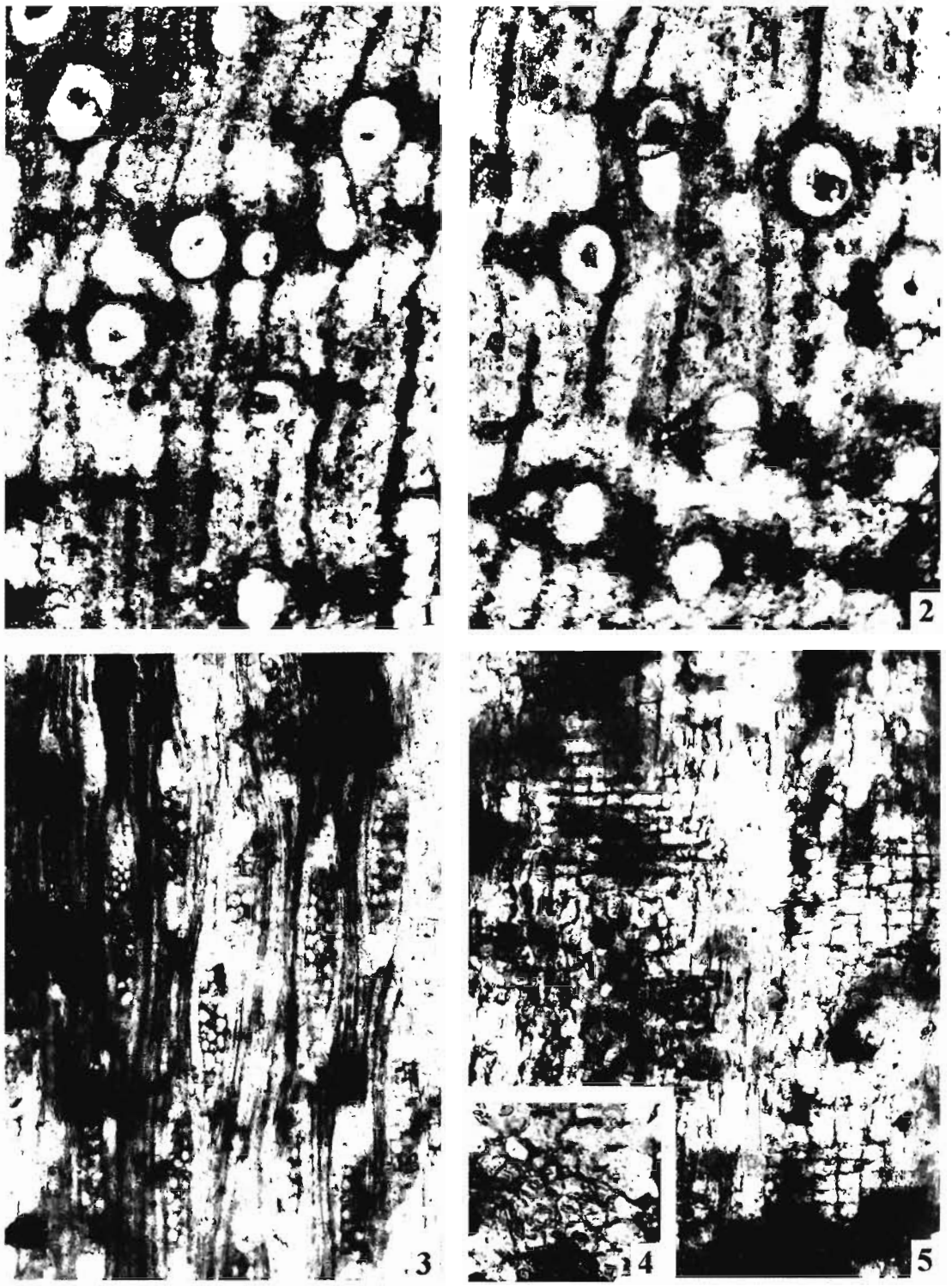

PLATE 3

Comparison and Discussion—Felix (1882) established the genus *Cassioxylon* for the fossil woods showing resemblance with the modern woods of genus *Cassia* Linn. Muller-Stoll and Mädel (1967) while working on fossil woods of Leguminosae re-examined the type slides of *Cassioxylon* and found that the fossil does not show the characters of *Cassia* woods and may not even belong to family Leguminosae. Consequently, they instituted a genus *Peltophoroxylon* to include fossil woods of *Cassia*, *Peltophorum* Vogel and *Xylia* Benth. on account of their close similarity. This genus was further amended by Prakash and Awasthi (1970) and later Prakash (1975, pp. 200-201) further circumscribed the genus *Peltophoroxylon* and instituted a new genus *Cassinium* for the fossil woods showing affinities with the modern woods of *Cassia*. Of the known *Peltophoroxylon* species he transferred four to the new genus *Cassinium* (Prakash, 1975, p. 201). Almost at the same time a fossil wood, *Peltophoroxylon parenchymatosum* showing apparent similarities with the modern woods of *Cassia siamea* was reported from the Southeast Asia by Kramer (1974, p. 124). Since it was published just before Prakash's publication of 1975 and the paper was perhaps not available to Prakash, he could not comment on this species. We take this opportunity to point out that rays in *Peltophoroxylon parenchymatosum* are relatively broad, mostly 3-4 seriate (p. 124, pl. 28, fig. 112) and parenchyma relatively less than in the modern woods of *Cassia siamea*. Woods of *C. siamea* usually possess banded parenchyma and relatively fine 1-2 (3) seriate rays. It seems *Peltophoroxylon parenchymatosum* shows better resemblance with the woods of *Cassia fistula* in the type of parenchyma (Ramesh Rao *et al.*, 1972, pl. 73, fig. 437) and in the width of rays (up to 4 cells wide) have also been observed in this species. Thus in view of close similarity of *P. parenchymatosum* with the woods of *Cassia fistula, P. parenchymatosum* has been transferred under the genus *Cassinium* Prakash, viz., C. *parenchymatosum*. Thus the authors are aware of eleven species of *Cassinium* which are listed in Fig. 5 giving their main anatomical characters. Out of these *C. borooahii* (Prakash) Prakash, *C. ethiopicum* Prakash *et al.*, *C. tripuranum* Acharya and Roy and *C. dongolenese* Giraud and Lejal-Nicol possess banded parenchyma and hence can easily be differentiated from the present specimen. Likewise *C. cassinodosum* Prakash, differs from the present fossil in having relatively narrow rays 1-2 (mostly 2 seriate), bigger vessels (144-400 μm) and septate fibres. The present fossil resembles the remaining six species of *Cassinium*, though it may differ from them in some minor and variable characters. Since the present specimen shows close resemblance with *Cassinium cassioides* (Prakash & Awasthi) Prakash, *C. prefistulai* Prakash, *C. ballavpurense* Ghosh and Roy, *C. variegatum* (Ramanujam) Prakash, *C. arcotense* Awasthi and *C. parenchymatosum* (op. cit.), it forced the authors to re-evaluate the authenticity of these species as they have been instituted on overlapping and variable nature of characters. It is worth noting that inspite of exhibiting minor and variable anatomical differences from each other, the first three species have been compared with the woods of a single extant species, viz., *Cassia fistula*, the fourth, *C. variegatum* (Ramanujam) Prakash has not been compared with the woods of any modern *Cassia* species. Since anatomical features of *C. variegatum* and *C. parenchymatosum* fall within the range of characters observed in the extant woods of *Cassia fistula*, their affinities can easily be assigned to *Cassia fistula*. In 1979, Awasthi instituted a new species *Cassinium arcotense* on the assumption that it shows resemblance with the woods of *Cassia javanica*. However, all the characters of this species can also be seen in the woods of *Cassia fistula*. Awasthi did not mention a single point as to how *C. arcotense* differs from the woods of *Cassia fistula*. The wood characters of *Cassia javanica* and *C. fistula* overlap when a large number of samples were examined and it is difficult to distinguish the two on the basis of anatomical features alone. Prakash *et al.* (1994) while describing *C. cassioides* from the Miocene sediments of Assam have also opined that *C. cassioides* and *C. prefistulai* should be considered as one species although they did not actually merge the two species. Surprisingly they did not mention in their publication about three species of *Cassinium*, namely, *C. ballavpurense, C. tripuranum* and *C. ethiopicum,* specially when the last species was established by Prakash himself in association with Awasthi and Lemoigne. Thus in view of the very close structural similarities in the above referred six species (differences exhibited being of variable nature), it has been considered to merge the following five species, viz., *Cassinium cassioides* (Prakash & Awasthi) Prakash (1975); *C. ballavpurese* Ghosh and Roy (1981); *C. variegatum* (Ramanujam) Prakash (1975); *C. arcotense* Awasthi (1979) and *C. parenchymatosum* (op. cit.) under the type species *C. prefistulai* Prakash (1975). As the present wood specimen also

PLATE 4

Kingiodendron prepinnatum Awasthi & Prakash 1987

1. Cross section showing shape, size and distribution of vessels, parenchyma and gum canals. x 40. Slide no. BSIP 38308-I.
2. Tangential longitudinal section enlarged showing mostly 1-3 seriate xylem rays. x 100. Slide no. BSIP 38308-II.
3. Radial longitudinal section showing weakly heterocellular xylem rays. x 100. Slide no BSIP 38308-III.
4. Tangential longitudinal section showing distribution of xylem rays. x40. Slide no. BSIP 38308-II.
5. Vestured intervessel pits. x 400. Slide no. BSIP 38308-II.

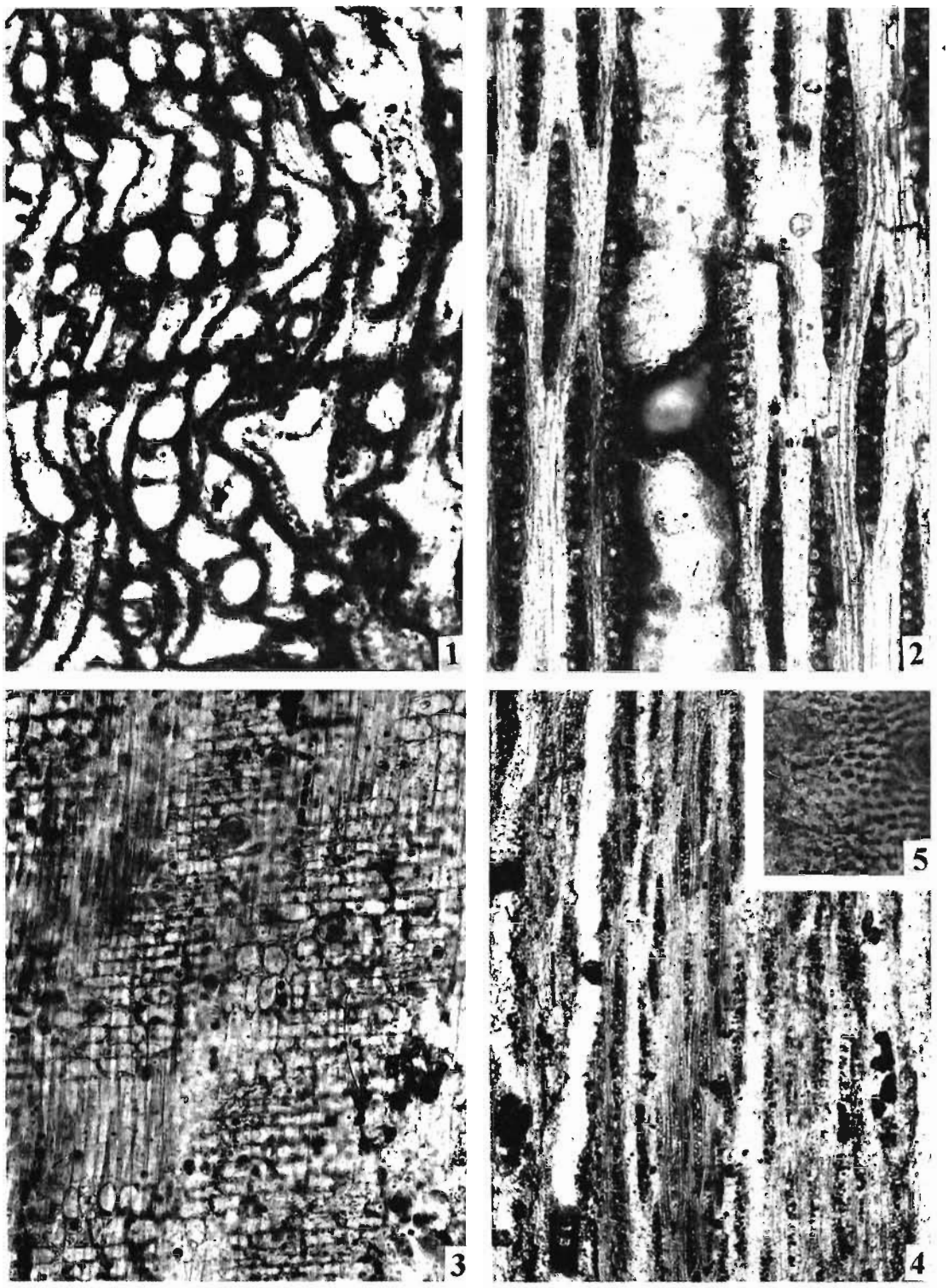

PLATE 4

Name	Vessels	Parenchyma	Rays	Fibres	Modern Comparable Forms	Locality & Age
* *Cassinium varigatum* (Ramanujam, 1960) Prakash 1975	Medium-large, diameter 185-310 µm; solitary and in radial multiples of 2-4.	Terminal and paratracheal confluent bands.	1-3 seriate; homocellular to weakly heterocellular.	Septate.	*Cassia*	Muratandichavadi, South Arcot District; Cuddalore Formation; Miocene-Pliocene.
Cassinium borooahi (Prakash, 1966) Prakash 1975, 1978; Bande & Prakash, 1980; Mehrotra *et al.* 1999; Bera & Banerjee 2001	Medium-large, t.d. 106-380 µm; mostly solitary, sometimes in radial multiples of 2-4; tyloses present.	Paratracheal, banded, aliform confluent bands alternating with fibrous bands.	1-3 seriate, uniseriate rare, homocellular, made up of procumbent cells; 10-30 cells long.	Non-septate; thick walled.	*C. siamea* Lam.	Dimapur-Diphu Road, Assam; Tipam Sandstone; Middle Miocene; Santiniketan, Bolpur District and Uttar Raipur, Birbhum District of West Bengal, Upper Miocene; Subansiri District, Arunachal Pradesh, Late Mio-Pliocene.
* *Cassinium cassioides* (Prakash & Awasthi, 1970) Prakash 1975	Small-large, t.d. 96-240 µm, r.d. 112-320 µm; solitary and in multiples of 2-6 (mostly 2-3); 4-12 per sq mm; tyloses absent.	Paratracheal, mostly aliform to confluent joining many vessels; terminal parenchyma not seen.	1-3 (mostly 2-3) seriate, homocellular consisting of procumbent cells only; 4-24 cells long.	Non-septate; thick walled.	*C. fistula* Linn.	Bhuri-Dehing River bed, near Jaipur, Assam; Tipam Sandstones; Middle Miocene.
Cassinium cassinodosum (Prakash, 1973) Prakash 1975	Medium-large, t.d. 144-400 µm, r.d. 160-416 µm; solitary and in multiples of 2-3 (rarely 6); 2-4 per sq mm, tyloses absent.	Terminal parenchyma appears to be present; paratracheal aliform to confluent forming irregular bands joining many vessels.	1-2 (mostly 2) seriate; homocellular made up of procumbent cells only; 7-34 cells long.	Septate; thick walled.	*C. nodosa* Ham.	Myanmar; Tertiary.
* *Cassinium parenchymatosum* (Kramer, 1974) Guleria *et al.*	Small-large, t.d. 70-300 µm, rd. 70-400 µm; solitary and in radial multiples of 2-3(4); 2-4 per sq mm; mostly empty, tyloses absent.	Terminal parenchyma present; paratracheal aliform to mostly confluent forming undulating bands joining adjacent vessels.	1-4 (mostly 3-4) seriate, homocellular or weakly heterocellular composed mainly of procumbent cells; 15-22 cells or 350-500 µm long; 5 per mm.	Non-spetate; thick walled.	*C. fistula* Linn. and *C. siamea* Lam	South Sumatra and West Java, Indonesia; Tertiary.
Cassinium prefistulai Prakash 1975; Awasthi & Srivastava 1992	Small-large, t.d. 40-240 µm, r.d. 60-300 µm; mostly solitary, sometimes in radial multiples of 2-3; 3-7 per sq	Terminal parenchyma present; paratracheal aliform to mostly confluent forming	1-4 seriate, homocellular or weakly heterocellular	Non-spetate; thick walled.	*C. fistula* Linn.	Khokhra near Nalagarh, Himachal Pradesh and Kalagarh, Uttranchal; Lower Siwalik Series; Middle Miocene;

	mm; mostly empty, sometimes plugged with black-brown deposits.	undulating broad bands joining adjacent vessels.	composed mainly of procumbent cells.			Paddappakara, Kollam District, Kerala; Warkalli Formation; Miocene.
* *Cassinium arcotense* Awasthi 1979	Small-large, t.d. 60-280 µm, r.d. 40-280 µm; solitary and in multiples of 2-4; 4-6 per sq mm; tyloses absent.	Terminal parenchyma present; paratracheal mostly aliform, sometimes confluent.	1-4 (mostly 2-4) seriate, homocelluler, wholly of procumbent cells; upto 25 cells long.	Probably septate; thick walled.	*C. javanica* Linn.	Muratandichavadi near Pondicherry; Cuddalore Series; Miocene-Pliocene.
* *Cassinium ballavpurense* Ghosh & Roy 1981	Small-large, t.d. 160-280 µm, r.d. 200-480 µm; solitary and in radial multiples of 2-5; 3-6 per sq mm.	Paratracheal, aliform-confluent forming undulating bands joining adjacent vessels.	1-4 (mostly 2-3) seriate; homocellular, 15-30 cells long.	Septate; thick walled.	*C. fistula* Linn. & *C. nodosa* Ham.	Ballavpur near Bolpur, Birbhum District., West Bengal; Upper Miocene.
Cassinium ethiopicum Prakash *et al.* 1982	Small-medium, t.d. 30-160 µm, r.d. 25-155 µm; solitary and in multiples of 2-5 (mostly 2-3); 15-30 per sq mm.	Paratracheal banded, bands irregular and wavy, seldom bifurcating.	1-4 seriate; homocellular, 4-27 cells long; 7-12 per mm.	Non-septate; semilibri form, thick walled.	*C. aubrevillei* Pellegr.	Blue Nile Valley, Ethiopia; Mio-Pliocene.
Cassinium tripuranum Acharya & Roy 1986	Medium-large, t.d. 140-268 µm; solitary and in radial multiples of 2-4; 4-8 per sq mm; tyloses absent.	Paratracheal confluent band, wholly or partially encircling vessels; bands 4-10 cells wide.	1-3 (mostly 2) seriate, weakly heterocellular with 1-2 upright cells at the ends, 15-25 cells long.	Non-septate.	*Cassia*	Khowai, Teliamura, Tripura; ? Tipam Sandstone; Upper Miocene.
Cassinium dongolense Giraud & Lejal-Nicol 1989	Medium-large, t.d. 169-206 µm, r.d. 206-356 µm; mostly solitary, rarely in radial multiples of 2-4; 2-6 per sq mm; tyloses present.	Paratracheal forming 3-7(12) cells thick bands.	1-3 (mostly 2) seriate; homocellular; 1-30 cells long.	Non-septate, 18-32 µm in diameter.	*C. siamea* Linn.	Wadi Howar Formation; Northern Sudan; Upper Cretaceous ? or Tertiary.
Present specimen	Small-large, t.d. 70-325 µm, r.d. 65-350 µm; solitary and in radial multiples of 2-3 (rarely 6); 4-7 per sq mm.	Paratracheal, aliform to aliform confluent joining adjacent vessels.	1-3 (mostly 3) seriate, homocellular, 8-20 cells or 170-550 µm long.	Non-septate; semi-libriform.	*C. fistula* Linn.	Ramnagar, Jammu & Kashmir; Middle Siwalik; Upper Miocene.

The age of *C. dongolense* has been mentioned as Upper Cretaceous as well as Cretaceous (?) or Tertiary (Giraud & Lejal-Nicol, 1989, pp. 39, 49). It seems the exact provenance of the fossil is not known. The advanced wood structure of the fossil and our experience on fossil woods says that the age of the species cannot be Cretaceous, it may most probably be Upper Tertiary.

Species marked with * have now been merged under *Cassinium prefistulai.*

Fig. 5—List of *Cassinium* species with their anatomical features and other details.

has characters identical to *C. prefistulai* Prakash, it is being placed under the same species. Thus with the merger of the above five species under *C. prefistulai,* at present there are a total of six valid species of *Cassinium.*

The genus *Cassia* was widespread in India during the Late Tertiary. In the fossil form it is represented by its wood and leaf remains. Its leaf remains have been reported from Bihar, Gujarat, Himachal Pradesh and Uttaranchal (Awasthi & Lakhanpal, 1990; Guleria *et al.*, 2000) and woods have been reported from Himachal Pradesh, Arunachal Pradesh, Uttaranchal, Assam, Tripura, West Bengal, Tamil Nadu and Kerala (see Fig. 5).

Cassia Linn. (*sensu lato*) is a large genus of over 500 species of herbs, shrubs and trees. It is pantropical in distribution. The genus occurs in both the eastern and western hemisphere excluding Europe (Record & Hess, 1943; Willis, 1973). *Cassia fistula* Linn. with which the present fossil shows close resemblance is found throughout the forests of India, Myanmar and Sri Lanka. It is one of the most widespread of the Indian trees ascending up to 1,200 m in the Himalayas and extending further north-west to the hills of Peshawar (Gamble, 1902, p. 208; Ramesh Rao *et al.*, 1972, p. 72).

Genus—KINGIODENDRON Harms

KINGIODENDRON PREPINNATUM Awasthi and Prakash 1987

(Pl. 4.1-5)

Material—The species is represented by a well preserved piece of secondary wood measuring 27 cm in length and 13 cm in width.

Description—Wood diffuse-porous (Pl. 4.1). *Growth rings* present, demarcated by narrow 2-3 cells thick parenchyma lines (Pl. 4.1). *Vessels* small to large, mostly medium sized, tangential diameter 80-220 µm, radial diameter 80-340 µm; solitary as well as in radial multiples of 2-3; evenly distributed, 5-8 per sq mm; circular to oval when solitary, with flat contact walls when in multiples; tyloses absent (Pl. 4.1); vessels occasionally filled with dark contents; vessel elements 350-500 µm long with oblique or transverse end walls; perforations simple; inter-vessel pits small, alternate, vestured, 6-8 µm in diameter (Pl. 4.5). *Parenchyma* both paratracheal and apotracheal; paratracheal mostly vasicentric, occasionally aliform to confluent joining adjacent vessels; apotracheal forming 2-3 cell thick terminal lines at growth rings, also encircling gum canals (Pl. 4.1); each cell 25-38 µm in diameter and 32-120 µm long; vessel parenchyma pits larger than intervessel pits, alternate, vestured. *Rays* 1-4 (mostly 2-3) seriate (Pl. 4.2, 4); 6-9 rays per mm, fused rays present, ray tissue heterocellular (Pl. 4.3); uniseriate rays less frequent, made up of upright cells; 4-12 cells or 100-375 µm long, crystals present in ray cells (Pl. 4.3); multiseriate rays made up of procumbent cells in the central portions with few upright cells at the margins (Pl. 4.3); 7-35 cells or 100-980 µm long; procumbent cells 25-30 µm in tangential height and 62-120 µm in radial length; upright cells 60-100 µm in tangential height and 50-75 µm in radial length. *Fibres* aligned in radial rows, moderately thick walled, polygonal in cross-section, 25-30 µm in diameter; nonseptate. *Gum canals* normal, vertical, circular to oval, scattered, aligned tangentially in small groups of 4-8, enclosed by parenchyma cells, almost similar to vessel size (Pl. 4.1).

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Geological Survey of India, Jammu.

Specimen No.—BSIP 38308.

Locality—Gandla near Ramnagar, Jammu & Kashmir.

Horizon—Mohargarh Formation, Middle Siwalik.

Age—Middle Pliocene.

Affinities—The most important features of the present fossil wood are: growth rings present, demarcated by thin layer of apotracheal paranchyma; vessels small to large (mostly medium), solitary or in radial multiples of 2-3, intervessel pits vestured; paratracheal parenchyma mostly vasicentric, occasionally aliform, rarely confluent; xylem rays 1-4 (mostly 2-3) seriate, sometimes fusiform, weakly heterocellular; fibres non-libriform, non-septate; gum canals normal, vertical, scattered in small tangential groups, almost of vessel size, surrounded by apotracheal parenchymatous sheath. The combination of these characters is found in leguminous woods. Occurrence of vertical gum canals, which is one of the distinguishing characters of the fossil, has been reported in the secondary woods of a number of leguminous genera, such as, *Copaifera,* Linn., *Daniellia* Benn., *Detarium* Juss., *Eperua* Aubl., *Gossweilerodendron* Harms, *Kingiodendron* Harms, *Oxystigma* Harms, *Prioria* Griseb., *Pterygopodium* Harms and *Sindora* Miq. Besides, wood of *Gymnostemon* Aubrev and Pellegr. of Simarubaceae also show apparent similarity with the present fossil (Normand, 1955, pp. 53-55, Pl. LXXVI). However, scanty paratracheal parenchyma, non-vestured

PLATE 5

Bischofia palaeojavanicum Awasthi 1989

1. Cross section showing size, shape and distribution of vessels and parenchyma. x 40. Slide no. BSIP 38309-I.
2. Tangential longitudinal section showing xylem rays and vessel segments filled with tyloses. x 40. Slide no. BSIP 38309-II.
3. Tangential longitudinal section enlarged showing fine as well as broad xylem rays and septate fibres. x 100. Slide no. BSIP 38309-II.
4. Radial longitudinal section showing heterocellular xylem rays. x 100. Slide no. BSIP 38309-III.
5. Magnified radial longitudinal section showing prismatic crystals in xylem ray cells. x 200. Slide no. BSIP 38309-III.

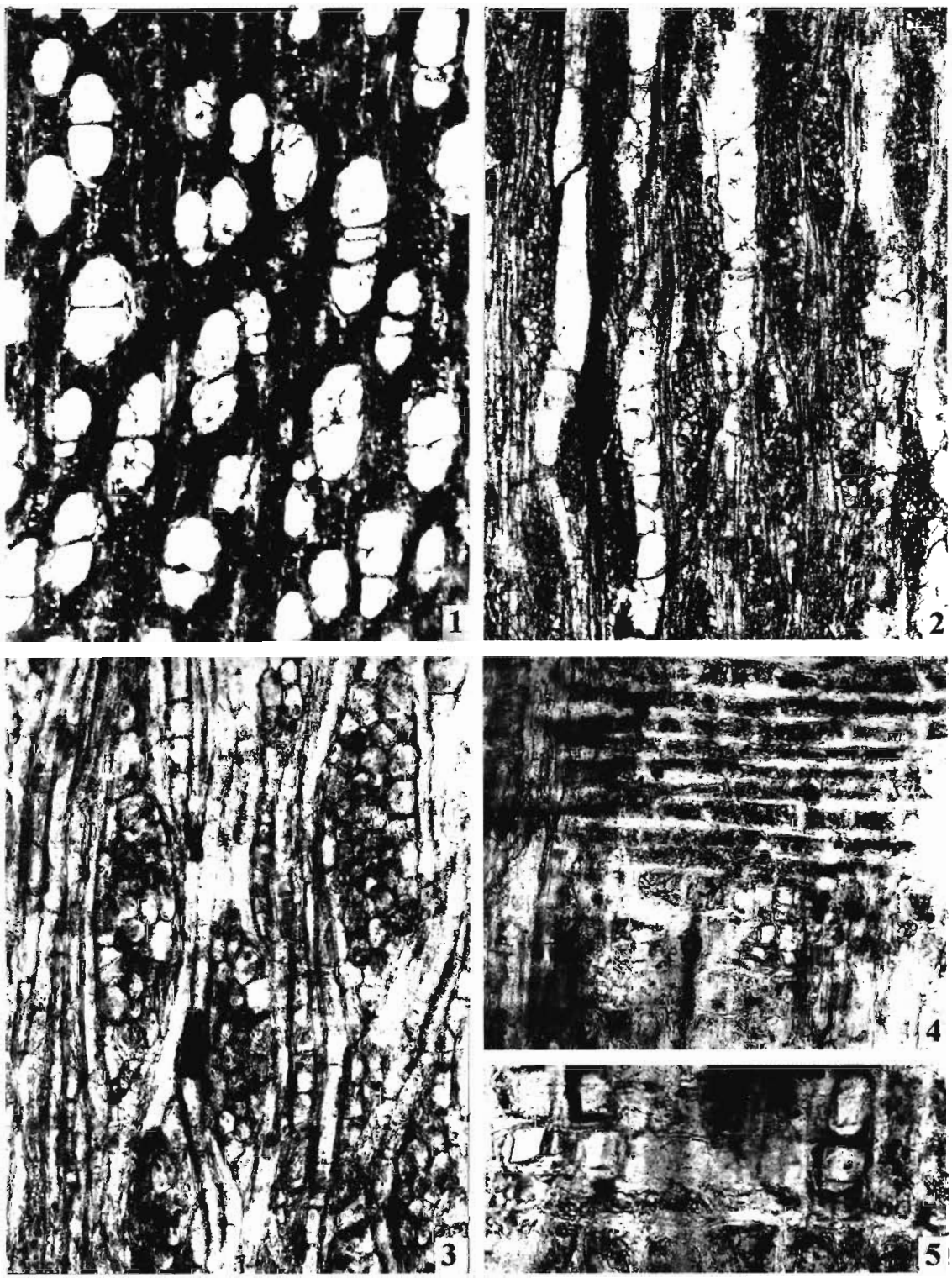

PLATE 5

intervessel pits and taller rays easily differentiate *Gymnostemon* from the present fossil. Among the above mentioned leguminous genera, *Copaifera, Detarium, Eperua,* and *Sindora* and the genus *Gymnostemon* of Simarubaceae, gum canals are found in concentric rows while in the remaining seven genera they are solitary or in pairs or sometimes in short tangential groups. Since the gum canals in the present fossil are scattered and in short tangential groups, it is comparable with the latter six genera, viz., *Daniellia, Gossweilerodendron, Kingiodendron, Oxystigma, Prioria* and *Pterygopodium*. The storied nature of xylem rays, parenchyma and vessel-members in *Daniellia* (Normand, 1950, p. 109, 113, pl. 41; Henderson, 1953, figs 193-194, 201; Kribs, 1959, pp. 77-78, fig. 190) easily separates it from the present fossil. *Gossweilerodendron* differs in having plenty of difffuse-in-aggregate parenchyma forming lines along with homocellular rays (Kribs, 1959, pp. 81-82, fig. 196; Miles, 1978, p. 104; Ilic, 1991, p. 274, fig. 2097). *Oxystigma* and *Pterygopodium* differ in having higher frequency of uniseriate rays and relatively wider gum canals (Kribs, 1959, pp. 90-91, figs 415-416), *Pterygopodium* further differs from the present fossil in having abundant aliform-confluent parenchyma (Kribs, 1959, fig. 416; Miles, 1978, p. 114). Similarly *Prioria* differs from the present fossil in having bigger gum canals (not in tangential groups as in the fossil) and tall rays comprising 30-60 cells (Kribs, 1959, pp. 95-96, fig. 219; Miles, 1978, p. 117). The fossil shows close resembles in its anatomical features with the modern woods of *Hardwickia* Roxb. and *Kingiodendron* Harms (Ramesh Rao *et al.*, 1972, pp. 6-7, 79-82; Ilic, 1991, p. 277, fig. 2109). However, the absence of gum ducts in *Hardwickia* easily differentiates it from the fossil. On examining the slides of modern wood and surveying available literature it was found that the fossil shows best resemblance with the wood of *Kingiodendron* which is characterized by the presence of gum ducts, particularly with *K. pinnatum* (Roxb). Harms (syn. *Hardwickia pinnata* Roxb.) (BSIP wood slide no. 233).

Comparison and Discussion—The authors are aware of only one record of fossil wood of *Kingiodendron*, namely *Kingiodendron prepinnatum* reported by Awasthi and Prakash (1987) from the Mio-Pliocene sediments of Deomali in Arunachal Pradesh, northeast India showing resemblance with the modern woods of *Kingiodendron pinnatum* (Roxb.) Harms. Since affinities of the present fossil wood have been traced to the modern woods of *K. pinnatum* and it also shows resemblance with the only known fossil wood species of *Kingiodendron,* it has been placed under the known species, *Kingiodendron prepinnatum* Awasthi and Prakash (1987).

The genus *Kingiodendron* consists of six species, confined to India, Philippines, Solomon and Fiji islands (Willis, 1973, p. 616; Mabberley, 1997, p. 379). It is represented in India by a single species viz., *Kingiodendron pinnatum* (Roxb.) Harms. It is a large tree occurring in the evergreen forests of Western Ghats from South Kanara to Kerala and Tirunelveli (Ramesh Rao *et al.*, 1972, p. 81) mostly in association with *Vateria indica, Artocarpus hirsutus, Dysoxylum malabaricum, Dipterocarpus indicus, Filicium decipiens, Bischofia javanica, Toona ciliata, Elaeocarpus* sp. and *Hopea parviflora* (Champion & Seth, 1968, pp. 68-69). The occurrence of fossil woods of *Kingiodendron pinnatum* in the northeast as well as in the northwest corners of the country indicate that unlike its present restricted distribution to Western Ghats it was wide-spread in the north during Mio-Pliocene time.

Family—EUPHORBIACEAE

Subfamily—PHYLLANTHOIDEAE

Genus—BISCHOFIA Blume

BISCHOFIA PALAEOJAVANICA Awasthi 1989

(Pl. 5.1-5)

Material—The species is represented by single piece of well preserved secondary wood measuring 30.5 cm in length and 18 cm in width.

Description—Wood diffuse-porous. *Growth rings* not seen. *Vessels* small to large, mostly medium sized, tangential diameter 50-220 µm and radial diameter 68-260 µm (Pl. 5.1); solitary and in radial multiples of 2-3; mostly filled with tyloses and some kind of gummy deposits; vessel members 250-550 µm long with truncate or oblique end walls; perforations simple; inter-vessel pits alternate, bordered, hexagonal with lenticular aperture, 10-12 µm in diameter. *Parenchyma* scanty paratracheal, few cells associated with some of the vessels (Pl. 5.1); each cell 30-50 µm in diameter and 80-136 µm long, disjunctive parenchyma present. *Rays* 1-6 seriate (Pl. 5.2, 3), 5-8 per mm; uniseriate rare, 3-8 cells or 170-400 µm long, consists wholly of upright cells; multiseriate rays heterocellular, 2-6 cells or 60-180 µm broad and 8-32 cells or 240-1,275 µm long; made up of procumbent cells in the centre with extensions of 1-9 upright cells at one or both the ends; end to end ray fusion present; sheath cells present on lateral margins; procumbent cells 60-76 µm in tangential height and 100-120 µm in radial length; upright cells 120-156 µm in tangential height and 48-60 µm in radial length; vessel-ray pits many per cell; prismatic crystals present in upright cells (Pl. 5.4, 5). *Fibres* aligned in radial rows; mostly oval to flattered and polygonal (Pl. 5.1), libriform and tracheid like, thick walled, 48-60 µm in diameter in cross section, frequently septate (Pl. 5.3), interfibre pits present.

Repository—Birbal Sahni Institute of Palaeobotany, Lucknow; Geological Survey of India, Jammu.

Specimen No.—BSIP 38309.

Locality—Gandla near Ramnagar, Jammu & Kashmir.

Horizon—Mohargarh Formation, Middle Siwalik.

Age—Middle Pliocene.

Affinities—The important anatomical characters exhibited by the fossil wood are : wood diffuse-porous; growth rings absent; vessels solitary or in multiples of 2-3, medium to large, filled with abundant tyloses, perforations simple; scanty paratracheal perenchyma; rays 1-6 seriate, heterocellular; fibres thick walled, septate, sometimes tracheid like. The combination of these characters indicate that the fossil belongs to the *Glochidion* group of sub-family Phyllanthoideae (Metcalfe & Chaik, 1950) of the family Euphorbiaceae. Among the genera in the *Glochidion* group, the fossil shows best resemblance with the woods of modern genus *Bischofia* Bl. particularly with *Bischofia javanica* Bl. (Pearson & Brown, 1932; Desch, 1957; Ilic, 1991). The genus *Bischofia* is included in the sub-family Phyllanthoideae (Tribe Bischofieae) of the family Euphorbiaceae (Mabberley, 1997 p. 273). In 1960, Ramanujam created the genus *Bischofioxylon,* for a fossil wood resembling *Bischofia,* from near Pondicherry, South India. Mädel (1962) working on euphorbiaceous woods opined that *Bischofioxylon miocenicum* Ramanujam (1960) did not belong to *Bischofia,* instead it showed resemblance with *Bridelia* woods. Accordingly she transferred it to the genus *Bridelioxylon* Ramanujam (1956). Subsequently Bande in 1974 instituted a new genus *Bischofinium* gen. nov. for the fossil woods resembling the modern woods of *Bischofia* Bl. Awasthi (1989, p. 150) critically examined the type slides of both *Bischofioxylon miocenicum* Ramanujam and *Bischofinium deccanii* Bande while describing a fossil wood of *Bischofia* from the Miocene-Pliocene sediments of Arunachal Pradesh, India. He concluded that the exact affinities of these two woods need to be ascertained and that the former belongs neither to *Bischofia* nor to *Bridelia* and the latter also differs from *Bischofia*. He described his fossil wood as a new species of *Bischofia* viz., *Bischofia palaeojavanica* sp. nov. on account of its close similarity with the modern woods of *Bischofia javanica* Bl. (Awasthi, 1989, pp.147-150). This species has since been reported from the Neyveli lignite deposits (Miocene) of Tamil Nadu (Agarwal, 1994, pp. 335-336); Late Miocene sediments of Mon District, Nagaland (Awasthi & Mehrotra, 1990, p. 283), Middle Miocene deposits of Thiruvananthapuram District, Kerala (Srivastava & Awasthi, 1996, p. 96) and Deccan Intertrappean sediments of Kachchh, Gujarat (Guleria & Srivastava, 2001, p. 23). The authors are aware of two more records of fossil woods of *Bischofia,* viz., *Bischofia javanica* Bl. and *B. polycarpa* Airy-Shaw, both reported from the Late Tertiary rocks of Wuhan, Xinzhou County, Hubei Province of China (Qi Guo-fan *et al.*, 1987, pp. 309-313; Yang Jia-ju *et al.*, 1998, pp. 68-76). Of the three fossil woods, *Bischofia polycarpa* can easily be differentiated from the present fossil in having smaller vessels (t.d. 45-78 µm). *Bischofia javanica* shows apparent similarity with the present fossil, nevertheless, it differs in having greater frequency of vessels in radial chains and the vessels without tyloses. It is pointed out that the number of radial multiples of vessels seen in accompanied photographs (Qi Guo-fan *et al.*, 1987, pl. 1, figs 1, 2) is not similar to the wood of *Bischofia javanica* (see Pearson & Brown, 1932, fig. 275; Kanehira, 1924a, b; Lecomte, 1926). The present fossil shows closest resemblance to *Bischofia palaeojavanica* Awasthi (1989) and hence placed in the same species.

The genus *Bischofia* consists of two extant species, viz., *B. javanica* Bl. and *B. polycarpa* Airy Shaw. The former is a tall straight deciduous tree and is mainly confined to Indo-Malaysian region whereas the latter is found in central and south-east China (Willis, 1973, p. 141; Mabberley, 1997, p. 88). In India it occurs in Lower Himalayas up to 1335 m and sub-Himalayan tract from Yamuna River eastward through Uttar Pradesh, Bihar, Assam, Orissa, Tinnevelly and Madurai; Konkan to Nilgiris and also in Andaman Islands (Pearson & Brown, 1932, p. 881; Santapau & Henry, 1973, p. 23). It is apparent from the fossil evidence that like its present day distribution the genus was also wide spread in India during the past.

GENERAL DISCUSSION

The occurrence of *Dipterocarpus* Gaertn.f. and *Kingiodendron* (Roxb.) Harms, in the Middle Siwalik sediments as far west as Jammu region is highly significant in view of their present distribution and climatic requirements. Both the genera are mainly confined to tropical evergreen forests of the Indo-Malaysian region, with their westward limit in India. As far as their distribution in India is concerned, *Dipterocarpus* is found in the Assam, Andamans and Western Ghats and *Kingiodendron* is confined to Western Ghats, South Kanara southwards to Travancore and Tinnevelly (Brandis, 1906; Chowdhury & Ghosh, 1958; Ramesh Rao *et al.*, 1972). Likewise *Bischofia* Blume, a large to very large tree, occurs in sub-Himalayan forests and outer hills up to 1,335 m from Yamuna eastwards to Assam, Orissa, Tinnevelly and Andaman Islands and on the western coast from the Konkan to Nilgiris. It is found scattered and is a characteristic tree of shady ravines, swamps, river banks and also grows in valleys (Gamble, 1902; Pearson & Brown, 1932). Thus its occurrence west of the Yamuna River during the past is significant. *Dipterocarpus* and *Kingiodendron* are typical canopy trees and form the top storey of evergreen to semi-evergreen forests of India. They form a natural association with *Bischofia javanica* and *Artocarpus* in low elevation, evergreen to semi-evergreen forests (Champion & Seth,1968, pp. 60, 68-69, 87). *Cassia* Linn. is a widespread genus in India and is found in moist deciduous to dry forests. Its occurrence indicates that the area had started experiencing dry climate and the overall assemblage probably represents dwindling components of the semi-evergreen forest. Nevertheless, the fossil records of *Dipterocarpus* species, *Kingiodendron pinnatum* and *Bischofia javanica* indicate the existence of fairly thick

vegetation with warm and humid conditions in the Jammu region during the Middle Siwalik time. Based on more or less similar modern analogue as given by Champion and Seth (1968, pp. 87, 89-90), the envisaged mean annual rainfall most probably may have been about 2,000 mm or more and temperature 24° to 25°C in contrast to the present day average annual rainfall of 1,115 mm and average maximum and minimum temperature range of 39°C to 6.8° C (Sharma & Kachroo, 1981). As a result of limited rainfall the area at present is covered by tropical mixed dry deciduous forest. Thus the higher precipitation at the time of fossilization must have supported the occurrence of the above mentioned genera. Their disappearance from the area signifies drastic change in climate. Evidently with the change in climatic conditions from moist to dry during post-Pliocene time, the moisture loving elements like *Dipterocarpus, Kingiodendron* and *Bischofia* died out in the area and only *Cassia* could survive due to its greater adaptability towards drier conditions. It is important to mention that *Dipterocarpus* was a wide spread genus in India during Neogene (Awasthi, 1996; Guleria, 1996). *Dipterocarpus* and *Kingiodendron* are typical Indo-Malaysian genera and have not been reported from the pre-Neogene sediments of India. It seems they entered into India through north-east sometimes in Late Oligocene-Early Miocene when the land connections between India, Myanmar and Malaysia were well established and the Tethys Sea in the Himalayan Fore-deep had completely vanished (Smith *et al.*, 1994, p. 27, map 4). The gradual increase in aridity during post-Pliocene made the environment hostile for the growth of moisture loving plants. The cumulative effect of various factors such as final phase of Himalayan uplift, onset of glaciation, change in drainage patterns of rivers, shift in the course of monsoon currents, etc. perhaps led to change in climatic conditions from warm and humid to dry and cool which adversely affected the past vegetation of this region. Thus the dicotyledonous woods have furnished dependable evidence of existence of favourable climatic conditions with higher precipitation and the occurrence of mixed tropical forest comprising moist deciduous to evergreen elements of C_3 types of plants with swampy and marshy sites in the Jammu region during the Upper Tertiary.

Based on lithology and faunal evidences similar climatic conditions during the Middle Siwalik have been deduced by Badgley and Behremeyer (1980), Gaur and Chopra (1983) and Retallack (1985). Yokoyama *et al.* (1987) have also inferred warm and humid climate in the Jammu region at the time of deposition of Paramandal Sandstone Formation which is now considered equivalent to Mohargarh Formation. However, in view of the available faunal and floral (both mega and microfossils) evidences it can be said that the area was covered by woodland to savanna type of vegetation. The absence of gymnospermous megafossils and lack of distinct upland components in the fossil wood assemblage indicate that the area was occupied by lowland tropical forest. It is apparent from the above plant fossil records that there was no sudden or marked changes in the vegetation from C_3 to C_4 types up to the Late Middle Siwalik in the area and the changes must have been gradual with the progressive increase in desiccation.

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