OCCURRENCE OF MALAYAN DIPTEROCARPS IN THE SIWALIK SEDIMENTS OF UTTAR PRADESH

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Abstract

Fossil woods resembling modern genera *Shorea* Roxb. and *Hopea* Roxb. of Dipterocarpaceae are described from the Lower Siwalik beds of Kalagarh, Uttar Pradesh. These woods are characterised by the presence of vasicentric tracheids and gum canals in concentric rows. The xylem rays are heterocellular consisting of both upright and procumbent cells. Moreover, in case of *Hopea* some crystalliferous upright cells are interspersed in the median portion of the rays. As the modern eqivalents of these fossil woods now grow in Malayan region, their presence in the Siwalik flora is phytogeographically important and indicates more humid climate at the time of deposition as contrary to the present day dry conditions around Kalagarh area.

Introduction

A number of dipterocarpaceous fossil woods have been described from the Siwalik beds of India. The fossil woods so far known are *Anisopteroxylon kalagarhensis* Prakash (1978), *A. jawalamukhi* Ghosh & Ghosh (1958), *Dipterocarpoxylon nalagarhense*, *D. siwalicus*, *D. premacrocarpum* (Prakash, 1975), *D. kalagarhensis*, *D. parabaudii* (Prakash, 1978), *D. nungarhensis* Trivedi & Ahuja (1980), *Dipterocarpoxylon* sp. Rawat (1964), *Shoreoxylon ornatum* (Trivedi & Ahuja) Prakash & Bande (1980), *Vaterioxylon kalagarhense* and *V. miocenicum* (Trivedi & Misra, 1980). They resemble closely the modern genera *Anisoptera* Korth, *Dipterocarpus* Gaertn., *Shorea* Roxb., *Pentacme* A.DC., and *Vateria* Linn.

The present study on the fossil woods from the Lower Siwalik beds of Kalagarh in Pauri Garhwal District of Uttar Pradesh shows three new dipterocarpaceous woods which are described here in detail. The woods were collected from Sukhasot Nala, about 2 km north of the Kalagarh town.

Systematic Description

FAMILY—DIPTEROCARPACEAE

Genus—*SHOREOXYLON* Den Berger, 1923

Shoreoxylon siwalicus sp. nov.

Pl. 1, figs. 1, 3, 5

Material—This species is based on a single piece of secondary wood measuring about 8 cm in length and 6 cm in diameter. Although the preservation of the fossil wood is not very satisfactory, the anatomical details could be studied from a large number of sections prepared by us.

Description—Wood diffuse porous. *Growth rings* absent. *Vessels* mostly large to medium sized, t.d. 100-264 μm, r.d. 105-284 μm, usually solitary, rarely in radial multiples of 2-3,

circular to oval, evenly distributed, tylosed (Pl. 1, fig. 1); vessel members 200-594 μm in length with truncate ends; perforation simple; intervessel pit-pairs 4-6 μm in diameter, vestured, circular to orbicular in shape, alternate with liear to lenticular apertures (Pl. 1, fig. 3). *Vasicentric tracheids* paratracheal sparse, but difficult to distinguish from neighbouring parenchyma cells in cross section. *Parenchyma* both paratracheal and apotracheal (Pl. 1, figs. 1, 5); paratracheal parenchyma scanty to vasicentric forming 1-4 seriate interrupted sheath around the vessel; apotracheal parenchyma quite abundant, diffuse to diffuse in aggregate forming usually 1-3 (rarely 4-5) seriate lines in between the xylem rays and also occurring as thick 5-7 seriate tangential bands enclosing concentric rows of gum canals (Pl. 1, fig. 5); parenchyma cells oval in cross section, thin-walled, 60-110 μm in length and 12-20 μm in diameter, some time with crystals. *Xylem rays* fine to broad, 1-7 (mostly 5-6) seriate, 15-110 μm wide, 3-65 cells or 178-1440 μm high (Pl. 1, fig. 3), closely spaced, 6-8 per mm; ray tissue heterogeneous, rays both homocellular and heterocellular; multiseriate rays heterocellular consisting of procumbent cells through the median thickened portion and 1-6 marginal rows of upright cell (Pl. 1, fig. 6); uniseriate rays both heterocellular and homocellular, the latter are few consisting wholly of upright cells ; ray cells oval to polygonal in tangential section, thin-walled; upright cells 30-50 μm in tangential height, 25-35 μm in radial length ; procumbent cells 35-110 μm in radial length and 16-35 μm in tangential height. Sheath cells present, forming almost complete row on one or both the flanks. *Fibres* aligned in radial rows in between the consecutive xylem rays, libriform, moderately thick-walled, non-septate (Pl. 1, fig. 3), round to oval or angular in shape, 10-20 μm in diameter and 330-660 μm in length, interfibre pits could not be seen. *Gum canals* normal, vertical, arranged in concentric rows, circular to oval in shape, 88-176 μm in diameter (Pl. 1, fig. 5).

Affinities—The characteristic features of the present fossil wood are the presence of normal, vertical gum canals in concentric rings, vasicentric tracheids, mostly solitary and large to medium-sized vessels, usually abundant, diffuse and diffuse-in-aggregate parenchyma, heterocellular xylem rays and thick-walled fibres. These features collectively indicate its affinity with the modern woods of the family Dipterocarpaceae. On the basis of the distribution of gum canals the woods of this family can be divided into three groups.

Group I—Gum canals absent, e.g. *Monotes* and *Marquesia*.

Group II—Gum canals present, always in concentric rings, e.g. *Shorea*, *Doona*, *Hopea*, *Isoptera*, *Parashorea*, *Pentacme*, *Balanocarpus*, *Dryobalanops* and *Dioticarpus*.

Group III—Gum canals diffuse, solitary and in short tangential rows, e.g. *Anisoptera*, *Dipterocarpus*, *Vateria*, *Vatica*, *Upuna*, *Cotylelobium* and *Monoporandra*.

Due to the presence of concentric rings of gum canals the present fossil wood can be assigned to the genera included in Group II. Although the fossil wood shows somewhat near resemblance with the woods of *Parashorea* and *Pentacme* but the latter can be easily distinguished from the fossil due to the presence of only one or two marginal rows of upright cells as against 1-6 marginal rows in the fossil wood. *Parashorea* also differs from the present fossil wood in having somewhat narrow, 1-6 (usually 3-5) seriate xylem rays with occasional sheath cells on one or both the flanks. However, in the fossil wood the rays are 1-7 (usually 5-6) seriate with almost complete row of sheath cells on both the flanks. *Balanocarpus* and *Dioticarpus* are also different in possessing mostly small to medium-sized vessels. *Balanocarpus* can further be differentiated due to the presence of ripple marks (*B. heinii*). *Dryobalanops* possesses almost exclusively solitary vessels

and thick-walled fibres with distinct bordered pits. The wood ot *Hopea* can also be easily differentiated from the present fossil wood in possessing mostly small-sized vessels and upright cells interspersed among the procumbent cells of the rays. However, in the present fossil wood there are mostly large vessels and upright cells only arranged at the ends of the rays. The woods of *Isoptera* differ from the present fossil in possessing small, 1-5 seriate, spindle shaped rays without sheath cells. Similarly *Doona* can be differentiated in having abundant paratracheal parenchyma varying from aliform to confluent and uniseriate xylem rays in contrast to scanty or vasicentric, paratracheal parenchyma and 1-7 seriate xylem rays in the present fossil wood.

Further from a detailed examination of thin sections and published literature on anatomy of all the available species of the genera belonging to this group, it has been found that the present fossil wood resembles the wood of the extant genus *Shorea* Roxb. In order to find out the nearest modern equivalent of the present fossil wood, thin-sections of modern woods of about 56 species of *Shorea* Roxb. were examined. Besides, literature dealing with the anatomy of many other species were consulted (Pearson & Brown, 1932, pp. 108, 122, figs 39-49 ; Metcalfe & Chalk, 1950, pp. 212-220, figs 55A, H ; Desch, 1957, pp. 126-142, pls 34-43 ; Chowdhury & Ghosh, 1958, pp. 98-170, pls. 20-22, figs, 118-132 ; Kribs, 1959, pp. 35-37, figs 120-126; Gamble 1972, pp. 77-83). A study of the anatomical characters of the species of *Shorea* indicates that the wood of *Shorea minor* shows closest affinity with the present fossil wood. Both the modern wood of *Shorea minor* (Pl. 1, figs, 2, 4) and the present fossil possess mostly large to medium-sized vessels, paratracheal and abundant diffuse to diffuse-in-aggregate parenchyma forming 1-5 seriate lines in between the xylem rays, 1-7 (usually 5-6) seriate, heterocellular xylem rays with 1-6 rows of marginal upright cells at the ends and thick-walled fibres (Pl. 1, figs. 1-6). Besides, there is almost complete row of sheath cells at one or both the flanks of the rays in both of them.

Fossil records and comparison—Recently, Schweitzer (1958) classified the fossil dipterocarpaceous woods which have gum canals in tangential bands into two form genera, viz., *Shoreoxylon* Den Berger (1923) and *Dryobalanoxylon* Den Berger (1923). The genus *Dryobalanoxylon* includes woods with both libriform fibres and fibre trachieds and exclusively solitary vessels while *Shoreoxylon* consists of woods possessing only libriform fibres. The first group includes only *Dryobalanops*, while the other one includes all the remaining genera of Shoreae group. A number of fossil woods resembling the genera of shoreae group are described from India and abroad. These are *Shoreoxylon palembangense* (Kraüsel) Den Berger (1923), *S. djambiense* Den Berger (1923), *S. asiaticum* Schweitzer (1958), *S. maximum*, *Shoreoxylon* cf. *posthumi* Schweitzer (1958) from the Tertiary of Sumatra, *S. multiporosum*, *S. pulchrum* and *S. posthumi* Schweitzer (1958) from the Quaternary of Sumatra, *S. moroides* Den Berger (1927), *S. parvum* Schweitzer (1958) from the Pliocene of Java, *S. swendenbergi* (Schuster) Schweitzer (1958) from the Pliocene of East Indies, *S. burmense* Prakash (1965) and *S. irrawaddiensis* Prakash & Bande (1980) from the Tertiary of Burma, *S. evidens* Eyde (1963), *S. tipamense* Prakash and Awasthi (1970). *S. deomaliense* Prakash and Awasthi (1971) from the Tertiary of Assam, *S. speciosum* Navale (1963), *S. krauseli* Ramanujam and Rao (1967, 1969), *S. indicum* and *S. arcotense* Awasthi (1974) from the Miocene-Pliocene of Cuddalore Series, South India, *S. bengalensis* Roy and Ghosh (1979) and *S. tipamense* Prakash & Awasthi (Bande and Prakash, 1980) from the Tertiary of West Bengal and *S. ornatum* (Trivedi & Ahuja) Bande & Prakash, (1980) from the Lower Siwalik beds of Kalagarh, India.

Out of these eleven species are known from out side the Indian subcontinent and occur mostly in the Tertiary of Southeast Asia (Den Berger, 1923, 1927; Schweitzer,

1958). However, none of them is comparable to the present fossil wood and differs from it in the parenchyma pattern and type of xylem rays. There is not so abundant apotracheal parenchyma in any of the above species as found in the present fossil wood. Besides, the xylem rays in most of the species are narrower than our fossil wood. However, in *S. asiaticum* the xylem rays are broad, 1-9 seriate in comparison to 1-7 seriate in the present fossil wood. Moreover, there are horizontal gum canals in the rays of *S. asiaticum*. The species recorded from the Indian subcontinent are also quite different from our present fosssil wood. *S. krauseli* and *S. irrawaddiensis* differ from the present fossil wood in having only 1 or 2 marginal row of upright cells in the xylem rays as against 1-6 marginal rows of upright cells in the rays of the fossil wood. *S. burmense* and *S. tipamense* also differ from the present fossil wood in the parenchyma distribution as the diffuse and diffuse-in-aggregate parenchyma is sparse and does not form reticulum with the xylem rays whereas the diffuse and diffuse-in-aggregate parenchyma is usually in 1-3-rarely 4-5 seriate lines forming close reticulum with the xylem rays in the present fossil. Moreover, the xylem rays are narrow, 1-5 seriate with occasional sheath cells in *S. tipamense* as against 1-7 seriate xylem rays with complete row of sheath cells on one or both the flanks in the present fossil wood. *Shoreoxylon speciosum*, *S. evidens*, *S. deomaliense* and *S. arcotense* differ from the present fossil in the absence of apotracheal, diffuse and diffuse-in-aggregate parenchyma. The apotracheal parenchyma is found only enclosing the concentric gum canals, whereas in the fossil wood there is apotracheal diffuse and diffuse-in-aggregate parenchyma usually in 1-3, rarely 4 (5) seriate, interrupted tangential lines forming a close reticulum with the xylem rays. Besides, the xylem rays in *S. speciosum* are homogeneous as against heterogeneous rays in the present fossil wood. *S. indicum* can also be differentiated from the fossil wood in having abundant, confluent to banded paratracheal parenchyma and only 1-2 seriate marginal rows of upright cells in the xylem rays as against scanty to vasicentric paratracheal parenchyma and 1-6 rows of upright cells in the xylem rays of the fossil wood. *S. bengalensis* is also markedly different from this Siwalik fossil wood because diffuse and diffuse-in-aggregate parenchyma is absent and the xylem rays are narrow. *S. ornatum* also known from the same locality differs from the present fossil wood in the presence of narrower (1-6, mostly 3-4) seriate xylem rays. Besides, diffuse and diffuse-in-aggregate parenchyma do not form lines in between the xylem rays as found in the present fossil wood. Thus, from the above detailed comparison, it is quite evident that the present fossil wood is different from all the species of *Shoreoxylon* Den Berger (1923) known so far. Therefore, a new specific name *Shoreoxylon siwalicus* has been proposed for it, the specific name indicating the formation from where the fossil was collected.

Shorea Roxb. includes 167 species which are widely distributed in the world from Sri Lanka and India on the west and throughout Burma and other countries of Southeast Asia up to Philippines on the east. Out of them nearly one hundred species of trees grow throughout the tropical parts of Indo-Malayan region (Pearson & Brown, 1932, pp. 109). *Shorea minor* with which the fossil wood closely resembles is found in Malayasia.

Specific Diagnosis

Shoreoxylon siwalicus sp. nov.

Wood diffuse-porous. *Growth rings* absent. *Vessels* mostly large to medium, usually solitary sometimes in radial multiples of 2-3, 8-12 per sq mm; tyloses present; perforation simple; intervessel pits vestured, 4-8 μm in diameter. *Parenchyma* para-

tracheal and apotracheal ; paratracheal parenchyma scanty to vasicentric forming 1-3 seriate, interrupted sheath around the vessles ; apotracheal parenchyma diffuse to diffuse- in -aggregate forming 1-5 (usually 1-3) seriate lines in between the xylem rays, occasionally with 5-7 cells thick, tangential bands surrounding the gum canals. *Xylem rays* fine to broad, 1-7 (usually 5-6) cells or 15-110 μm wide and 3-65 cells or 178-1440 μm in height, ray tissue heterogeneous, rays homo- to heterocellular with 1-6 marginal rows of upright cells at the ends, sheath cells almost continuously arranged in one or both the flanks. *Fibres* semi-libriform, moderately thick-walled, nonseptate, 12-30 μm in diameter and 330-660 μm in length; interfibre pits could not be seen. *Gum canals* normal, vertically arranged in concentric rows, enclosed by thick apotracheal bands of parenchyma, and 60-154 μm in tangential diameter.

Holotype—Specimen no. BSIP 4/2561.

Genus—*HOPENIUM* Awasthi, 1980

2. *Hopenium prenutansoides* sp. nov.

Pl. 1, figs. 7,9 ; Pl. 2, figs. 10, 12

Material—A small piece of petrified secondary xylem measuring about 5 cm in length and 4 cm in diameter. The preservation is satisfactory.

Description—Wood diffuse porous. *Growth rings* distinct demarcated by thick-walled fibres at some places. *Vessels* small to medium, t.d. 50-112 μm, r.d. 54-135 μm, usually solitary, rarely in radial multiples of 2-3 and occasionally in clusters, numerous, 15-35 per sq mm (Pl. 1, figs. 7, 9), circular to oval in shape; tyloses present; vessel segments 50-400 μm in length with truncate to tailed ends, perforation simple ; intervessel pit-pairs alternate, vestured, round to oval in shape, 4-6 μm in diameter with linear to lenticular apertures. *Vasicentric tracheids* angular to oval or orbicular in cross section. *Parenchyma* paratracheal and apotracheal (Pl. 1, figs. 7,9); paratracheal parenchyma scanty ; apotracheal parenchyma diffuse to diffuse-in-aggregate, occasionally occurring in thick bands surrounding the gum canals ; parenchyma cells thin-walled, angular to oval in shape, 15-24 μm in diameter and 220-780 μm in length. *Xylem rays* 1-5 seriate, 18-65 μm in width, 4-35 cells and 90-650 μm in height, 5-7 per mm, ray tissue heterogeneous (Pl. 2, fig. 10), rays heterocellular consisting of 1-4 marginal rows of upright cells and procumbent cells through the median portion, interspersed with crystalliferous upright to square cells bigger than procumbent cells ; upright to square cells 27-67 μm in vertical height and 12-45 μm in radial length ; procumbent cells 11-32 μm in vertical height and 20-128 μm in radial length (Pl. 2, fig. 12). *Fibres* aligned in radial rows, angular to oval in shape, semi-libriform, moderately thick-walled, nonseptate, 12-15 μm in width and 780-1750 μm in length ; interfibre pits could not be seen. *Gum canals* normal, vertical, bead-like, small about 40-65 μm in tangential diameter occurring at irregular intervals in concentric rows (Pl. 1, fig. 7).

Affinities—The presence of normal, vertical gum canals in the fossil wood under investigation is one of the most important diagnostic features. Besides the gum canals, the fossil wood is also characterised by small to medium mostly, solitary vessels with simple perforations, vasicentric tracheids, diffuse and diffuse-in-aggregate parenchyma, 1-5 seriate, heterocellular xylem rays and thick-walled, nonseptate fibres. All these features undoubtedly indicate the affinity of the present fossil with the woods of the family Dipterocarpa-

ceae (Pearson & Brown, 1932, pp. 67-131 ; Metcalfe & Chalk, 1950, pp. 215-219 ; Chowdhury & Ghosh, 1958, pp. 98-167).

Because the wood is characterised by the presence of mostly small to medium-sized vessels, vertical, bead-like gum canals in tangential rows at irregular intervals and crystalliferous upright to square cells interspersed among the procumbent cells in the rays, it shows affinity with the modern woods of *Hopea* Roxb. Although the woods of *Balanocarpus* also possess small to medium-sized vessels but they can be differentiated from the fossil wood due to presence of ripple marks (*B. heinii*). *Dryobalanops* can also be distinguished in having exclusively solitary vessels and thick-walled fibres with distinct bordered and simple pits.

A detailed study of thin sections of the modern woods of *Hopea beccariana* Burck., *H. cordifolia* Trim, *H. ferruginea* Parijs, *H. flagata* Vidal, *H. glabra* W & A, *H. helferi* Brandis, *H. intermedia* King, *H. mengarawan* Miq., *H. minutiflora* Fischer, *H. nutans* Ridl., *H. odorata* Roxb., *H. oblongifolia* Dyer, *H. parviflora* Bedd ; *H. pentamerria* Sym. ex Wood, *H. plagata* Vidal, *H. sangal* Korth., *H. shingkeng* Dunn., *H. sulcata* Sym. and *H. wightiana* Wall. was made for comparison with the fossil wood. Besides, published descriptions and illustrations of many other species of this genus, viz., *H. acuminata* Merr., *H. griffthii* Kurz., *H. nervosa* King, *H. pierrei* Hance, *H. resinosa* Sym., *H. semicuneata* Sym. and *H. subalata* Sym. were also consulted (Pearson & Brown, 1932, pp. 92-110, figs. 34-37; Metcalfe & Chalk, 1950, p. 216, figs. 54A, G; Desch, 1957, pp. 118-121, pl. 27, figs. 1-2; pl. 28; figs. 1-3, pl. 29, figs. 1-2, pl. 30, figs. 1-3; Chowdhury & Ghosh, 1958, pp. 123-130; pl. 18, figs. 106-108; pl. 19, figs. 109-114; Kribs, 1959, p. 34, fig. 117 ; Gamble 1972, pp. 74-76, pl. 2).

From the detailed study it is seen that the fossil wood resembles closely the modern wood of the extant species *Hopea nutans* Ridl. (Pl. 1, fig. 8; Pl. 2, fig. 11). The resemblance can be seen with the presence of mostly small to medium, profusely tylosed vessels, scanty paratracheal, diffuse to diffuse-in aggregate, apotracheal parenchyma, thick-walled, non-septate fibres and normal vertical, bead-like gum canals arranged in tangential rows occurring at irregular intervals. Moreover, the xylem rays in both of them are 1-5 (usually 3-4) seriate, heterocellular, consisting of 1-4 marginal rows of upright to square cells and procumbent cells through the median portion ; these are interspersed with crystalliferous upright to square cells bigger than procumbent cells (Pl. 1, figs. 7-9; Pl. 2, figs. 10-12).

The genus *Hopea* Roxb. comprises about 55 species of trees mainly extremely large and occur throughout the Indo-Malayan region. Of these, eleven species are found in India and 35 species grow in Malaya (Pearson & Brown, 1932, p. 92 ; Ridley, 1967, pp. 235-236 ; Gamble, 1972, p. 74). *Hopea nutans* Ridl. with which the fossil wood closely resembles is a Malayan tree growing in the forests of Pahang and Kwantan in Malaya (Desch, 1957 ; Ridley, 1967).

Fossil records and comparison—*Hopenium pondicherriense* Awasthi (1980) and *H. neyvelensis* Awasthi (1984) are fossil woods known from the Cuddalore sandstones and Neyveli Legnite of South India which resemble the modern woods of *Hopea*.

The present fossil entirely differs from both *Hopenium pondicherriense* and *H. neyvelensis* in having bead-like gum canals in tangential rows occurring at irregular intervals as against large, circular gum canals distributed in tangential rows at regular intervals. Because the present fossil is quite different from the known fossil woods it is being described here as a new species *Hopenium prenutansoides*, the specific name indicating its resemblance with that of *Hopea nutans*.

SPECIFIC DIAGNOSIS

Hopenium prenutansoides sp. nov.

Wood diffuse-porous. *Growth rings* distinct, delimited by thick-walled fibres at places. *Vessels* mostly small to medium, usually solitary, rarely in radial multiples of 2-3 and occasionally in clusters, t.d. 50-112 μm, r.d. 54-135 μm, 15-35 per sq mm and profusely tylosed; perforation simple; intervessel pit-pairs alternate, vestured, 4-6 μm in diameter. *Vasicentric tracheids* interspersed with parenchyma cells. *Parenchyma* scanty paratracheal and diffuse to diffuse-in-aggregate, occasionally occurring in thick bands enclosing the gum canals. *Xylem rays* 1-5 (usually 3-4) seriate an 18-65 μm in width, 4-35 cells and 90-650 μm in height; ray tissue heterogeneous, rays heterocellular consisting of procumbent cells through the median portion and crystalliferous upright to square cells at both the ends as well as interspersed among the procumbent cells. *Fibres* semi-libriform, thick-walled, 12-15 μm in diameter and 780-1760 μm in length ; interfibre pits could not be seen. *Gum canals* bead-like, about 40-65 μm in diameter, arranged in concentric rings at irregular intervals.

Holotype—Specimen no. BSIP 14/2561.

3. *Hopenium kalagarhensis* sp. nov.

Pl. 12, figs. 13, 15, 16, 18, 19

Material—This species is based on a single piece of decorticated secondary wood mesuring about 12 cm in length and 10 cm in diameter. The fossil wood is poorly preserved.

Description—Wood diffuse porous. *Growth rings* not seen, mostly small to medium sized, t.d. 40-180 μm, r.d. 45-205 μm, mostly solitary, rarely in radial multiples of 2-3, moderately numerous, 10-15 per sq mm, circular to oval, thick-walled, tyloses present (Pl. 2, figs. 13, 15); vessel segments 143-330 μm in length with truncate to tailed ends; perforations simple ; intervessel pitpairs medium in size, 4-8 μm in diameter, alternate, vestured, round to oval in shape with linear to lenticular apertures (Pl. 2, fig. 19). *Vasicentric tracheids* present, difficult to distinguish in cross section, angular to oval with 1-2 seriate, bordered pits. *Parenchyma* paratracheal and apotracheal, paratracheal parenchyma intermingled with vasicentric tracheids, scanty to vasicentric or sometimes aliform; apotracheal parenchyma diffuse and diffuse-in-aggregate, also forming thick bands associated with gum canals (Pl. 2, fig. 13). Parenchyma cells thin-walled, usually angular in shape, 8-18 μm in diameter and 20-690 μm in length. *Xylem rays* 1-5 (usually 1-4) seriate, 15-60 μm in width, 4-60 cells and 32-1200 μm in height (Pl. 2, fig. 16); ray tissue heterogeneous, rays heterocellular consisting of 1-4, rarely 5 marginal rows of upright cells and procumbent cells through the median portion, interspersed with crystalliferous upright to square cells which are bigger than procumbent cells ; upright cells 27-45 μm in vertical height and 12-36 μm in radial length ; procumbent cells 10-20 μm in vertical height and 15-60 μm in radial length (Pl. 2, fig. 18), crystals present. *Fibres* aligned in radial rows in between two consecutive xylem rays, angular to oval in shape, semi-libriform, non-septate, 6-16 μm in diameter and 830-1870 μm in length, interfibre pits could not be seen (Pl. 2, fig. 19). *Gum canals* normal, vertical, circular to oval, t. d. 36-120 μm, arranged in concentric rows, embeded in narrow to moderately thick parenchyma bands (Pl. 2, fig. 13).

Affinities—The fossil wood is characterised by the presence of gum canals in concentric rows, vasicentric tracheids, vestured intervessel pits and heterocellular xylem rays. These features indicate that this fossil wood belongs to family Dipterocarpaceae. Because the

gum canals are present in long concentric rows, it can be compared with those of *Hopea*, *Balanocarpus*, *Shorea*, *Parashorea*, *Pentacme*, *Dioticarpus*, *Doona*, *Isoptera* and *Dryobalanops*. In addition to above mentioned features, the fossil wood further possesses mostly solitary, small to medium vessels, scanty to vasicentric, sometimes aliform and diffuse to diffuse-in-aggregate parenchyma and heterocellular xylem rays consisting of upright cells at one or both the ends and procumbent cells through the median portion with upright cells interspersed among the procumbent cells. These features collectively indicate its resemblance with the species of *Hopea* Roxb. where it exhibits a close affinity with the modern wood of *Hopea sulcata* sym. (Pl. 2, figs. 14, 17).

Both the present fossil wood and *Hopea sulcata* Sym. (Pl. 2, figs. 13-19) possess small to medium sized vessels with similar distributional pattern, vestured intervessel pits, simple perforations and almost similar parenchyma and gum canals. Moreover, in both of them xylem rays are 1-5 (usually 1-4) seriate, heterocellular with upright cells interspersed among the procumbent cells through the median portion.

Fossil records and comparison—Three fossil woods of *Hopea* are known so far from India and abroad. These are *Hopenium pondicherriense* Awasthi (1980) from Cuddalore sandstones and *H. neyvelensis* Awasthi (1984) from Neyveli Lignite of South India, whereas *H. prenutansoides* has been recorded in this paper from Lower Siwalik beds of Kalagarh. *H. pondicherriense* can be distinguished from the present fossil wood in having smaller vessels and longer rays (6-80 cells in length). Besides, the Cuddalore fossil possesses abundat, aliform to confluent parenchyma as against scanty paratracheal to vasicentric, sometimes slightly aliform parenchyma in the present fossil wood. *H. neyvelensis* also differs from the present fossil wood in the frequency of the vessels which is comparatively more (30-50/sq mm). Besides, the gum canals in the wood from Neyveli Lignite are comparatively large. Further, this fossil wood is also different fom *H. prenutensoides* in having comparatively bigger vessels and abundant paratracheal parenchyma as well as bigger gum canals in concentric rows occurring at regular intervals. Thus, the present fossil wood is entirely different from already known fossil woods of *Hopea*. Hence a new specific name *Hopenium kalagarhensis* is proposed for it.

Hopea Roxb. consists of about 55 species of trees distributed throughout the Indo-Malayan region (Pearson & Brown, 1932, p. 92 ; Ridley, 1967, pp. 235-236 ; Gamble, 1972, p. 74). *Hopea sulcata* Sym. with which the present fossil closely resembles grows in Malaya and Borneo.

Specific Diagnosis

Hopenium kalagarhensis sp. nov.

Wood diffuse-porous. *Growth rings* indistinct. *Vessels* small to medium, mostly solitary, rarely in radial multiples of 2-3, t.d. 40-180 μm, r.d. 45-205 μm, 10-15 per sq mm and tylosed ; perforations simple; intervessel pit-pairs alternate, vestured, 4-8 μm in diameter. *Vasicentric tracheids* present. *Parenchyma* scanty paratracheal to slightly aliform and diffuse and diffuse-in-aggregate, sometimes forming thick bands enclosing gum canals. *Xylem rays* 1-5 (usually 1-4) seriate, 15-60 μm in width, 6-60 cells and 132-1200 μm in height, ray tissue heterogeneous, rays heterocellular consisting of 1-4 rarely 5 marginal rows of upright cells and procumbent cells through the median portion, interspersed with crystalliferous upright cells. *Fibres* libriform to semilibriform, moderately thick-walled, usually angular in cross section, nonseptate, 8-16 μm in width and 730-1650 in length ;

interfibre pits could not be seen. *Gum canals* normal, vertical, circular to oval, about 36-120 μm in diameter, arranged in concentric rings.

Holotype—Specimen no. BSIP 36127.

Discussion

The modern comparable forms of the fossil woods described from the Lower Siwalik beds of Kalagarh, Uttar Pradesh do not grow now in the Siwalik region. They are presently distributed in the wet-evergreen forests of Malayan region where there is more atmospheric precipitation. This suggests that after the rise of Himalaya, drier conditions prevailed due to which such moist loving species could not survive there. These, however, still grow in the Malayan region where the climate is more favourable for their survival. The presence of these tropical evergreen dipterocarps in the Siwalik sediments at Kalagarh indicates that evergreen forests were flourishing during the Lower Siwalik period as compared to moist deciduous forests of the present day. These comparable forms being Malayan may also provide a strong evidence that certain Malayan elements existed in India during the geological past. Further, the occurrence of these Malayan dipterocarps in India during the Tertiary peroid confirmed that the dipterocarps really migrated in India from Malaya during the early Miocene when there was a land connection between Malaya, Burma and Eastern India.

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Explanation of Plate

Plate 1

1. *Shoreoxylon siwalicus* sp. nov.—Cross section of the fossil wood showing shape, size and distribution of vessels and parenchyma pattern, ×45; BSIP slide no. 9597.
2. *Shorea minor*—Cross section of the modern wood showing Similar shape, size and distribution of the vessels and parenchyma pattern, ×45.
3. *Shoreoxylon siwalicus* sp. nov.—Tangential longitudinal section of the fossil wood showing structure of xylem rays and fibres, ×80; BSIP slide no. 9598.
4. *Shorea minor* —Tangential longitudinal section of the modern wood showing similar structure of the xylem rays and fibres, ×80.
5. *Shoreoxylon siwalicus*—sp. nov.—Cross section of the fossil wood in low power showing tangential row of gum canals, ×20; BSIP slide no. 9599.
6. *Shoreoxylon siwalicus*—sp. nov. Radial langitudinal section of the fossil wood showing hetrocellular xylem rays, ×80; BSIP slide no. 9600.
7. *Hopenium prenutansoides* sp. nov.—Cross section of the fossil wood in low power showing shape, size and distribution of the vessels. ×20; BSIP slide no. 9601.
8. *Hopea nutans*—Cross section of the modern wood in low power showing similar shape, size and distribution of the vessels. ×30.
9. *Hopenium prenutansoides* sp. nov.—Cross section of the fossil wood in high power showing shape and size of the vessels and parenchyma pattern, ×80; BSIP slide no. 9601.


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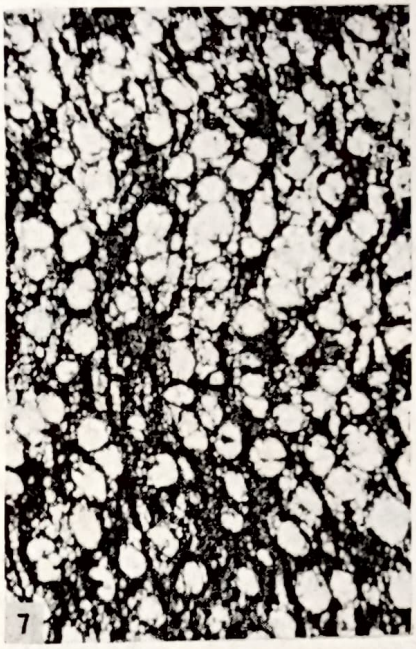
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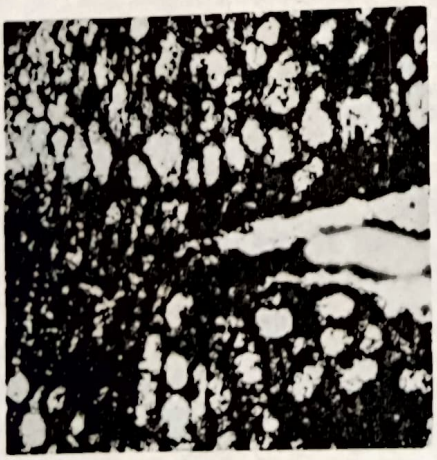


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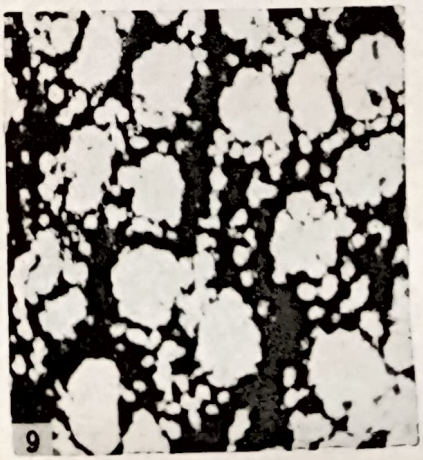
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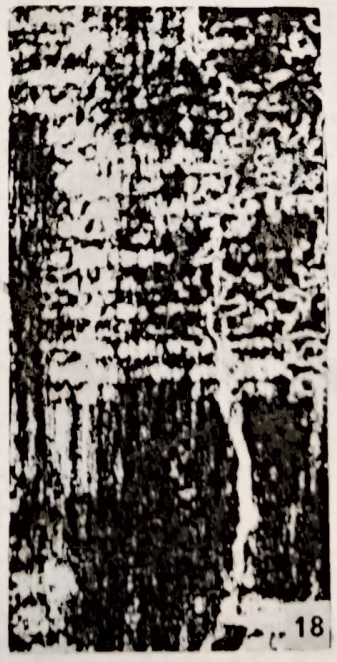
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Plate 2

10. *Hopenium prenutansoides* sp. nov.—Tangential longitudinal section of the fossil wood showing structure of the xylem rays and fibres, ×80; BSIP slide no. 9602.
11. *Hopea nutans*—Tangential longitudinal section of the modern wood showing similar structure of the xylem rays and fibres, ×80;
12. *Hopenium prenutansoides* sp. nov.—Radial longitudinal section of the fossil wood showing heterocellular xylem rays, ×80; BSIP slide no. 9603.
13. *Hopenium kalagarhensis* sp. nov.—Cross section of the fossil wood in low power showing distribution of the vessels and gum canals, ×30; BSIP slide no. 36127-I.
14. *Hopea sulcata*—Cross section of the modern wood showing similar distribution of the vessels and gum canals. ×30.
15. *Hopenium kalagarhensis* sp. nov.—Cross section of the fossil wood in high power showing shape, size and distribution of the vessels and parenchyma pattern, ×80; BSIP slide no. 36127-II.
16. *Hopenium kalagarhensis* sp. nov.—Tangential longitudinal section of the fossil wood showing structure of the xylem rays. ×80; BSIP slide no. 36127-III.
17. *Hopea sulcata*—Tangential longitudinal section of the modern wood showing similar structure of the xylem rays, ×80.
18. *Hopenium kalagarhensis* sp. nov.—Radial longitudinal section of the fossil wood showing heterocellular xylem rays, ×80; BSIP slide no. 36127-IV.
19. *Hopenium kalagarhensis* sp. nov.—Magnified intervessel pit-pairs of the fossil wood, ×150; BSIP slide no. 36127-V.